

LUBRICATING OIL COMPOSITIONS COMPRISING BIOBASED BASE OILS**BACKGROUND**

[0001] Due to increasing demand for high performing lubricant base stocks there is a continuing need for improved lubricating oils which contain improved hydrocarbon mixtures. The industry requires these hydrocarbon mixtures to have superior Noack Volatility, and low temperature viscometric properties that can meet stricter engine oil requirements, preferably from renewable sources.

SUMMARY OF THE INVENTION

[0002] In accordance with one embodiment of the present invention, provided are lubricating oil compositions comprising a biobased base oil. In accordance with another embodiment of the present invention, provided are methods of lubricating an engine with said lubricating oil compositions. In accordance with another embodiment of the present invention, provided are uses of said lubricating oil compositions in an engine.

DEFINITIONS

[0003] As used herein, the following terms have the following meanings, unless expressly stated to the contrary. In this specification, the following words and expressions, if and when used, have the meanings given below.

[0004] A “major amount” means in excess of 50 weight % of a composition.

[0005] A “minor amount” means less than 50 weight % of a composition, expressed in respect of the stated additive and in respect of the total mass of all the additives present in the composition, reckoned as active ingredient of the additive or additives.

[0006] “Active ingredients” or “actives” or “oil free” refers to additive material that is not diluent or solvent.

[0007] All percentages reported are weight % on an active ingredient basis (i.e., without regard to carrier or diluent oil) unless otherwise stated.

[0008] Process oils are special oils which are used in a wide variety of chemical and technical industries either as raw material component or as an aid to processing.

[0009] Diluent oils (also referred to as carrier oils) are diluting agents. Certain fluids are too viscous to be pumped easily or too dense to flow from one particular point to the other. This improves handling, decreases the viscosity of the fluids, thereby also decreasing the pumping/transportation costs.

[0010] The abbreviation “ppm” means parts per million by weight, based on the total weight of the lubricating oil composition.

[0011] High temperature high shear (HTHS) viscosity at 150°C was determined in accordance with ASTM D4683.

[0012] Kinematic viscosity at 100°C (KV₁₀₀) was determined in accordance with ASTM D445.

[0013] Metal – The term “metal” refers to alkali metals, alkaline earth metals, or mixtures thereof.

[0014] An automotive engine refers to an “internal combustion engine” and can be spark ignited, combustion ignited, direct / indirect injected or port flow injected, turbo-compounded with yes/no intercooling or natural aspirated, with or without EGR or exhaust gas after treatment systems suitable for passenger cars, trucks off road etc.

[0015] A hybrid engine refers to an engine coupled to an electric motor/battery system in a hybrid vehicle.

[0016] Oil mist separator cleanliness (OMS) refers to deposit types such as sludge, varnish lacquer, carbonaceous, ash type etc. These differ depending on location like pistons, liners, valve stems, exhaust ports, rocker covers, sump, oil filter (plugging), cylinder head, oil orifices etc.

[0017] “Additive packages” mean lubricant additives which are chemical components or blends that provide one or more functions in the lubricant fluid, when used at a specific treat rate.

[0018] Throughout the specification and claims the expression oil soluble or dispersible is used. By oil soluble or dispersible is meant that an amount needed to provide the desired level of activity or performance can be incorporated by being dissolved, dispersed or suspended in an oil of lubricating viscosity. Usually, this means that at least about 0.001% by weight of the material can be incorporated in a lubricating oil composition. For a further discussion of the terms oil soluble and dispersible, particularly “stably dispersible”, see U.S. Pat. No. 4,320,019 which is expressly incorporated herein by reference for relevant teachings in this regard.

[0019] The term “sulfated ash” as used herein refers to the non-combustible residue resulting from detergents and metallic additives in lubricating oil. Sulfated ash may be determined using ASTM Test D874.

[0020] The term “Total Base Number” or “TBN” as used herein refers to the amount of base equivalent to milligrams of KOH in one gram of sample. Thus, higher TBN numbers

reflect more alkaline products, and therefore a greater alkalinity. TBN was determined using ASTM D 2896 test.

[0021] Boron, calcium, magnesium, molybdenum, phosphorus, sulfur, and zinc contents were determined in accordance with ASTM D5185.

[0022] Nitrogen content was determined in accordance with ASTM D4629.

[0023] NOACK volatility was determined by any one of ASTM D5800A-D or ASTM D6417.

[0024] All ASTM standards referred to herein are the most current versions as of the filing date of the present application.

[0025] Unless otherwise specified, all percentages are in weight percent.

[0026] While the disclosure is susceptible to various modifications and alternative forms, specific embodiments thereof are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure as defined by the appended claims.

[0027] Note that not all of the activities described in the general description or the examples are required, that a portion of a specific activity may not be required, and that one or more further activities may be performed in addition to those described. Still further, the order in which activities are listed is not necessarily the order in which they are performed.

[0028] Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

[0029] The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments.

[0030] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or other features that are inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive-or and not to an exclusive-or. For

example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0031] The use of “a” or “an” is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the embodiments of the disclosure. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise. The term “averaged,” when referring to a value, is intended to mean an average, a geometric mean, or a median value. Group numbers corresponding to columns within the Periodic Table of the elements use the “New Notation” convention as seen in the CRC Handbook of Chemistry and Physics, 81st Edition (2000-2001).

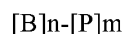
[0032] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and may be found in textbooks and other sources within the lubricants as well as the oil and gas industries.

DETAILED DESCRIPTION

[0033] The specification and illustrations are not intended to serve as an exhaustive and comprehensive description of all the elements and features of formulations, compositions, apparatus and systems that use the structures or methods described herein. Separate embodiments may also be provided in combination in a single embodiment, and conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any sub-combination. Further, reference to values stated in ranges includes each and every value within that range. Many other embodiments may be apparent to skilled artisans only after reading this specification. Other embodiments may be used and derived from the disclosure, such that a structural substitution, logical substitution, or another change may be made without departing from the scope of the disclosure. Accordingly, the disclosure is to be regarded as illustrative rather than restrictive.

[0034] Aspects of the disclosure include, but are not limited to, the following claims:

1. A lubricating oil composition comprising a biobased base oil, wherein the biobased base oil has the molecular structure:



wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

2. The lubricating oil composition of claim 1, wherein the composition further comprises a wear inhibitor, detergent, dispersant, friction modifier, viscosity index improver, pour point depressant, thickener, or antioxidant.
3. The lubricating oil composition of any preceding claim, wherein the composition further comprises a calcium detergent.
4. The lubricating oil composition of claim 3, wherein the calcium detergent is a calcium sulfonate, calcium salicylate, calcium carboxylate, or calcium phenate detergent.
5. The lubricating oil composition of claim 3, wherein the calcium detergent is one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, calcium salicylate, calcium carboxylate or calcium phenate detergent.
6. The lubricating oil composition of any preceding claim, wherein the composition further comprises a magnesium detergent.
7. The lubricating oil composition of claim 6, wherein the magnesium detergent is a magnesium sulfonate or magnesium salicylate detergent.
8. The lubricating oil composition of any preceding claim, wherein the composition further comprises a detergent derived from an isomerized normal alpha olefin.
9. The lubricating oil composition of claim 8, wherein the alkyl substituent of the calcium detergent is derived from an alpha olefin having from 12 to 40 carbon atoms per molecule.
10. The lubricating oil composition of claim 8, wherein the alkyl substituent of the calcium detergent is a residue derived from an isomerized normal alpha-olefin having from 14 to 28 carbon atoms per molecule.
11. The lubricating oil composition of claim 8, wherein the isomerized normal alpha olefin has an isomerization level (I) of the normal alpha olefin of from about 0.1 to about 0.4,

where the isomerization level (I) of the olefin is determined by hydrogen-1 (¹H) NMR obtained on a Bruker Ultrashield Plus 400 in chloroform-d₁ at 400 MHz using TopSpin 3.2 spectral processing software, and the isomerization level (I) is:

$$I = m/(m+n),$$

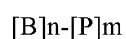
where m is NMR integral for methyl groups with chemical shifts between 0.3 ± 0.03 to 1.01 ± 0.03 ppm, and n is NMR integral for methylene groups with chemical shifts between 1.01 ± 0.03 to 1.38 ± 0.10 ppm.

12. The lubricating oil composition of any preceding claim, wherein the composition further comprises an ashless detergent.
13. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises both a magnesium sulfonate detergent and a calcium salicylate detergent.
14. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises a magnesium sulfonate detergent and a calcium detergent selected from calcium phenate and calcium sulfonate.
15. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises from about 200 to about 3000 ppm of calcium, based on the weight of the lubricating oil composition.
16. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises from about 100 to about 2000 ppm of magnesium, based on the weight of the lubricating oil composition.
17. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises an organic friction modifier derived from a fatty acid source.
18. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises an antioxidant in greater than 1.0 wt.% based on the total weight of the lubricating oil composition.
19. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises an antioxidant in greater than 2.0 wt.% based on the total weight of the lubricating oil composition.
20. The lubricating oil composition of any preceding claim wherein the lubricating oil composition further comprises an antioxidant in greater than 3.0 wt.% based on the total weight of the lubricating oil composition.

21. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises an antiwear additive selected from a C₄/C₆ secondary ZnDTP, C₃/C₆ primary, C₁₂ aryl, C₄/C₈ primary, C₃/C₆ secondary, C₃/C₈ secondary, and C₈ primary ZnDTP.
22. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the organomolybdenum compound is a sulfur-containing organomolybdenum compound or a non-sulfur-containing organomolybdenum compound.
23. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the molybdenum compound is a molybdenum-succinimide complex.
24. The lubricating oil composition of claim 23, wherein the molybdenum succinimide complex is derived from a C₂₄ to C₃₅₀ alkyl or alkenyl succinimide.
25. The lubricating oil composition of claim 23 or 24, wherein the succinimide is a polyisobutenyl succinimide derived from the reaction of a C₇₀ to C₁₂₈ polyisobutenyl succinic anhydride and a polyalkylene polyamine selected from triethylenetetramine, tetraethylenepentamine, and combinations thereof.
26. The lubricating oil composition of any of claims 1-22, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the molybdenum compound is selected from the group consisting of molybdenum dithiocarbamates, molybdenum dithiophosphates, molybdenum carboxylates, molybdenum esters, molybdenum amines, molybdenum amides, and combinations thereof.
27. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition has a viscosity index of greater than 200 and a NOACK volatility of less than 15%.
28. The lubricating oil composition of any preceding claim, wherein the lubricating oil composition has a viscosity index of greater than 250 and a NOACK volatility of less than 15%.

29. The lubricating oil composition of any preceding claim, wherein the lubricating oil is an automotive engine oil (spark or compression ignition, direct or port injected), hybrid engine oil, engine coupled to an electric motor/battery system in a hybrid vehicle oil, marine oil, gear oil, agricultural machinery oil, continuously variable transmission oil, manual transmission oil, automatic transmission oil, electric vehicle transmission oil, mobile natural gas oil, stationary natural gas oil, power railroad engine oil, power generation oil, hydraulic oil, dual fuel oil, tractor hydraulic fluid oil, anti-wear hydraulic fluid oil, hybrid driveline oil, motorcycle oil, grease, grease used under reduced pressure or high vacuum, reduction gears, hydraulic equipment, bearings used in aircraft, rockets, space engineering machinery, robot joints, or vacuum pump lubricating oil composition.
30. The lubricating oil composition of claim 29, wherein the lubricating oil composition is for an engine that is fueled in part or wholly fueled by a bio-derived fuel, ethanol, or methanol.
31. A 0W-4, 0W-8, 0W-12, 0W-16, 0W-20, 0W-30, 0W-40, 5W-20, or 5W-30 heavy duty or passenger car lubricating oil composition comprising: (a) from 1 to 99% by wt. of biobased base oil, wherein the biobased base oil has the molecular structure:
- $$[B]_n-[P]_m$$
- wherein,
- [B] is a biobased hydrocarbon repeating unit;
- [P] is a non-biobased hydrocarbon repeating unit;
- n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol; (b) from 1 to 99 wt.% of a secondary base oil, and (c) a minor amount of a dispersant inhibitor additive package.
32. The lubricating oil composition of claim 31, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 30 cSt.
33. The lubricating oil composition of claim 31, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 10 cSt.

34. The lubricating oil composition of claim 31, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 6 cSt.
35. The lubricating oil composition of claim 31, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil or mixtures thereof having a KV 100 from about 2 cSt to about 4 cSt.
36. The lubricating oil composition of claim 31, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 3 cSt.
37. The lubricating oil composition according to any preceding claim, wherein the lubricating oil is an automotive lubricant where the sulfated ash is less than 0.8, less than 0.7, less than 0.6, less than 0.5, less than 0.4, less than 0.3, less than 0.2 wt.% based on the lubricating oil composition.
38. The lubricating oil composition according to any preceding claim, wherein the lubricating oil is an automotive lubricant where the phosphorus content is less than 0.08, less than 0.07, less than 0.06, less than 0.05, less than 0.04, less than 0.03, less than 0.02 wt.% based on the lubricating oil composition.
39. The lubricating oil composition of claim 29, wherein the vacuum pump oil is ISO VG 32, 46, or 68.
40. A process oil comprising a biobased base oil, wherein the biobased base oil has the molecular structure:



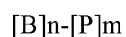
wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

41. Use of the process oil of claim 40 in the manufacture of a detergent.
42. A diluent oil comprising a biobased base oil, wherein the biobased base oil has the molecular structure:



wherein,

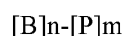
[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

43. Use of the diluent oil of claim 42 in the manufacture of a detergent.

44. An additive concentrate comprising (a) a biobased base oil, wherein the biobased base oil has the molecular structure:



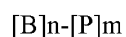
wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol and (b) a minor amount of a lubricant additive.

45. A viscosity index improver concentrate comprising (a) a biobased base oil, wherein the biobased base oil has the molecular structure:



wherein,

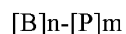
[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol and (b) a minor amount of a viscosity index improver selected from olefin copolymer, diene-based copolymers, poly(meth)acrylate copolymers all of which can be a star, comb, or linear, and block, di-block or tri-block copolymers.

46. The viscosity index improver concentrate of claim 45, wherein the viscosity index improver is a dispersant viscosity index improver.

47. A solvent comprising a biobased base oil, wherein the biobased base oil has the molecular structure:



wherein,

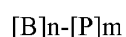
[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

48. A method for reducing timing chain stretch in an engine comprising a step of lubricating said timing chain with a lubricating oil composition of any of claims 1 to 38.
49. A method for improving used oil low speed pre-ignition (LSPI) in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
50. A method for reducing and/or inhibiting oxidation in the presence of biodiesel in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
51. A method for suppressing or reducing NOACK volatility of a lubricating oil composition comprising formulating a lubricating oil composition of any of claims 1 to 38.
52. A method for improving piston cleanliness in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
53. A method for reducing piston deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
54. A method for reducing turbocharger deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.

55. A method for reducing deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
56. A method for improving oil mist separator cleanliness (OMS) in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
57. A method for improving fresh oil heavy duty (HD) or passenger car (PC) fuel economy in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
58. The method of any of claims 53 to 57 wherein deposits are reduced in intercooler systems and their tubing.
59. A method for improving fuel economy retention in a heavy duty (HD) or passenger car (PC) engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
60. A method for improving seal elastomer compatibility in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
61. A method for improving oxidative stability in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38, and (b) operating said engine for a period of time.
62. A method for improving additive package stability comprising adding to said package a biobased base oil having the molecular structure:



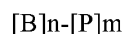
wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

63. A method for improving additive package solubility comprising adding to said package a biobased base oil having the molecular structure:



wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

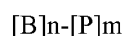
64. A method for improving low temperature properties of a lubricating oil composition in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine, wherein the properties of both fresh and used oils are determined by Pour Point, CCS, MRV, Gelation Index, ROBO, Mack T10A/T11A/T12A tests.
65. A method for inhibiting corrosion in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.
66. A method for inhibiting foam formation in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.
67. A method for improving aeration control in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.
68. A method for stabilizing an emulsion in an internal combustion engine that becomes contaminated with fuel and/or water comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.
69. A method for reducing friction in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.
70. A method for reducing sludge formation in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine.

71. A method improving fresh oil wear performance in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
72. A method improving used oil wear performance in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
73. A method reducing oil consumption in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
74. A method for extending oil drain intervals comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
75. A method for improving compatibility with after treatment devices selected from a gasoline particulate filter (GPF), diesel particulate filter (DPF), EGR system, diesel oxidation catalyst (DOC), lean NO_x trap (LNT), or selective catalytic reduction (SCR) comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
76. A method for improving BioDiesel compatibility, as measured measured in CEC L-109-16 and or L105-12 tests, comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 1 to 38 and operating said engine for a period of time.
77. A method for preventing or inhibiting deposit formation in a natural gas engine containing one or more steel pistons comprising the step of operating the natural gas engine with a natural gas engine lubricating oil composition of any of claims 1 to 29.
78. A method of improving brake and clutch capacity while maintaining low torque variation at low speed of a tractor hydraulic system, the method comprising lubricating said hydraulic system with a lubricating oil composition of any of claims 1 to 29.
79. The lubricating oil composition of any of claims 1 to 28, wherein the lubricating oil composition is a marine lubricating oil composition wherein the marine lubricating oil composition is a system oil, a marine cylinder lubricating oil (MCL), or a trunk piston oil (TPEO) composition.
80. The lubricating oil composition of claim 79, wherein the lubricating oil composition is a monograde lubricant meeting specifications for SAE J300 revised January 2015

requirements for a SAE 20, 30, 40, 50, or 60 monograde engine oil, and has a TBN of 5 to 200 mg KOH/g, as determined by ASTM D2896.

81. The lubricating oil composition of claim 79 or 80, wherein the lubricating oil composition has a TBN in one of the following ranges: 5 to 200 mg KOH/g, 5 to 150 mg KOH/g, 5 to 100 mg KOH/g, 15 to 150 mg KOH/g, 20 to 80 mg KOH/g, 30 to 100 mg KOH/g, 30 to 80 mg KOH/g, 60 to 100 mg KOH/g, 60 to 150 mg KOH/g, 20 to 70 mg KOH/g, 15 to 55 mg KOH/g, and 5 to 15 mg KOH/g.
82. The lubricating oil composition of any of claims 79 to 81, wherein the composition is for an engine that is fueled in part or wholly fueled by a bio-derived fuel, ethanol, or methanol, ammonia, a gaseous fuel, a residual fuel, a marine residual fuel, a low sulfur marine residual fuel, a marine distillate fuel, a low sulfur marine distillate fuel, or a high sulfur fuel.
83. The lubricating oil composition of any of claims 79 to 82, wherein the composition is for a compression-ignited 4-stroke internal combustion engine operated at 250 to 1100 rpm.
84. The lubricating oil composition of any of claims 79 to 82, wherein the lubricant is for a compression-ignited 2-stroke internal combustion engine operated at 200 rpm or less.
85. A method for improving the fuel economy of a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
86. A method for improving the oil consumption of a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
87. A method for improving low temperature properties of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
88. A method for improving the neutralization capability of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
89. A method for improving the wear performance of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.

90. A method for improving the oxidative stability of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
91. A method for reducing sludge formation in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
92. A method for improving viscosity increase control in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
93. A method for reducing scuffing in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
94. A method for reducing deposits in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
95. A method for reducing the rate of depletion of basicity of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
96. A method for inhibiting foam formation of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
97. A method for improving asphaltene dispersancy of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 79 to 84 and operating said engine.
98. A method for thickening a lubricating oil composition comprising adding to said lubricating oil composition a biobased base oil having the molecular structure:



wherein,

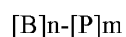
[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block,

alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

99. A method for improving storage stability of a lubricating oil composition comprising adding to said lubricating oil composition a biobased base oil having the molecular structure:



wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4; the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic; the sequential arrangement of [B] and [P] is block, alternating or random; the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol.

100. A lubricating oil composition comprising a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule.
101. The lubricating oil composition of claim 100, wherein the composition further comprises a wear inhibitor, detergent, dispersant, friction modifier, viscosity index improver, pour point depressant, thickener, or antioxidant.
102. The lubricating oil composition of claim 100 or 101, wherein the composition further comprises a calcium detergent.
103. The lubricating oil composition of claim 102, wherein the calcium detergent is a calcium sulfonate, calcium salicylate, calcium carboxylate, or calcium phenate detergent.
104. The lubricating oil composition of claim 102, wherein the calcium detergent is one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, calcium salicylate, calcium carboxylate or calcium phenate detergent.
105. The lubricating oil composition of any of claims 100 to 104, wherein the composition further comprises a magnesium detergent.

106. The lubricating oil composition of claim 105, wherein the magnesium detergent is a magnesium sulfonate or magnesium salicylate detergent.
107. The lubricating oil composition of any of claims 100 to 106, wherein the composition further comprises a detergent derived from an isomerized normal alpha olefin.
108. The lubricating oil composition of claim 107, wherein the alkyl substituent of the calcium detergent is derived from an alpha olefin having from 12 to 40 carbon atoms per molecule.
109. The lubricating oil composition of claim 107, wherein the alkyl substituent of the calcium detergent is a residue derived from an isomerized normal alpha-olefin having from 14 to 28 carbon atoms per molecule.
110. The lubricating oil composition of claim 107, wherein the isomerized normal alpha olefin has an isomerization level (I) of the normal alpha olefin of from about 0.1 to about 0.4, where the isomerization level (I) of the olefin is determined by hydrogen-1 (1H) NMR obtained on a Bruker Ultrashield Plus 400 in chloroform-d1 at 400 MHz using TopSpin 3.2 spectral processing software, and the isomerization level (I) is:
- $$I = m/(m+n),$$
- where m is NMR integral for methyl groups with chemical shifts between 0.3 ± 0.03 to 1.01 ± 0.03 ppm, and n is NMR integral for methylene groups with chemical shifts between 1.01 ± 0.03 to 1.38 ± 0.10 ppm.
111. The lubricating oil composition of any of claims 100 to 110, wherein the composition further comprises an ashless detergent.
112. The lubricating oil composition of any of claims 100 to 111, wherein the lubricating oil composition further comprises both a magnesium sulfonate detergent and a calcium salicylate detergent.
113. The lubricating oil composition of any of claims 100 to 112, wherein the lubricating oil composition further comprises a magnesium sulfonate detergent and a calcium detergent selected from calcium phenate and calcium sulfonate.
114. The lubricating oil composition of any of claims 100 to 113, wherein the lubricating oil composition further comprises from about 200 to about 3000 ppm of calcium, based on the weight of the lubricating oil composition.

115. The lubricating oil composition of any of claims 100 to 114, wherein the lubricating oil composition further comprises from about 100 to about 2000 ppm of magnesium, based on the weight of the lubricating oil composition.
116. The lubricating oil composition of any of claims 100 to 115, wherein the lubricating oil composition further comprises an organic friction modifier derived from a fatty acid source.
117. The lubricating oil composition of any of claims 100 to 116, wherein the lubricating oil composition further comprises an antioxidant in greater than 1.0 wt.% based on the total weight of the lubricating oil composition.
118. The lubricating oil composition of any of claims 100 to 117, wherein the lubricating oil composition further comprises an antioxidant in greater than 2.0 wt.% based on the total weight of the lubricating oil composition.
119. The lubricating oil composition of any of claims 100 to 118 wherein the lubricating oil composition further comprises an antioxidant in greater than 3.0 wt.% based on the total weight of the lubricating oil composition.
120. The lubricating oil composition of any of claims 100 to 119, wherein the lubricating oil composition further comprises an antiwear additive selected from a C₄/C₆ secondary ZnDTP, C₃/C₆ primary, C₁₂ aryl, C₄/C₈ primary, C₃/C₆ secondary, C₃/C₈ secondary, and C₈ primary ZnDTP.
121. The lubricating oil composition of any of claims 100 to 120, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the organomolybdenum compound is a sulfur-containing organomolybdenum compound or a non-sulfur-containing organomolybdenum compound.
122. The lubricating oil composition of any of claims 100 to 121, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the molybdenum compound is a molybdenum-succinimide complex.
123. The lubricating oil composition of claim 122, wherein the molybdenum succinimide complex is derived from a C₂₄ to C₃₅₀ alkyl or alkenyl succinimide.

124. The lubricating oil composition of claim 122, wherein the succinimide is a polyisobutenyl succinimide derived from the reaction of a C₇₀ to C₁₂₈ polyisobutenyl succinic anhydride and a polyalkylene polyamine selected from triethylenetetramine, tetraethylenepentamine, and combinations thereof.
125. The lubricating oil composition of any of claims 100-121, wherein the lubricating oil composition further comprises a molybdenum compound in an amount from 50 to 2000 ppm of molybdenum based on the total weight of the lubricating oil composition and wherein the molybdenum compound is selected from the group consisting of molybdenum dithiocarbamates, molybdenum dithiophosphates, molybdenum carboxylates, molybdenum esters, molybdenum amines, molybdenum amides, and combinations thereof.
126. The lubricating oil composition of any of claims 100 to 125, wherein the lubricating oil composition has a viscosity index of greater than 200 and a NOACK volatility of less than 15%.
127. The lubricating oil composition of any of claims 100 to 126, wherein the lubricating oil composition has a viscosity index of greater than 250 and a NOACK volatility of less than 15%.
128. The lubricating oil composition of any of claims 100 to 127, wherein the lubricating oil is an automotive engine oil (spark or compression ignition, direct or port injected), hybrid engine oil, engine coupled to an electric motor/battery system in a hybrid vehicle oil, marine oil, gear oil, agricultural machinery oil, continuously variable transmission oil, manual transmission oil, automatic transmission oil, electric vehicle transmission oil, mobile natural gas oil, stationary natural gas oil, power railroad engine oil, power generation oil, hydraulic oil, dual fuel oil, tractor hydraulic fluid oil, anti-wear hydraulic fluid oil, hybrid driveline oil, motorcycle oil, grease, grease used under reduced pressure or high vacuum, reduction gears, hydraulic equipment, bearings used in aircraft, rockets, space engineering machinery, robot joints, or vacuum pump lubricating oil composition.
129. The lubricating oil composition of claim 128, wherein the lubricating oil composition is for an engine that is fueled in part or wholly fueled by a bio-derived fuel, ethanol, or methanol.
130. A 0W-4, 0W-8, 0W-12, 0W-16, 0W-20, 0W-30, 0W-40, 5W-20, or 5W-30 heavy duty or passenger car lubricating oil composition comprising (a) from 1 to 99%

by wt. of biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:

- i. the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
- ii. the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
- iii. on average there are 0.3 to 1.5 5+ methyl per molecule;

(b) from 1 to 99 wt.% of a secondary base oil, and (c) a minor amount of a dispersant inhibitor additive package.

131. The lubricating oil composition of claim 130, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil or mixtures thereof having a KV 100 from about 2 cSt to about 30 cSt.
132. The lubricating oil composition of claim 130, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 10 cSt.
133. The lubricating oil composition of claim 130, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 6 cSt.
134. The lubricating oil composition of claim 130, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 4 cSt.
135. The lubricating oil composition of claim 130, wherein the secondary base oil is a poly-alpha-olefin (PAO), aromatic, group I, group II, group III, ester base oil, or mixtures thereof having a KV 100 from about 2 cSt to about 3 cSt.
136. The lubricating oil composition of any of claims 100 to 135, wherein the lubricating oil is an automotive lubricant where the sulfated ash is less than 0.8, less than 0.7, less than 0.6, less than 0.5, less than 0.4, less than 0.3, less than 0.2 wt.% based on the lubricating oil composition.
137. The lubricating oil composition of any of claims 100-136, wherein the lubricating oil is an automotive lubricant where the phosphorus content is less than 0.08, less than 0.07, less than 0.06, less than 0.05, less than 0.04, less than 0.03, less than 0.02 wt.% based on the lubricating oil composition.
138. The lubricating oil composition of claim 128, wherein the vacuum pump oil is ISO VG 32, 46, or 68.

139. A process oil comprising a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule.
140. Use of the process oil of claim 139 in the manufacture of a detergent.
141. A diluent oil comprising a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule.
142. Use of the diluent oil of claim 141 in the manufacture of a detergent.
143. An additive concentrate comprising (a) a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule; and
- (b) a minor amount of a lubricant additive.
144. A viscosity index improver concentrate comprising (a) a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule; and
- (b) a minor amount of a viscosity index improver selected from olefin copolymer, diene-based copolymers, poly(meth)acrylate copolymers all of which can be a star, comb, or linear, and block, di-block or tri-block copolymers.
145. The viscosity index improver concentrate of claim 144, wherein the viscosity index improver is a dispersant viscosity index improver.

146. A solvent comprising a biobased base oil, wherein the biobased base oil is described by a hydrocarbon mixture in which:
- the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - on average there are 0.3 to 1.5 5+ methyl per molecule.
147. A method for reducing timing chain stretch in an engine comprising a step of lubricating said timing chain with a lubricating oil composition of any of claims 100 to 137.
148. A method for improving used oil low speed pre-ignition (LSPI) in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
149. A method for reducing and/or inhibiting oxidation in the presence of biodiesel in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
150. A method for suppressing or reducing NOACK volatility of a lubricating oil composition comprising formulating a lubricating oil composition of any of claims 100 to 137.
151. A method for improving piston cleanliness in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
152. A method for reducing piston deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
153. A method for reducing turbocharger deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
154. A method for reducing deposits in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.

155. A method for improving oil mist separator cleanliness (OMS) in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
156. A method for improving fresh oil heavy duty (HD) or passenger car (PC) fuel economy in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
157. The method of any of claims 152 to 156 wherein deposits are reduced in intercooler systems and their tubing.
158. A method for improving fuel economy retention in a heavy duty (HD) or passenger car (PC) engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
159. A method for improving seal elastomer compatibility in an internal combustion engine comprising the steps of (a) lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
160. A method for improving oxidative stability in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137, and (b) operating said engine for a period of time.
161. A method for improving additive package stability comprising adding a biobased base oil which is described by a hydrocarbon mixture in which:
- a. the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - b. the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - c. on average there are 0.3 to 1.5 5+ methyl per molecule.
162. A method for improving additive package solubility comprising adding a biobased base oil which is described by a hydrocarbon mixture in which:
- a. the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - b. the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
 - c. on average there are 0.3 to 1.5 5+ methyl per molecule.

163. A method for improving low temperature properties of a lubricating oil composition in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
164. A method for inhibiting corrosion in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
165. A method for inhibiting foam formation in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
166. A method for improving aeration control in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
167. A method for stabilizing an emulsion in an internal combustion engine that becomes contaminated with fuel and/or water comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
168. A method for reducing friction in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
169. A method for reducing sludge formation in an internal combustion engine comprising the steps of lubricating the engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine.
170. A method improving fresh oil wear performance in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.
171. A method improving used oil wear performance in an engine comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.
172. A method improving oil consumption in an internal combustion engine comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.

173. A method for extending oil drain intervals comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.
174. A method for improving compatibility with after treatment devices selected from a gasoline particulate filter (GPF), diesel particulate filter (DPF), EGR systems, diesel oxidation catalyst (DOC), lean NOx trap (LNT), or selective catalytic reduction (SCR) comprising the steps of lubricating an engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.
175. A method for improving BioDiesel compatibility, as measured measured in CEC L-109-16 and or L105-12 tests, comprising the steps of lubricating an internal combustion engine with a lubricating oil composition of any of claims 100 to 137 and operating said engine for a period of time.
176. A method for preventing or inhibiting deposit formation in a natural gas engine containing one or more steel pistons, or one or more aluminum pistons, comprising the step of operating the natural gas engine with a natural gas engine lubricating oil composition of any of claims 100 to 128.
177. A method of improving brake and clutch capacity while maintaining low torque variation at low speed of a tractor hydraulic system, the method comprising lubricating said hydraulic system with a lubricating oil composition of any of claims 100 to 128.
178. The lubricating oil composition of any of claims 100 to 127, wherein the lubricating oil composition is a marine lubricating oil composition wherein the marine lubricating oil composition is a system oil, a marine cylinder lubricating oil (MCL), or a trunk piston oil (TPEO) composition.
179. The lubricating oil composition of claim 178, wherein the lubricating oil composition is a monograde lubricant meeting specifications for SAE J300 revised January 2015 requirements for a SAE 20, 30, 40, 50, or 60 monograde engine oil, and has a TBN of 5 to 200 mg KOH/g, as determined by ASTM D2896.
180. The lubricating oil composition of claim 178 or 179, wherein the lubricating oil composition has a TBN in one of the following ranges: 5 to 200 mg KOH/g, 5 to 150 mg KOH/g, 5 to 100 mg KOH/g, 15 to 150 mg KOH/g, 20 to 80 mg KOH/g, 30 to 100 mg KOH/g, 30 to 80 mg KOH/g, 60 to 100 mg KOH/g, 60 to 150 mg KOH/g, 20 to 70 mg KOH/g, 15 to 55 mg KOH/g, and 5 to 15 mg KOH/g.

181. The lubricating oil composition of any of claims 178 to 180, wherein the composition is for an engine that is fueled in part or wholly fueled by a bio-derived fuel, ethanol, or methanol, ammonia, a gaseous fuel, a residual fuel, a marine residual fuel, a low sulfur marine residual fuel, a marine distillate fuel, a low sulfur marine distillate fuel, or a high sulfur fuel.
182. The lubricating oil composition of any of claims 178 to 181, wherein the composition is for a compression-ignited 4-stroke internal combustion engine operated at 250 to 1100 rpm.
183. The lubricating oil composition of any of claims 178-181, wherein the lubricant is for a compression-ignited 2-stroke internal combustion engine operated at 200 rpm or less.
184. A method for improving the fuel economy of a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
185. A method for improving the oil consumption of a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
186. A method for improving low temperature properties of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
187. A method for improving the neutralization capability of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
188. A method for improving the wear performance of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
189. A method for improving the oxidative stability of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.

190. A method for reducing sludge formation in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
191. A method for improving viscosity increase control in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
192. A method for reducing scuffing in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
193. A method for reducing deposits in a diesel internal combustion engine, comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
194. A method for reducing the rate of depletion of basicity of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
195. A method for inhibiting foam formation of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
196. A method for improving asphaltene dispersancy of a lubricating oil composition in a diesel internal combustion engine comprising the steps of lubricating said engine with the lubricating oil composition of any of claims 178 to 183 and operating said engine.
197. A method for thickening a lubricating oil composition for a diesel internal combustion engine comprising adding to said lubricating oil composition a biobased base oil which is described by a hydrocarbon mixture in which:
- a. the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
 - b. the $BP/BI \geq -0.6037 (\text{Internal alkyl branching per molecule}) + 2.0$;
 - c. on average there are 0.3 to 1.5 5+ methyl per molecule.
198. A method for improving storage stability of a lubricating oil composition comprising adding a biobased base oil which is described by a hydrocarbon mixture in which:

- a. the percentage of molecules with even carbon number is $\geq 80\%$ according to FIMS;
- b. the $BP/BI \geq -0.6037$ (Internal alkyl branching per molecule)+2.0;
- c. on average there are 0.3 to 1.5 5+ methyl per molecule.

THE BIOBASED BASE OIL

[0034] In one aspect, the biobased oil can be described by the following. Base oils, and more particularly isoparaffins, derived from biobased hydrocarbon terpenes such as myrcene, ocimene and farnesene, have been described in PCT Patent Application No. PCT/US2012/024926, entitled "Base Oils and Methods for Making the Same," filed, February 13, 2012 and published as WO 2012/141784 on October 18, 2012, by Nicholas Ohler, et al., and assigned to Amyris, Inc. in Emeryville, California. WO 2012/141784 discloses that terpenes are capable of being derived from isopentyl pyrophosphate or dimethylallyl pyrophosphate and the term "terpene" encompasses hemiterpenes, monoterpenes, sesquiterpenes, diterpenes, sesterterpenes, triterpenes, tetraterpenes and polyterpenes. A hydrocarbon terpene contains only hydrogen and carbon atoms and no heteroatoms such as oxygen, and in some embodiments has the general formula $(C_5H_8)_n$, where n is 1 or greater. A "conjugated terpene" or "conjugated hydrocarbon terpene" refers to a terpene comprising at least one conjugated diene moiety. The conjugated diene moiety of a conjugated terpene may have any stereochemistry (e.g., cis or trans) and may be part of a longer conjugated segment of a terpene, e.g., the conjugated diene moiety may be part of a conjugated triene moiety. Hydrocarbon terpenes also encompass monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, tetraterpenoids, and polyterpenoids that exhibit the same carbon skeleton as the corresponding terpene but have either a lesser or greater number of hydrogen atoms than the corresponding terpene, e.g., terpenoids having 2 fewer, 4 fewer, or 6 fewer hydrogen atoms than the corresponding terpene, or terpenoids having 2-additional, 4-additional, or 6-additional hydrogen atoms than the corresponding terpene. Some non-limiting examples of conjugated hydrocarbon terpenes include isoprene, myrcene, α -ocimene, β -ocimene, α -farnesene, β -farnesene, β -springene, geranylfarnesene, neophytadiene, c/s-phyta-1,3-diene, trans-phyta-1,3-diene, isodehydrosqualene, isosqualane precursor I, and isosqualane precursor II. The terms terpene and isoprenoids may be used interchangeably and are a large and varied class of organic molecules that can be produced by a wide variety of plants and some insects. Some terpenes or isoprenoid compounds can also be made from organic compounds such as sugars by

microorganisms, including bioengineered microorganisms, such as yeast. Because terpenes or isoprenoid compounds can be obtained from various renewable sources, they are useful monomers for making eco-friendly and renewable base oils. In some embodiments, the conjugated hydrocarbon terpenes are derived from microorganisms using a renewable carbon source, such as a sugar. Further processing of certain of such biobased base oil stocks has been found to yield highly useful and superior engine oils. For example, C₁₅ hydrocarbons containing four double bonds such as Biofene™ β-farnesene, commercially available from Amyris, Inc. (Emeryville, California) may be pre-treated to eliminate impurities and then hydrogenated so that three of the four double bonds are reduced to single bonds. The partially hydrogenated intermediate product is then subjected to an oligomerization reaction with a linear alpha olefin (LAO) using a catalyst such as BF₃ or a BF₃ complex. A further intermediate product, consisting of a mixture of hydrocarbons ranging from C₁₀ to about C₇₅, results. This oligomeric mixture of hydrocarbons is then hydrogenated to reduce the amount of unsaturation. The saturated hydrocarbon mixture is then distilled to obtain the targeted composition and finally blended to meet desirable base oil product specifications (such as kinematic viscosity at 40 °C) for the engine oil. Desirable examples of biobased base oil specifications that can be used to produce blends suitable for engine oil formulation for one embodiment are set forth in Table 1. In some embodiments in this disclosure, a commercially available biobased hydrocarbon base oil (a hydrogenated reaction product between a partially hydrogenated p-3,7,11-trimethyldodeca-1,3,6,10-tetraene and a linear C₈-C₁₆ alpha olefin, hydrogenated) sold under the commercial designation NOVASPEC (Novvi LLC, Emeryville, CA, United States; (REACH registration number 01 -2120031429-59-0000), is used.

Table 1

Example Biobased Base Oil Specifications

<i>Properties</i>	<i>Method</i>	<i>3cSt base oil</i>	<i>4cSt base oil</i>	<i>7cSt base oil</i>	<i>12cSt base oil</i>
Appearance	Visual	Bright and Clear	Bright and Clear	Bright and Clear	Bright and Clear
Color	ASTM D1500-12	0.5	0.5	0.5	0.5
Density, 15°C (kg/l)	ASTM D4052-11	0.82	0.82	0.82	0.82
Viscosity, 40°C (cSt)	ASTM D445-14E2	12.5	19.2	46.1	105.5
Viscosity, 100°C (cSt)	ASTM D445-14E2	3.1	4.2	7.5	12.3
Viscosity Index	ASTM D445-14E2	110	124	126	122
Four point (°C)	ASTM D97-12	-60	-42	-51	-42
Flash point (°C)	ASTM D92-12b	188	226	254	280

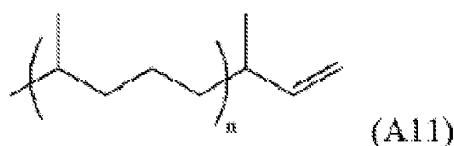
[0035] Advantageously, in certain embodiments, at least about 20% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. For example, in one such embodiment at least about 30% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 40% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 50% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 60% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 70% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 80% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 90% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. In some variations, the

carbon atoms of the base oil component of the engine oil comprises at least about 95%, at least about 97%, at least about 99%, or about 100% of originate from renewable carbon sources. The origin of carbon atoms in the reaction product adducts may be determined by any suitable method, including but not limited to reaction mechanism combined with analytical results that demonstrate structure and/or molecular weight of adducts, or by carbon dating (e.g., according to ASTM D6866-12 "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis," which is incorporated herein by reference in its entirety). For example, using ASTM D6866-12 or another suitable technique, a ratio of carbon 14 to carbon 12 isotopes in the biobased base oil can be measured by liquid scintillation counting and/or isotope ratio mass spectroscopy to determine the amount of modern carbon content in the sample. A measurement of no modern carbon content indicates all carbon is derived from fossil fuels. A sample derived from renewable carbon sources will indicate a concomitant amount of modern carbon content, up to 100%.

[0036] In some embodiments of this disclosure, one or more repeating units of biobased hydrocarbon base oil are specific species of partially hydrogenated conjugated hydrocarbon terpenes. Such specific species of partially hydrogenated conjugated terpenes may or may not be produced by a hydrogenation process. In certain variations, a partially hydrogenated hydrocarbon terpene species is prepared by a method that includes one or more steps in addition to or other than catalytic hydrogenation.

[0037] Non-limiting examples of specific species partially hydrogenated conjugated hydrocarbon terpenes include any of the structures provided herein for dihydrofarnesene, tetrahydrofarnesene, and hexahydrofarnesene; any of the structures provided herein for dihydromyrcene and tetrahydromyrcene; and any of the structures provided herein for dihydroocimene and tetrahydroocimene.

[0038] One example of a particular species of partially hydrogenated conjugated hydrocarbon terpene that may have utility as a feedstock is a terminal olefin having a saturated hydrocarbon tail with structure (A11):



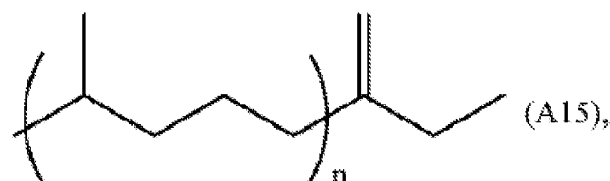
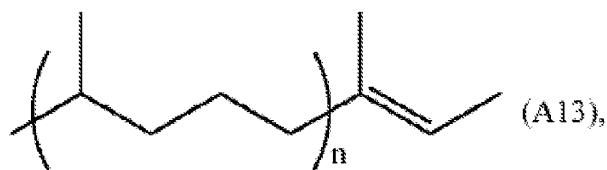
where $n = 1, 2, 3, \text{ or } 4$.

[0039] In some variations, a mono-olefinic alpha-olefin having structure A11 may be derived from a conjugated hydrocarbon terpene wherein the conjugated diene is at the 1,3 - position of the terpene. Examples include alpha-olefins derived from a 1,3- diene conjugated hydrocarbon terpene (e.g., a C₁₀-C₃₀ conjugated hydrocarbon terpene such as farnesene, myrcene, ocimene, springene, geranyl farnesene, neophytadiene, trans-phyta- 1,3 -diene, or cz's-phyta-1,3-diene). Another non-limiting example of an alpha-olefin having the general structure A11 includes 3,7,11 - trimethyldodecene having structure A12.



[0040] A mono-olefinic alpha-olefin having structure A11 may be prepared from the appropriate conjugated hydrocarbon terpene using any suitable method. In some variations, the mono-olefinic alpha-olefin having structure A11 is produced from primary alcohol of corresponding to the hydrocarbon terpene (e.g., farnesol in the case of farnesene, or geraniol in the case of myrcene). The methods comprise hydrogenating the primary alcohol, forming a carboxylic acid ester or carbamate ester from the hydrogenated alcohol, and pyrolyzing the ester (or heating the ester to drive the elimination reaction) to form the alpha-olefin with a saturated hydrocarbon tail, e.g., as described in Smith, L. E.; Rouault, G. F., J. Am. Chem. Soc. 1943, 65, 745-750, for the preparation of 3,7-dimethyloctene, which is incorporated by reference herein in its entirety. The primary alcohol of the corresponding hydrocarbon terpene may be obtained using any suitable method.

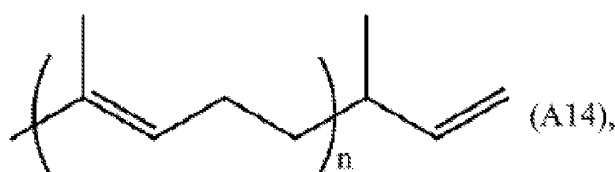
[0041] Other examples of particular species of partially hydrogenated conjugated hydrocarbon terpene that may have utility as a feedstock are mono-olefins having a saturated hydrocarbon tail with structure (A13) or structure (A15):



where $n = 1, 2, 3$, or 4 . A mono-olefin having the general structure A13, A15 or A11 may in certain instances be derived from a conjugated hydrocarbon terpene having a 1,3-diene moiety, such as myrcene, farnesene, springene, geranylfarnesene, neophytadiene, *trans*-phyta-1,3-diene, or *cis*-phyta-1,3-diene. Here again, the conjugated may be functionalized with a protecting group (e.g., via a Diels-Alder reaction) in a first step, exocyclic olefinic bonds hydrogenated in a second step, and the protecting group eliminated in a third step. In one non-limiting example of a method for making mono-olefins having the structure A13, A15 or A11, a conjugated hydrocarbon terpene having a 1,3-diene is reacted with SO_2 in the presence of a catalyst to form a Diels-Alder adduct. The Diels-Alder adduct may be hydrogenated with an appropriate hydrogenation catalyst to saturate exocyclic olefinic bonds. A retro Diels-Alder reaction may be carried out on hydrogenated adduct (e.g., by heating, and in some instances in the presence of an appropriate catalyst) to eliminate the sulfone to form a 1,3-diene. The 1,3-diene can then be selectively hydrogenated using a catalyst known in the art to result in a mono-olefin having structure A11, A13 or A15, or a mixture of two or more of the foregoing. Non-limiting examples of regioselective hydrogenation catalysts for 1,3-dienes are provided in Jong Tae Lee et al, "Regioselective hydrogenation of conjugated dienes catalyzed by hydridopentacyanocobaltate anion using β -cyclodextrin as the phase transfer agent and lanthanide halides as promoters," *J. Org. Chem.*, 1990, 55 (6), pp. 1854-1856, in V. M. Frolov et al, "Highly active supported palladium catalysts for selective hydrogenation of conjugated dienes into olefins," *Reaction Kinetics and Catalysis Letters*, 1984, Volume 25, Numbers 3-4, pp. 319-322, in Tungler, A., Hegedus, L., Fodor, K., Farkas, G., Furcht, A. and Karancsi, Z. P. (2003) "Reduction of Dienes and Polyenes," in *The Chemistry of Dienes and Polyenes*, Volume 2 (ed. Z. Rappoport), John Wiley & Sons, Ltd, Chichester, UK., and in Tungler, A., Hegedus,

L., Fodor, K., Farkas, G., Furcht, A. and Karancsi, Z. P., "Reduction of Dienes and Polyenes" in Patai's Chemistry of Functional Groups (John Wiley and Sons, Ltd, published online December 15, 2009,, each of which is incorporated herein by reference in its entirety. For example, a catalyst known in the art for 1,4 hydrogen addition to 1,3- dienes results in a mono-olefin having structure A13. In one non-limiting example, β - farnesene can be reacted with SO₂ in the presence of a catalyst to form a Diels-Alder adduct, which is subsequently hydrogenated, and the sulfone eliminated to form a 1,3- diene, which is subsequently selectively hydrogenated using a catalyst known in the art for regioselective hydrogen additions to 1,3- dienes to form 3,7,11-trimethyldodec-2-ene, 3,7,11 - trimethyldodec-1 -ene, or 3-methylene-7,11 -dimethyldodecane, or a mixture of any two or more of the foregoing.

[0042] In yet another example of a particular species of partially hydrogenated hydrocarbon terpene that may have utility as a feedstock, a terminal olefin of the general structure A14 may be made from a conjugated hydrocarbon terpene having a 1,3-conjugated diene and at least one additional olefinic bond (e.g., myrcene, farnesene, springene, or geranylfarnesene):



where $n = 1, 2, 3$, or 4 . In one non-limiting variation, a compound having the structure A14 may be derived from an unsaturated primary alcohol corresponding to the relevant hydrocarbon terpene (e.g., farnesol in the case of farnesene, or geraniol in the case of myrcene). The unsaturated primary alcohol may be exposed to a suitable catalyst under suitable reaction conditions to dehydrate the primary alcohol to form the terminal olefin A 14.

[0043] An olefinic feedstock as described herein may comprise any useful amount of the particular species (e.g., alpha-olefinic species having structure A11, A12 or A15, mono-olefinic species having structure A13, or unsaturated terminal olefin species having structure A14), made either by a partial hydrogenation route or by another route, e.g., as described herein. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% species having structure A11, A12, A13, A14, or A15. In certain variations, an olefinic

feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodec-1-ene. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3-methylene-7,11-dimethyldodecane. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodec-2-ene. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodeca-1,6,10-triene. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethyloct-1-ene. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethyloct-2-ene. In certain variations, an olefinic feedstock comprises at least about 1 %, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethylocta-1,6-diene.

[0044] As described herein, in some variations, the hydrocarbon terpene feedstock comprising alpha-olefinic species or internal olefinic species of partially hydrogenated hydrocarbon terpenes are suitable for catalytic reaction with one or more alpha-olefins to form a mixture of isoparaffins comprising adducts of the terpene and the one or more alpha-olefins. In some variations, at least a portion of the mixture of isoparaffins so produced may be used as a base oil.

[0045] In one embodiment, the biobased oil contains at least about 25% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, at least about 40% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, at least about 50% of the carbon

atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, at least about 60% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, at least about 70% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, at least about 80% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12, or at least about 90% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0046] In one embodiment the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 7, has an average methyl branch index (methyl branches per 100 carbons) of at least 8, has an average methyl branch index (methyl branches per 100 carbons) of at least 9, has an average methyl branch index (methyl branches per 100 carbons) of at least 10, has an average methyl branch index (methyl branches per 100 carbons) of at least 11, has an average methyl branch index (methyl branches per 100 carbons) of at least 15, has an average methyl branch index (methyl branches per 100 carbons) of at least 20, has an average methyl branch index (methyl branches per 100 carbons) of at least 22, has an average methyl branch index (methyl branches per 100 carbons) of at least 24, has an average methyl branch index (methyl branches per 100 carbons) of at least 26, has an average methyl branch index (methyl branches per 100 carbons) of at least 27.

[0047] In one embodiment, the molecular weight of the biobased base oil is in range of 300 g/mol to 800 g/mol, the molecular weight of the biobased base oil is in range of 390 g/mol to 510 g/mol.

[0048] The biobased base oil comprises at least 95% non-cyclic isoparaffins having a molecular structure in which 25-34% of total carbon atoms are contained in the branches and less than half of the total isoparaffin branches contain two or more carbon atoms and the engine oil has a renewable hydrocarbon content greater than 25%, as measured by ASTM-D6866 method.

[0049] In one embodiment, at least 95 wt% of the biobased base oil comprises acyclic isoparaffins and at least 25 wt% of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units, at least 30 wt% of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units, at least 35 wt% of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units, or at least 45 wt% of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.

[0050] In one embodiment, the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301 B test method, the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301 B test method, the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301 B test method.

[0051] In one embodiment, the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10, and has a branch ratio of less than 0.41 .

[0052] In one embodiment, the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10, and greater than 40% of the biobased base oil molecules have more than 3 methyl branch per molecule, at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule, at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule,

[0053] In one embodiment, the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10, and greater than 25% of the biobased base oil molecules have more than 6 methyl branch per molecule, at least 30% of the biobased base oil molecules have more than 3 methyl branch per molecule, at least 40% of the biobased base oil molecules have more than 3 methyl branch per molecule, at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule, at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule.

[0054] In one embodiment, the biobased base oil is characterized in having a renewable carbon content greater than 60% as measured by ASTM-D6866-12, greater than 70% as measured by ASTM-D6866-12, greater than 80% as measured by ASTM-D6866-12, greater than 90% as measured by ASTM-D6866-12.

[0055] The base oil has a saturate content of at least 90% as determined by ASTM-D2007-1.

[0056] In one embodiment at least 50% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule, at least 60% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule, at least 70% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule, at least 80% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.

[0057] In one embodiment, the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301 B test method, the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301 B test method.

[0058] The base oil comprises a biobased terpene selected from the group consisting of myrcene, ocimene, farnesene, and combinations thereof. In one embodiment, the base oil comprises farnesene. In one embodiment, the biobased base oil is derived from farnesene. In one embodiment the biobased base oil is derived from sugar.

[0059] In an aspect, the bio-based base oil is a saturated hydrocarbon mixture having a unique branching structure as characterized by NMR that makes it suitable to be used as a high-quality synthetic base stock. The hydrocarbon mixture has outstanding properties including extremely low volatility, good low-temperature properties, etc., which are important performance attributes of high-quality base stocks. Specifically, the mixture comprises greater than 80% of the molecules with an even carbon number according to FIMS. The branching characteristics of the hydrocarbon mixture by NMR comprises a BP/BI in the range ≥ -0.6037 (Internal alkyl branching per molecule)+2.0. Moreover, on average, at least 0.3 to 1.5 of the internal methyl branches are located more than four carbons away from the end carbon. A saturated hydrocarbon with this unique branching structure exhibits a surprising cold crank simulated viscosity (CCS) vs. Noack volatility relationship that is beneficial for blending low-viscosity automotive engine oils.

[0060] In one embodiment, the hydrocarbon mixtures described herein are the product of oligomerization of olefins and a subsequent hydroisomerization. C₁₄ to C₂₀ olefins are oligomerized to form an oligomer distribution consisting of unreacted monomer, dimers (C₂₈-C₄₀), and trimers and higher oligomers ($\geq$ C₄₂). The unreacted monomers are distilled off for possible re-use in a subsequent oligomerization. The remaining oligomers are then hydroisomerized to achieve the final branching structures described herein which consistently impart a surprising cold crank simulated viscosity (CCS) vs. Noack volatility relationship.

Definition of Hydrocarbon Properties

[0061] The following properties are used in describing the saturated hydrocarbon mixtures:

[0062] Viscosity is the physical property that measures the fluidity of the base stock. Viscosity is a strong function of temperature. Two commonly used viscosity measurements are dynamic viscosity and kinematic viscosity. Dynamic viscosity measures the fluid's internal resistance to flow. Cold cranking simulator (CCS) viscosity at -35° C. for engine oil is an

example of dynamic viscosity measurements. The SI unit of dynamic viscosity is Pa·s. The traditional unit used is centipoise (cP), which is equal to 0.001 Pa·s (or 1 mPa·s). The industry is slowly moving to SI units. Kinematic viscosity is the ratio of dynamic viscosity to density. The SI unit of kinematic viscosity is mm²/s. The other commonly used units in industry are centistokes (cSt) at 40° C. (KV40) and 100° C. (KV100) and Saybolt Universal Second (SUS) at 100° F. and 210° F. Conveniently, 1 mm²/s equals 1 cSt. ASTM D5293 and D445 are the respective methods for CCS and kinematic viscosity measurements.

[0063] Viscosity Index (VI) is an empirical number used to measure the change in the base stock's kinematic viscosity as a function of temperature. The higher the VI, the less relative change is in viscosity with temperature. High VI base stocks are desired for most of the lubricant applications, especially in multigrade automotive engine oils and other automotive lubricants subject to large operating temperature variations. ASTM D2270 is a commonly accepted method to determine VI.

[0064] Pour point is the lowest temperature at which movement of the test specimen is observed. It is one of the most important properties for base stocks as most lubricants are designed to operate in the liquid phase. Low pour point is usually desirable, especially in cold weather lubrication. ASTM D97 is the standard manual method to measure pour point. It is being gradually replaced by automatic methods, such as ASTM D5950 and ASTM D6749. ASTM D5950 with 1° C testing interval is used for pour point measurement for the examples in this patent.

[0065] Volatility is a measurement of oil loss from evaporation at an elevated temperature. It has become a very important specification due to emission and operating life concerns, especially for lighter grade base stocks. Volatility is dependent on the oil's molecular composition, especially at the front end of the boiling point curve. Noack (ASTM D5800) is a commonly accepted method to measure volatility for automotive lubricants. The Noack test method itself simulates evaporative loss in high temperature service, such as an operating internal combustion engine.

[0066] Boiling point distribution is the boiling point range that is defined by the True Boiling Points (TBP) at which 5% and 95% materials evaporates. It is measured by ASTM D2887 herein.

NMR Branching Analysis

[0067] Branching parameters measured by NMR spectroscopy for the hydrocarbon characterization include:

[0068] Branching Index (BI): the percentage of methyl hydrogens appearing in the chemical shift range of 0.5 to 1.05 ppm among all hydrogens appearing in the ^1H NMR chemical range 0.5 to 2.1 ppm in an isoparaffinic hydrocarbon.

[0069] Branching Proximity (BP): the percentage of recurring methylene carbons which are four or more number of carbon atoms removed from an end group or branch appearing at ^{13}C NMR chemical shift 29.8 ppm.

[0070] Internal Alkyl Carbons: is the number of methyl, ethyl, or propyl carbons which are three or more carbons removed from end methyl carbons, that includes 3-methyl, 4-methyl, 5+ methyl, adjacent methyl, internal ethyl, n-propyl and unknown methyl appearing between ^{13}C NMR chemical shift 0.5 ppm and 22.0 ppm, except end methyl carbons appearing at 13.8 ppm.

[0071] 5+ Methyl Carbons: is the number of methyl carbons attached to a methine carbon which is more than four carbons away from an end carbon appearing at ^{13}C NMR chemical shift 19.6 ppm in an average isoparaffinic molecule.

[0072] The NMR spectra were acquired using Bruker AVANCE 500 spectrometer using a 5 mm BBI probe. Each sample was mixed 1:1 (wt:wt) with CDCl_3 . The ^1H NMR was recorded at 500.11 MHz and using a $9.0\ \mu\text{s}$ (30°) pulse applied at 4 s intervals with 64 scans co-added for each spectrum. The ^{13}C NMR was recorded at 125.75 MHz using a $7.0\ \mu\text{s}$ pulse and with inverse gated decoupling, applied at 6 sec intervals with 4096 scans co-added for each spectrum. A small amount of 0.1 M $\text{Cr}(\text{acac})_3$ was added as a relaxation agent and TMS was used as an internal standard.

[0073] The branching properties of the lubricant base stock samples of the present invention are determined according to the following six-step process. Procedure is provided in detail in US 20050077208 A1, which is incorporated herein in its entirety. The following procedure is slightly modified to characterize the current set of samples:

(1) Identify the CH branch centers and the CH_3 branch termination points using the DEPT Pulse sequence (Doddrell, D. T.; D. T. Pegg; M. R. Bendall, *Journal of Magnetic Resonance* 1982, 48, 323ff.).

(2) Verify the absence of carbons initiating multiple branches (quaternary carbons) using the APT pulse sequence (Patt, S. L.; J. N. Shoolery, *Journal of Magnetic Resonance* 1982, 46, 535ff.).

(3) Assign the various branch carbon resonances to specific branch positions and lengths using tabulated and calculated values (Lindeman, L. P., *Journal of Qualitative*

Analytical Chemistry 43, 1971 1245ff; Netzel, D. A., et. al., Fuel, 60, 1981, 307ff.). Branch NMR Chemical Shift (ppm)

TABLE 2

Describes ppm shift of alkyl branching by Carbon NMR

	NMR Chemical Shift
Branch	(ppm)
2-methyl	22.5
3-methyl	19.1 or 11.4
4-methyl	14.0
5+ methyl	19.6
Internal ethyl	10.8
n-propyl	14.4
Adjacent methyl	16.7

(4) Quantify the relative frequency of branch occurrence at different carbon positions by comparing the integrated intensity of its terminal methyl carbon to the intensity of a single carbon (total integral/number of carbons per molecule in the mixture). For example, number of 5+ methyl branches per molecule is calculated from the signal intensity at a chemical shift of 19.6 ppm relative to intensity of a single carbon. For the unique case of the 2-methyl branch, where both the terminal and the branch methyl occur at the same resonance position, the intensity was divided by two before doing the frequency of branch occurrence calculation. If the 4-methyl branch fraction is calculated and tabulated, its contribution to the 5+ methyls must be subtracted to avoid double counting. Unknown methyl branches are calculated from contribution of signals that appear between 5.0 ppm and 22.5 ppm, however not including any branches reported in Table 2.

(5) Calculate the Branching Index (BI) and Branching Proximity (BP) using the calculations described in U.S. Pat. No. 6,090,989, which is incorporated by reference herein in its entirety. 6) Calculate the total internal alkyl branches per molecule by adding up the

branches found in steps 3 and 4, except the 2-methyl branches. These branches would include 3-methyl, 4-methyl, 5+ methyl, internal ethyl, n-propyl, adjacent methyl and unknown methyl.

[0074] FIMS Analysis: The hydrocarbon distribution of the current invention is determined by FIMS (field ionization mass spectroscopy). FIMS spectra were obtained on a Waters GCT-TOF mass spectrometer. The samples were introduced via a solid probe, which was heated from about 40° C. to 500° C. at a rate of 50° C. per minute. The mass spectrometer was scanned from m/z 40 to m/z 1000 at a rate of 5 seconds per decade. The acquired mass spectra were summed to generate one averaged spectrum which provides carbon number distribution of paraffins and cycloparaffins containing up to six rings.

Hydrocarbon Structure and Properties

[0075] The structure of the hydrocarbon mixtures disclosed herein are characterized by FIMS and NMR. FIMS analysis demonstrate that more than 80% of the molecules in the hydrocarbon mixtures have an even carbon number.

[0076] The unique branching structure of the hydrocarbon mixtures disclosed herein are characterized by NMR parameters, such as BP, BI, internal alkyl branching, and 5+ methyls. BP/BI of the hydrocarbon mixtures are in the range of >-0.6037 (Internal alkyl branching per molecule)+2.0. The 5+ methyls of the hydrocarbon mixtures average from 0.3 to 1.5 per molecule.

[0077] The hydrocarbon mixture can be classified into two carbon ranges based on the carbon number distribution, C₂₈ to C₄₀ carbons, and greater than or equal to C₄₂. Generally, about or greater than 95% of the molecules present in each hydrocarbon mixture have carbon numbers within the specified range. Representative molecular structures for the C₂₈ to C₄₀ range can be proposed based on the NMR and FIMS analysis. Without wishing to be bound to any one particular theory, it is believed that the structures made by oligomerization and hydroisomerization of olefins has methyl, ethyl, butyl branches distributed throughout the structure and the branch index and branch proximity contribute to the surprisingly good low temperature properties of the product. Exemplary structures in the present hydrocarbon mixture are as follows:

[0078] The unique branching structure and narrow carbon distribution of the hydrocarbon mixtures makes them suitable to be used as high-quality synthetic base oils, especially for low-viscosity engine oil applications. The hydrocarbon mixtures exhibit: a KV100 in the range of 3.0-10.0 cSt; a pour point in the range of -20 to -55° C.; a Noack and CCS at -35° C. relationship such that Noack is between $2750 \text{ (CCS at } -35^\circ \text{ C.)}^{(-0.8)} \pm 2$;

[0079] A hydrocarbon mixture in accordance with the present invention with carbon numbers in the range of C₂₈ to C₄₀, and in another embodiment carbon numbers in the range of from C₂₈ to C₃₆, or in another embodiment molecules with a carbon number of C₃₂, will generally exhibit the following characteristics in addition to the characteristics of BP/BI, Internal alkyl branches per molecule, 5+ methyl branches per molecule, and Noack/CCS relationship described above: a KV100 in the range of 3.0-6.0 cSt; a VI in the range of 11 ln(BP/BI)+135 to 11 ln(BP/BI)+145; and a pour point in the range of 33 ln(BP/BI)-45 to 33 ln(BP/BI)-35.

[0080] In one embodiment, the KV100 for the C₂₈-C₄₀ hydrocarbon mixture ranges from 3.2 to 5.5 cSt; in another embodiment the KV100 ranges from 4.0 to 5.2 cSt; and from 4.1 to 4.5 cSt in another embodiment.

[0081] The VI for the C₂₈-C₄₀ hydrocarbon mixture ranges from 125 to 155 in one embodiment and from 135 to 145 in another embodiment.

[0082] The Pour Point of the hydrocarbon mixture, in one embodiment ranges from 25 to -55° C. and from 35 to -45° C. in another embodiment.

[0083] The boiling point range of the C₂₈-C₄₀ hydrocarbon mixture in one embodiment is no greater than 125° C. (TBP at 95%-TBP at 5%) as measured by ASTM D2887; no greater than 100° C. in another embodiment; no greater than 75° C. in one embodiment; no greater than 50° C. in another embodiment; and no greater than 30° C. in one embodiment. In the preferred embodiments, those with a boiling point range no greater than 50° C., and even more preferably no greater than 30° C., give a surprisingly low Noack Volatility (ASTM D5800) for a given KV100.

[0084] The C₂₈-C₄₀ hydrocarbon mixture in one embodiment has a Branching Proximity (BP) in the range of 14-30 with a Branching Index (BI) in the range of 15-25; and in another embodiment a BP in the range of 15-28 and a BI in the range of 16-24.

[0085] The Noack volatility (ASTM D5800) of the C₂₈-C₄₀ hydrocarbon mixture is less than 16 wt % in one embodiment; less than 12 wt % in one embodiment; less than 10 wt % in one embodiment; less than 8 wt % in one embodiment and less than 7 wt % in one embodiment. The C₂₈-C₄₀ hydrocarbon mixture in one embodiment also has a CCS viscosity at -35° C. of less than 2700 cP; of less than 2000 cP in another embodiment; of less than 1700 cP in one embodiment; and less than 1500 cP in one embodiment.

[0086] The hydrocarbon mixture with the carbon number range of C₄₂ and greater will generally exhibit the following characteristics, in addition to the characteristics of BP/BI,

internal alkyl branches per molecule, 5+ methyl branches per molecule, and Noack and CCS at -35°C . relationship described above: a KV100 in the range of 6.0-10.0 cSt; a VI in the range of $11 \ln(\text{BP}/\text{BI})+145$ to $11 \ln(\text{BP}/\text{BI})+160$; and a Pour Point in the range of $33 \ln(\text{BP}/\text{BI})-40$ to $33 \ln(\text{BP}/\text{BI})-25$.

[0087] The hydrocarbon mixture comprising C_{42} carbons or greater, in one embodiment has a KV100 in the range of 8.0 to 10.0 cSt, and in another embodiment from 8.5 to 9.5 cSt.

[0088] The VI of the hydrocarbon mixture having ≥ 42 carbons is 140-170 in one embodiment; and, from 150-160 in another embodiment.

[0089] The pour point in one embodiment ranges from -15 to -50°C .; and, from -20 to -40°C . in another embodiment.

[0090] In one embodiment, the hydrocarbon mixture comprising ≥ 42 carbons has a BP in the range of 18-28 with a BI in the range of 17-23. In another embodiment, the hydrocarbon mixture has a BP in the range of 18-28 and a BI in the range of 17-23.

[0091] In general, both hydrocarbon mixtures disclosed above exhibit the following characteristics: at least 80% of the molecules have an even carbon number according to FIMS; a KV100 in the range of 3.0-10.0 cSt; a pour point in the range of -20 to -55°C .; a Noack and CCS @ -35°C . relationship such that Noack is between $2750 (\text{CCS @ } -35^{\circ}\text{C}.)^{(-0.8)} \pm 2$; a BP/BI in the range of ≥ -0.6037 (Internal alkyl branching)+2.0 per molecule; and, on average from 0.3 to 1.5 5+ methyl branches per molecule.

[0092] The hydroisomerized hydrocarbon mixtures are comprised of dimers having carbon numbers in the range of C_{28} - C_{40} , and a mixture of trimers+ having carbon numbers of C_{42} and greater. Each of the hydrocarbon mixtures will exhibit a BP/BI in the range of ≥ -0.6037 (internal alkyl branching) ± 2.0 per molecule, and, on average, from 0.3 to 1.5 methyl branches on the fifth or greater position per molecule. Importantly, at least 80% of the molecules in each composition also have an even carbon number as determined by FIMS. In another embodiment, each of the hydrocarbon compositions will also exhibit a Noack and CCS at -35°C . relationship such that the Noack is between $2750 (\text{CCS at } -35^{\circ}\text{C}.)^{(-0.8)} \pm 2$. These characteristics allow for the formulation of low-viscosity engine oils as well as many other high-performance lubricant products.

[0093] In one embodiment, C_{16} olefins are used as the feed for the oligomerization reaction. When using C_{16} olefins as the feed, the hydroisomerized dimer product generally exhibits a KV100 of 4.3 cSt with <8% Noack loss and a CCS at -35°C . of approximately

1,700 cP. The extremely low Noack volatility is due to the high starting boiling point and narrow boiling point distribution when compared other 3.9 to 4.4 cSt synthetic base stocks. This makes it ideal for use in low viscosity engine oils with strict volatility requirements. The excellent CCS and pour point characteristics are due to the branching characteristics discussed above. In one embodiment, the material has a pour point of $\leq -40^{\circ}\text{C}$. This is required to pass critical engine oil formulation requirements for 0W formulations, including Mini-Rotary Viscosity (ASTM D4684) and Scanning Brookfield Viscosity (ASTM D2983) specifications.

SECONDARY BASE OIL

[0094] The lubricating oil compositions disclosed herein generally comprise at least one oil of lubricating viscosity. Any base oil known to a skilled artisan can be used as the oil of lubricating viscosity disclosed herein. Some base oils suitable for preparing the lubricating oil compositions have been described in Mortier *et al.*, “*Chemistry and Technology of Lubricants*,” 3rd Edition, London, Springer, Chapters 1 and 2 (2011); and A. Sequeria, Jr., “*Lubricant Base Oil and Wax Processing*,” New York, Marcel Decker, Chapter 6, (1994); and D. V. Brock, *Lubrication Engineering*, Vol. 43, pages 184-5, (1987), all of which are incorporated herein by reference. Generally, the amount of the base oil in the lubricating oil composition may be from about 60 to about 99.5 wt.%, based on the total weight of the lubricating oil composition. In some embodiments, the amount of the base oil in the lubricating oil composition is from about 75 to about 99 wt.%, from about 80 to about 98.5 wt.%, or from about 80 to about 98 wt.%, based on the total weight of the lubricating oil composition.

[0095] In addition to the bio-based base oil outlined above, in certain embodiments, the base oil is or comprises any natural or synthetic lubricating base oil fraction. Some non-limiting examples of synthetic oils include oils, such as polyalphaolefins or PAOs, prepared from the polymerization of at least one alpha-olefin, such as ethylene; and oils or from hydrocarbon synthesis procedures using carbon monoxide and hydrogen gases, such as the Fisher-Tropsch process. In certain embodiments, the base oil comprises less than about 10 wt.% of one or more heavy fractions, based on the total weight of the base oil. A heavy fraction refers to a lube oil fraction having a viscosity of at least about 20 cSt at 100 °C. In certain embodiments, the heavy fraction has a viscosity of at least about 25 cSt or at least about 30 cSt at 100 °C. In further embodiments, the amount of the one or more heavy fractions in the base oil is less than about 10 wt.%, less than about 5 wt.%, less than about 2.5 wt.%, less than about

1 wt.%, or less than about 0.1 wt.%, based on the total weight of the base oil. In still further embodiments, the base oil comprises no heavy fraction.

[0096] In certain embodiments, the lubricating oil compositions comprise a major amount of a base oil of lubricating viscosity. In some embodiments, the base oil has a kinematic viscosity at 100 °C from about 2.5 centistokes (cSt) to about 20 cSt. The kinematic viscosity of the base oils or the lubricating oil compositions disclosed herein can be measured according to ASTM D 445, which is incorporated herein by reference.

[0097] In other embodiments, the base oil is or comprises a base stock or blend of base stocks. In further embodiments, the base stocks are manufactured using a variety of different processes including, but not limited to, distillation, solvent refining, hydrogen processing, oligomerization, esterification, and rerefining. In some embodiments, the base stocks comprise a rerefined stock. In further embodiments, the rerefined stock shall be substantially free from materials introduced through manufacturing, contamination, or previous use.

[0098] In some embodiments, the base oil comprises one or more of the base stocks in one or more of Groups I-V as specified in the American Petroleum Institute (API) Publication 1509, Seventeenth Edition, September 2012 (*i.e.*, API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils), which is incorporated herein by reference. The API guideline defines a base stock as a lubricant component that may be manufactured using a variety of different processes. Groups I, II and III base stocks are mineral oils, each with specific ranges of the amount of saturates, sulfur content and viscosity index. Suitable Group I base oils include any light overhead cuts from a vacuum distillation column, such as, for example, any Light Neutral, Medium Neutral, and Heavy Neutral base stocks. The base oil may also include residual base stocks or bottoms fractions such as bright stock. Bright stock is a high viscosity base oil which has been conventionally produced from residual stocks or bottoms and has been highly refined and dewaxed. Group IV base stocks are polyalphaolefins (PAO). Group V base stocks include all other base stocks not included in Group I, II, III, or IV.

[0099] The saturates levels, sulfur levels and viscosity indices for Group I, II and III base stocks are listed in Table 3 below.

TABLE 3

Group	Saturates (As determined by ASTM D 2007)	Sulfur (As determined by ASTM D 2270)	Viscosity Index (As determined by ASTM D 4294, ASTM D 4297 or ASTM D 3120)
I	Less than 90% saturates.	Greater than or equal to 0.03% sulfur.	Greater than or equal to 80 and less than 120.
II	Greater than or equal to 90% saturates.	Less than 0.03% sulfur.	Greater than or equal to 80 and less than 120.
III	Greater than or equal to 90% saturates.	Less than or equal to 0.03% sulfur.	Greater than or equal to 120.

[00100] In some embodiments, the base oil comprises one or more of the base stocks in Group I, II, III, IV, V or a combination thereof. In other embodiments, the base oil comprises one or more of the base stocks in Group II, III, IV or a combination thereof.

[00101] The base oil may be selected from the group consisting of natural oils of lubricating viscosity, synthetic oils of lubricating viscosity and mixtures thereof. In some embodiments, the base oil includes base stocks obtained by isomerization of synthetic wax and slack wax, as well as hydrocrackate base stocks produced by hydrocracking (in addition to or instead of solvent extracting) the aromatic and polar components of the crude. In other embodiments, the base oil of lubricating viscosity includes natural oils, such as animal oils, vegetable oils, mineral oils, oils derived from coal or shale, and combinations thereof. Some non-limiting examples of animal oils include bone oil, lanolin, fish oil, lard oil, dolphin oil, seal oil, shark oil, tallow oil, and whale oil. Some non-limiting examples of vegetable oils include castor oil, olive oil, peanut oil, rapeseed oil, corn oil, sesame oil, cottonseed oil, soybean oil, sunflower oil, safflower oil, hemp oil, linseed oil, tung oil, oiticica oil, jojoba oil, and meadow foam oil. Such oils may be partially or fully hydrogenated. Some non-limiting examples of mineral oils include Groups I, II, and III base stocks, liquid petroleum oils and solvent treated or acid-treated mineral oils of the paraffinic, naphthenic or mixed paraffinic-naphthenic types. In some embodiments, the mineral oils are neat or low viscosity mineral oils.

[00102] In some embodiments, the synthetic oils of lubricating viscosity include hydrocarbon oils and halo-substituted hydrocarbon oils such as polymerized and inter-

polymerized olefins, alkylbenzenes, polyphenyls, alkylated diphenyl ethers, alkylated diphenyl sulfides, as well as their derivatives, analogues and homologues thereof, and the like. In other embodiments, the synthetic oils include alkylene oxide polymers, interpolymers, copolymers and derivatives thereof wherein the terminal hydroxyl groups can be modified by esterification, etherification, and the like. In further embodiments, the synthetic oils include the esters of dicarboxylic acids with a variety of alcohols. In certain embodiments, the synthetic oils include esters made from C₅ to C₁₂ monocarboxylic acids and polyols and polyol ethers. In further embodiments, the synthetic oils include tri-alkyl phosphate ester oils, such as tri-n-butyl phosphate and tri-iso-butyl phosphate.

[00103] In some embodiments, the synthetic oils of lubricating viscosity include silicon-based oils (such as the polyalkyl-, polyaryl-, polyalkoxy-, polyaryloxy-siloxane oils and silicate oils). In other embodiments, the synthetic oils include liquid esters of phosphorus-containing acids, polymeric tetrahydrofurans, polyalphaolefins, and the like.

[00104] Base oil derived from the hydroisomerization of wax may also be used, either alone or in combination with the aforesaid natural and/or synthetic base oil. Such wax isomerate oil is produced by the hydroisomerization of natural or synthetic waxes or mixtures thereof over a hydroisomerization catalyst.

[00105] In further embodiments, the base oil comprises a poly-alpha-olefin (PAO). In general, the poly-alpha-olefins may be derived from an alpha-olefin having from about 2 to about 30, from about 4 to about 20, or from about 6 to about 16 carbon atoms. Non-limiting examples of suitable poly-alpha-olefins include those derived from octene, decene, mixtures thereof, and the like. These poly-alpha-olefins may have a viscosity from about 2 to about 15, from about 3 to about 12, or from about 4 to about 8 centistokes at 100 °C. In some instances, the poly-alpha-olefins may be used together with other base oils such as mineral oils.

[00106] In further embodiments, the base oil comprises a polyalkylene glycol or a polyalkylene glycol derivative, where the terminal hydroxyl groups of the polyalkylene glycol may be modified by esterification, etherification, acetylation and the like. Non-limiting examples of suitable polyalkylene glycols include polyethylene glycol, polypropylene glycol, polyisopropylene glycol, and combinations thereof. Non-limiting examples of suitable polyalkylene glycol derivatives include ethers of polyalkylene glycols (*e.g.*, methyl ether of polyisopropylene glycol, diphenyl ether of polyethylene glycol, diethyl ether of polypropylene glycol, *etc.*), mono- and polycarboxylic esters of polyalkylene glycols, and combinations

thereof. In some instances, the polyalkylene glycol or polyalkylene glycol derivative may be used together with other base oils such as poly- α -olefins and mineral oils.

[00107] In further embodiments, the base oil comprises any of the esters of dicarboxylic acids (*e.g.*, phthalic acid, succinic acid, alkyl succinic acids, alkenyl succinic acids, maleic acid, azelaic acid, suberic acid, sebacic acid, fumaric acid, adipic acid, linoleic acid dimer, malonic acid, alkyl malonic acids, alkenyl malonic acids, and the like) with a variety of alcohols (*e.g.*, butyl alcohol, hexyl alcohol, dodecyl alcohol, 2-ethylhexyl alcohol, ethylene glycol, diethylene glycol monoether, propylene glycol, and the like). Non-limiting examples of these esters include dibutyl adipate, di(2-ethylhexyl) sebacate, di-*n*-hexyl fumarate, dioctyl sebacate, diisooctyl azelate, diisodecyl azelate, dioctyl phthalate, didecyl phthalate, dieicosyl sebacate, the 2-ethylhexyl diester of linoleic acid dimer, and the like.

[00108] In further embodiments, the base oil comprises a hydrocarbon prepared by the Fischer-Tropsch process. The Fischer-Tropsch process prepares hydrocarbons from gases containing hydrogen and carbon monoxide using a Fischer-Tropsch catalyst. These hydrocarbons may require further processing in order to be useful as base oils. For example, the hydrocarbons may be dewaxed, hydroisomerized, and/or hydrocracked using processes known to a person of ordinary skill in the art.

[00109] In further embodiments, the base oil comprises an unrefined oil, a refined oil, a rerefined oil, or a mixture thereof. Unrefined oils are those obtained directly from a natural or synthetic source without further purification treatment. Non-limiting examples of unrefined oils include shale oils obtained directly from retorting operations, petroleum oils obtained directly from primary distillation, and ester oils obtained directly from an esterification process and used without further treatment. Refined oils are similar to the unrefined oils except the former have been further treated by one or more purification processes to improve one or more properties. Many such purification processes are known to those skilled in the art such as solvent extraction, secondary distillation, acid or base extraction, filtration, percolation, and the like. Rerefined oils are obtained by applying to refined oils processes similar to those used to obtain refined oils. Such rerefined oils are also known as reclaimed or reprocessed oils and often are additionally treated by processes directed to removal of spent additives and oil breakdown products.

INDUSTRIAL APPLICATION

Marine

[00110] The lubricating oil compositions of the present invention may be used as a Marine lubricant. Marine diesel internal combustion engines may generally be classified as slow-speed, medium-speed, or high-speed engines. Slow-speed diesel engines typically operate in the range of about 60 to 200 revolutions per minute (rpm). A slow-speed diesel engine operates on the two-stroke cycle and is typically a direct-coupled and direct-reversing engine of “crosshead” construction, with a diaphragm and one or more stuffing boxes separating the power cylinders from the crankcase to prevent combustion products from entering the crankcase and mixing with the crankcase oil. The complete separation of the crankcase from the combustion zone has led persons skilled in the art to lubricate the combustion chamber and the crankcase with different lubricating oils, a cylinder lubricant and a system oil respectively. Marine cylinder lubricants are typically made to the SAE 40, SAE 50 or SAE 60 monograde specification. Typically, marine diesel cylinder lubricants have a TBN ranging from 5 to 200 mg KOH/g (e.g., from 5 to 150 mg KOH/g, from 10 to 100 mg KOH/g, from 15 to 150 mg KOH/g, from 20 to 80 mg KOH/g, 30 to 80 mg KOH/g, from 30 to 60 mg KOH/g and from 30 to 50 mgKOH/g). Marine system oil lubricants are typically made to the SAE 20 or SAE 30 monograde specification. Typically, marine system oil lubricants have a TBN ranging from 5 to 15 mg KOH/g.

[00111] Medium-speed engines, typically operate in the range of about 250 to 1100 rpm and operate on the four-stroke cycle. These engines are typically of the trunk piston design. In trunk piston engines, a single lubricating oil is employed for lubrication of all areas of the engine. Marine trunk piston engine oil lubricants are typically made to the SAE 30 or SAE 40 monograde specification. Typically, marine trunk piston engine oil lubricants have a TBN ranging from 10 to 70 mg KOH/g (e.g., from 10 to 60 mg KOH/g, from 15 to 55 mg KOH/g, and from 15 to 60 mg KOH/g).

[00112] The term “marine” does not restrict the engines to those used in water-borne vessels; as is understood in the art, it also includes those for other industrial applications such as auxiliary power generation for main propulsion and stationary land-based engines for power generation. The lubricating oil compositions of the present invention may also be used in on-board blending systems such as systems designed for blending the oil for delivery to the cylinders of the main engine on board the marine vessel where the main engine is installed.

NGEO

[00113] The lubricating oil compositions of the present invention may be used as a natural gas engine lubricant. The natural gas engines to which the present disclosure is applicable may be characterized as those operated on, i.e., fueled by, natural gas and include internal combustion engines. The natural gas engine may be a stationary natural gas engine, a stationary biogas engine, a stationary landfill gas engine, a stationary unconventional (including mine gas or coal bed methane, landfill gas, biogas, wellhead or raw unprocessed natural gas) natural gas engine, or a dual-fuel engine. In one embodiment, the internal combustion engine is a stationary engine used in, for example, well-head gas gathering, compression, and other gas pipeline services; electrical power generation (including co-generation); and irrigation.

[00114] The lubricating oil composition disclosed herein may be utilized in controlling deposits in engines operating under high sustained load conditions, such as a brake mean effective pressure (BMEP) of at least 20 bar (2.0 MPa), e.g., at least 22 bar (2.2 MPa), at least 24 bar (2.4 MPa), at least 26 bar (2.6 MPa), 20 to 30 bar (2.0 to 3.0 MPa), 22 to 30 bar (2.2 to 3.0 MPa), 24 to 30 bar (2.4 to 3.0 MPa), or 22 to 28 bar (2.2 to 2.8 MPa).

[00115] The lubricating oil composition of the present disclosure may provide advantaged deposit control performance in any of a number of mechanical components of an engine. The mechanical component may be a piston, a piston ring, a cylinder liner, a cylinder, a cam, a tappet, a lifter, a gear, a valve, or a bearing including a journal, a roller, a tapered, a needle, or a ball bearing. In some aspects, the mechanical component comprises steel.

[00116] The lubricating oil composition of this disclosure may be a monograde engine oil, e.g., a SAE 20, SAE 30, SAE 40, SAE 50 or SAE 60 viscosity grade engine oil. The lubricating oil composition of this disclosure may also be multi grade engine oils.

Railroad engine oil

[00117] The lubricating oil compositions of the present invention may be used as a railroad engine lubricant. The lubricating oil composition of this disclosure may be a multi-grade engine oil for medium or low speed diesel engine, e.g., an engine oil with a SAE viscosity grade of 15W-x, 20W-x or 25W-x, where x may be selected from 30, 40, 50, or 60. The lubricating oil composition of this disclosure may also be mono grade engine oils.

[00118] Herein, a “low-speed” diesel engine means a compression-ignition internal combustion engine that is driven at a rotational speed that is less than 500 revolutions per

minute (rpm), such as marine crosshead diesel engines; a “medium-speed” diesel engine means a compression-ignition internal combustion engine that is driven at a rotational speed of 500 to 1800 rpm, such as locomotive diesel engines, marine trunk piston diesel engines, dual fuel engines for locomotives, or land-based stationary power diesel engines.

Functional Fluid

[00119] The lubricating oil compositions of the present invention may be used as a functional fluid lubricant. A functional fluid is a term which encompasses a variety of fluids including but not limited to tractor hydraulic fluids, power transmission fluids including automatic transmission fluids, continuously variable transmission fluids and manual transmission fluids, hydraulic fluids, gear oils, power steering fluids, fluids used in wind turbines and fluids related to power train components. It should be noted that within each of these fluids such as, for example, automatic transmission fluids, there are a variety of different types of fluids due to the various transmissions having different designs which have led to the need for fluids of markedly different functional characteristics.

[00120] With respect to tractor hydraulic fluids, these fluids are all-purpose products used for all lubricant applications in a tractor except for lubricating the engine. Also included as a tractor hydraulic fluid for the purposes of this invention are so-called Super Tractor Oil Universal fluids or “STOU” fluids, which also lubricate the engine. These lubricating applications may include lubrication of gearboxes, power take-off and clutch(es), rear axles, reduction gears, wet brakes, and hydraulic accessories. The components included within a tractor fluid must be carefully chosen so that the final resulting fluid composition will provide all the necessary characteristics required in the different applications. Such characteristics may include the ability to provide proper frictional properties for preventing wet brake chatter of oil immersed brakes while simultaneously providing the ability to actuate wet brakes and provide power take-off (PTO) clutch performance. A tractor fluid must provide sufficient antiwear and extreme pressure properties as well as water tolerance/filterability capabilities. The extreme pressure (EP) properties of tractor fluids, important in gearing applications, may be demonstrated by the ability of the fluid to pass a spiral bevel test as well as a straight spur gear test. The tractor fluid may need to pass wet brake chatter tests while providing adequate wet brake capacity when used in oil immersed disk brakes which are comprised of a bronze, graphitic-compositions and asbestos. The tractor fluid may need to demonstrate its ability to provide friction retention for power shift transmission clutches such as those clutches which include graphitic and bronze clutches.

[00121] When the functional fluid is an automatic transmission fluid, the automatic transmission fluids must have enough friction for the clutch plates to transfer power. However, the friction coefficient of fluids has a tendency to decline due to the temperature effects as the fluid heats up during operation. It is important that the tractor hydraulic fluid or automatic transmission fluid maintain its high friction coefficient at elevated temperatures, otherwise brake systems or automatic transmissions may fail.

[00122] The lubricating oil compositions of the present invention may be suitable for use in an electric vehicle, hybrid vehicles, and plug-in hybrid vehicles equipped with electric motors and/or generators built into the transmission. The lubricant is substantially free of metal compounds (e.g., Ca, Mo, or Zn) and demonstrates high volume resistivity, wear protection, and copper corrosion resistance.

ADDITIONAL LUBRICATING OIL ADDITIVES

[00123] The lubricating oil compositions of the present invention may also contain other conventional additives that can impart or improve any desirable property of the lubricating oil composition in which these additives are dispersed or dissolved. Any additive known to a person of ordinary skill in the art may be used in the lubricating oil compositions disclosed herein. Some suitable additives have been described in Mortier et al., "Chemistry and Technology of Lubricants", 2nd Edition, London, Springer, (1996); and Leslie R. Rudnick, "Lubricant Additives: Chemistry and Applications", New York, Marcel Dekker (2003), both of which are incorporated herein by reference. For example, the lubricating oil compositions can be blended with antioxidants, anti-wear agents, detergents such as metal detergents, rust inhibitors, dehazing agents, demulsifying agents, metal deactivating agents, friction modifiers, pour point depressants, antifoaming agents, co-solvents, package compatibilisers, corrosion-inhibitors, ashless dispersants, dyes, extreme pressure agents and the like and mixtures thereof. A variety of the additives are known and commercially available. These additives, or their analogous compounds, can be employed for the preparation of the lubricating oil compositions of the invention by the usual blending procedures.

[00124] In general, the concentration of each of the additives in the lubricating oil composition, when used, may range from about 0.001 wt.% to about 50.0 wt.%, from 0.001 to about 40.0 wt. %, from about 0.001 to about 30.0 wt.%, from about 0.001 wt. % to about 20 wt. %, from about 0.01 wt. % to about 15 wt. %, or from about 0.1 wt. % to about 10 wt. %, based on the total weight of the lubricating oil composition.

Ashless Dispersant

[00125] The lubricating oil compositions can contain one or more ashless dispersants containing one or more basic nitrogen atoms. When dispersants are used to formulate lubricating oil compositions, the dispersants are understood in the art to mean “dispersant inhibitor additive packages”. The basic nitrogen compound for use herein must contain basic nitrogen as measured, for example, by ASTM D664 test or D2896. The basic nitrogen compounds are selected from the group consisting of succinimides, polysuccinimides, carboxylic acid amides, hydrocarbyl monoamines, hydrocarbon polyamines, Mannich bases, phosphoramides, thiophosphoramides, phosphoramides, dispersant viscosity index improvers, and mixtures thereof. These basic nitrogen-containing compounds are described below (keeping in mind the reservation that each must have at least one basic nitrogen). Any of the nitrogen-containing compositions may be post-treated with, e.g., boron or ethylene carbonate, using procedures well known in the art so long as the compositions continue to contain basic nitrogen.

[00126] Another class of nitrogen-containing compositions useful in preparing the dispersants employed in this invention includes the so-called dispersant viscosity index improvers (VI improvers). These VI improvers are commonly prepared by functionalizing a hydrocarbon polymer, especially a polymer derived from ethylene and/or propylene, optionally containing additional units derived from one or more co-monomers such as alicyclic or aliphatic olefins or diolefins. The functionalization may be carried out by a variety of processes which introduce a reactive site or sites which usually has at least one oxygen atom on the polymer. The polymer is then contacted with a nitrogen-containing source to introduce nitrogen-containing functional groups on the polymer backbone. Commonly used nitrogen sources include any basic nitrogen compound especially those nitrogen-containing compounds and compositions described herein. Preferred nitrogen sources are alkylene amines, such as ethylene amines, alkyl amines, and Mannich bases.

[00127] In one embodiment, the basic nitrogen compounds for use in making the dispersants are succinimides, carboxylic acid amides, and Mannich bases. In another preferred embodiment, the basic nitrogen compounds for use in making the dispersants are succinimides having an average molecular weight of about 1000 or about 1300 or about 2300 and mixtures thereof. Such succinimides can be post treated with boron or ethylene carbonate as known in the art.

[00128] Generally, the amount of the one or more dispersants in the lubricating oil composition will vary from about 0.05 to about 15 wt. %, based on the total weight of the lubricating oil composition. In another embodiment, the amount of the one or more dispersants will vary from about 0.1 to about 10 wt. %, based on the total weight of the lubricating oil composition.

Antioxidants

[00129] The lubricating oil composition of the can contain one or more antioxidants that can reduce or prevent the oxidation of the base oil. Any antioxidant known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable antioxidants include amine-based antioxidants (e.g., alkyl diphenylamines such as bis-nonylated diphenylamine, bis-octylated diphenylamine, and octylated/butylated diphenylamine, phenyl- α -naphthylamine, alkyl or arylalkyl substituted phenyl- α -naphthylamine, alkylated p-phenylene diamines, tetramethyl-diaminodiphenylamine and the like), phenolic antioxidants (e.g., 2-tert-butylphenol, 4-methyl-2,6-di-tert-butylphenol, 2,4,6-tri-tert-butylphenol, 2,6-di-tert-butyl-p-cresol, 2,6-di-tert-butylphenol, 4,4'-methylenebis-(2,6-di-tert-butylphenol), 4,4'-thiobis(6-di-tert-butyl-o-cresol) and the like), sulfur-based antioxidants (e.g., dilauryl-3,3'-thiodipropionate, sulfurized phenolic antioxidants and the like), phosphorous-based antioxidants (e.g., phosphites and the like), zinc dithiophosphate, oil-soluble copper compounds and combinations thereof. The amount of the antioxidant may vary from about 0.01 wt. % to about 10 wt. %, from about 0.05 wt. % to about 5 wt. %, or from about 0.1 wt. % to about 3 wt. %, based on the total weight of the lubricating oil composition.

Detergents

[00130] The lubricating oil composition of the present invention can contain one or more detergents. Metal-containing or ash-forming detergents function as both detergents to reduce or remove deposits and as acid neutralizers or rust inhibitors, thereby reducing wear and corrosion and extending engine life. Detergents generally comprise a polar head with a long hydrophobic tail. The polar head comprises a metal salt of an acidic organic compound. The salts may contain a substantially stoichiometric amount of the metal in which case they are usually described as normal, neutral salts or low overbased and would typically have a TBN at 100% active mass of from 0 to <150 mg KOH/g. A large amount of a metal base may be incorporated by reacting excess metal compound (e.g., an oxide or hydroxide) with an acidic gas (e.g., carbon dioxide). The resulting overbased detergent comprises neutralized detergent as an outer layer of a metal base (e.g., carbonate) micelle. Such overbased detergents may have

a TBN at 100% active mass of 100 mg KOH/g or greater to 250 mg KOH/g and are considered to be medium overbased. High overbased detergents may have a TBN at 100% active mass of greater than 250 mg KOH/g. Detergents that may be used include oil-soluble neutral, low overbased, medium overbased and high overbased sulfonates, borated sulfonates, phenates, sulfurized phenates, thiophosphonates, salicylates, and naphthenates and other oil-soluble carboxylates of a metal, particularly the alkali or alkaline earth metals, e.g., barium, sodium, potassium, lithium, calcium, and magnesium. The most commonly used metals are calcium and magnesium, which may both be present in detergents used in a lubricant, and mixtures of calcium and/or magnesium with sodium. The detergent can also be a complex, or hybrid, detergent which is known in the art as comprising a surfactant system derived from at least two surfactants described above.

[00131] The alkyl substituent of the overbased detergent may be a residue derived from an alpha-olefin having from 12 to 40 carbon atoms. The alkyl substituent can be a residue derived from an alpha-olefin having from 14 to 28 carbon atoms per molecule. The alkyl substituent can be a residue derived from an olefin comprising C₁₂ to C₄₀ oligomers of a monomer selected from propylene, butylene, or mixtures thereof. The olefins employed may be linear, isomerized linear, branched or partially branched linear. The olefin may be a mixture of linear olefins, a mixture of isomerized linear olefins, a mixture of branched olefins, a mixture of partially branched linear or a mixture of any of the foregoing. The alpha-olefin may be a normal alpha-olefin, an isomerized normal alpha-olefin, or a mixture thereof.

[00132] Generally, the amount of the additional detergent can be from about 0.001 wt.% to about 45.0 wt.%, from about 0.001 wt.% to about 40.0 wt.%, from about 0.001 wt. % to about 25 wt. %, from about 0.05 wt. % to about 20 wt. %, or from about 0.1 wt. % to about 15 wt. %, based on the total weight of the lubricating oil composition.

Friction Modifiers

[00133] In addition to the friction modifier of the present invention, the lubricating oil composition of the present invention can contain additional friction modifiers that can lower the friction between moving parts. Any friction modifier known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable friction modifiers include fatty carboxylic acids; derivatives (e.g., alcohol, esters, borated esters, amides, metal salts and the like) of fatty carboxylic acid; mono-, di- or tri-alkyl substituted phosphoric acids or phosphonic acids; derivatives (e.g., esters, amides, metal salts and the like) of mono-, di- or tri-alkyl substituted phosphoric acids or phosphonic acids; mono-

, di- or tri-alkyl substituted amines; mono- or di-alkyl substituted amides and combinations thereof. In some embodiments examples of friction modifiers include, but are not limited to, alkoxylated fatty amines; borated fatty epoxides; fatty phosphites, fatty epoxides, fatty amines, borated alkoxylated fatty amines, metal salts of fatty acids, fatty acid amides, glycerol esters, borated glycerol esters; and fatty imidazolines as disclosed in U.S. Patent No. 6,372,696, the contents of which are incorporated by reference herein; friction modifiers obtained from a reaction product of a C₄ to C₇₅, or a C₆ to C₂₄, or a C₆ to C₂₀, fatty acid ester and a nitrogen-containing compound selected from the group consisting of ammonia, and an alkanolamine and the like and mixtures thereof. The amount of the friction modifier may vary from about 0.01 wt. % to about 10 wt. %, from about 0.05 wt. % to about 5 wt. %, or from about 0.1 wt. % to about 3 wt. %, based on the total weight of the lubricating oil composition.

Antiwear Compounds

[00134] The lubricating oil composition of the present invention can contain one or more anti-wear agents that can reduce friction and excessive wear. Any anti-wear agent known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable anti-wear agents include zinc dithiophosphate, metal (e.g., Pb, Sb, Mo and the like) salts of dithiophosphates, metal (e.g., Zn, Pb, Sb, Mo and the like) salts of dithiocarbamates, metal (e.g., Zn, Pb, Sb and the like) salts of fatty acids, boron compounds, phosphate esters, phosphite esters, amine salts of phosphoric acid esters or thiophosphoric acid esters, reaction products of dicyclopentadiene and thiophosphoric acids and combinations thereof. The amount of the anti-wear agent may vary from about 0.01 wt. % to about 5 wt. %, from about 0.05 wt. % to about 3 wt. %, or from about 0.1 wt. % to about 1 wt. %, based on the total weight of the lubricating oil composition.

[00135] In certain embodiments, the anti-wear agent is or comprises a dihydrocarbyl dithiophosphate metal salt, such as zinc dialkyl dithiophosphate compounds. The metal of the dihydrocarbyl dithiophosphate metal salt may be an alkali or alkaline earth metal, or aluminum, lead, tin, molybdenum, manganese, nickel or copper. In some embodiments, the metal is zinc. In other embodiments, the alkyl group of the dihydrocarbyl dithiophosphate metal salt has from about 3 to about 22 carbon atoms, from about 3 to about 18 carbon atoms, from about 3 to about 12 carbon atoms, or from about 3 to about 8 carbon atoms. In further embodiments, the alkyl group is linear or branched.

[00136] The amount of the dihydrocarbyl dithiophosphate metal salt including the zinc dialkyl dithiophosphate salts in the lubricating oil composition disclosed herein is measured by

its phosphorus content. In some embodiments, the phosphorus content of the lubricating oil composition disclosed herein is from about 0.01 wt. % to about 0.14 wt.%, based on the total weight of the lubricating oil composition.

Foam Inhibitors

[00137] The lubricating oil composition of the present invention can contain one or more foam inhibitors or anti-foam inhibitors that can break up foams in oils. Any foam inhibitor or anti-foam known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable foam inhibitors or anti-foam inhibitors include silicone oils or polydimethylsiloxanes, fluorosilicones, alkoxylated aliphatic acids, polyethers (e.g., polyethylene glycols), branched polyvinyl ethers, alkyl acrylate polymers, alkyl methacrylate polymers, polyalkoxyamines and combinations thereof. In some embodiments, the foam inhibitors or anti-foam inhibitors comprises glycerol monostearate, polyglycol palmitate, a trialkyl monothiophosphate, an ester of sulfonated ricinoleic acid, benzoylacetone, methyl salicylate, glycerol monooleate, or glycerol dioleate. The amount of the foam inhibitors or anti-foam inhibitors may vary from about 0.001 wt. % to about 5 wt. %, from about 0.05 wt. % to about 3 wt. %, or from about 0.1 wt. % to about 1 wt. %, based on the total weight of the lubricating oil composition.

Pour Point Depressants

[00138] The lubricating oil composition of the present invention can contain one or more pour point depressants that can lower the pour point of the lubricating oil composition. Any pour point depressant known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable pour point depressants include polymethacrylates, alkyl acrylate polymers, alkyl methacrylate polymers, di(tetra-paraffin phenol)phthalate, condensates of tetra-paraffin phenol, condensates of a chlorinated paraffin with naphthalene and combinations thereof. In some embodiments, the pour point depressant comprises an ethylene-vinyl acetate copolymer, a condensate of chlorinated paraffin and phenol, polyalkyl styrene or the like. The amount of the pour point depressant may vary from about 0.01 wt. % to about 10 wt. %, from about 0.05 wt. % to about 5 wt. %, or from about 0.1 wt. % to about 3 wt. %, based on the total weight of the lubricating oil composition.

Demulsifiers

[00139] In one embodiment, the lubricating oil composition of the present invention does not contain one or more demulsifiers. In another embodiment, the lubricating oil composition of the present invention can contain one or more demulsifiers that can promote

oil-water separation in lubricating oil compositions that are exposed to water or steam. Any demulsifier known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable demulsifiers include anionic surfactants (e.g., alkyl-naphthalene sulfonates, alkyl benzene sulfonates and the like), nonionic alkoxylated alkyl phenol resins, polymers of alkylene oxides (e.g., polyethylene oxide, polypropylene oxide, block copolymers of ethylene oxide, propylene oxide and the like), esters of oil soluble acids, polyoxyethylene sorbitan ester and combinations thereof. The amount of the demulsifier may vary from about 0.01 wt. % to about 10 wt. %, from about 0.05 wt. % to about 5 wt. %, or from about 0.1 wt. % to about 3 wt. %, based on the total weight of the lubricating oil composition.

Corrosion Inhibitors

[00140] The lubricating oil composition of the present invention can contain one or more corrosion inhibitors that can reduce corrosion. Any corrosion inhibitor known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable corrosion inhibitor include half esters or amides of dodecylsuccinic acid, phosphate esters, thiophosphates, alkyl imidazolines, sarcosines and combinations thereof. The amount of the corrosion inhibitor may vary from about 0.01 wt. % to about 5 wt. %, from about 0.05 wt. % to about 3 wt. %, or from about 0.1 wt. % to about 1 wt. %, based on the total weight of the lubricating oil composition.

Extreme Pressure Agents

[00141] The lubricating oil composition of the present invention can contain one or more extreme pressure (EP) agents that can prevent sliding metal surfaces from seizing under conditions of extreme pressure. Any extreme pressure agent known by a person of ordinary skill in the art may be used in the lubricating oil composition. Generally, the extreme pressure agent is a compound that can combine chemically with a metal to form a surface film that prevents the welding of asperities in opposing metal surfaces under high loads. Non-limiting examples of suitable extreme pressure agents include sulfurized animal or vegetable fats or oils, sulfurized animal or vegetable fatty acid esters, fully or partially esterified esters of trivalent or pentavalent acids of phosphorus, sulfurized olefins, dihydrocarbyl polysulfides, sulfurized Diels-Alder adducts, sulfurized dicyclopentadiene, sulfurized or co-sulfurized mixtures of fatty acid esters and monounsaturated olefins, co-sulfurized blends of fatty acid, fatty acid ester and alpha-olefin, functionally-substituted dihydrocarbyl polysulfides, thia-aldehydes, thia-ketones, epithio compounds, sulfur-containing acetal derivatives, co-sulfurized blends of terpene and acyclic olefins, and polysulfide olefin products, amine salts of phosphoric

acid esters or thiophosphoric acid esters and combinations thereof. The amount of the extreme pressure agent may vary from about 0.01 wt. % to about 5 wt. %, from about 0.05 wt. % to about 3 wt. %, or from about 0.1 wt. % to about 1 wt. %, based on the total weight of the lubricating oil composition.

Rust Inhibitors

[00142] The lubricating oil composition of the present invention can contain one or more rust inhibitors that can inhibit the corrosion of ferrous metal surfaces. Any rust inhibitor known by a person of ordinary skill in the art may be used in the lubricating oil composition. Non-limiting examples of suitable rust inhibitors include nonionic polyoxyalkylene agents, e.g., polyoxyethylene lauryl ether, polyoxyethylene higher alcohol ether, polyoxyethylene nonylphenyl ether, polyoxyethylene octylphenyl ether, polyoxyethylene octyl stearyl ether, polyoxyethylene oleyl ether, polyoxyethylene sorbitol monostearate, polyoxyethylene sorbitol monooleate, and polyethylene glycol monooleate; stearic acid and other fatty acids; dicarboxylic acids; metal soaps; fatty acid amine salts; metal salts of heavy sulfonic acid; partial carboxylic acid ester of polyhydric alcohol; phosphoric esters; (short-chain) alkenyl succinic acids; partial esters thereof and nitrogen-containing derivatives thereof; synthetic alkarylsulfonates, e.g., metal dinonylnaphthalene sulfonates; and the like and mixtures thereof. The amount of the rust inhibitor may vary from about 0.01 wt. % to about 10 wt. %, from about 0.05 wt. % to about 5 wt. %, or from about 0.1 wt. % to about 3 wt. %, based on the total weight of the lubricating oil composition.

Multifunctional Additives

[00143] The lubricating oil composition of the present invention can contain one or more multifunctional additives. Non-limiting examples of suitable multifunctional additives include sulfurized oxymolybdenum dithiocarbamate, sulfurized oxymolybdenum organophosphorodithioate, oxymolybdenum monoglyceride, oxymolybdenum diethylate amide, amine-molybdenum complex compound, and sulfur-containing molybdenum complex compound.

Viscosity Index Improvers

[00144] The lubricating oil composition of the present invention can contain one or more viscosity index improvers. Non-limiting examples of suitable viscosity index improvers include, but are not limited to, olefin copolymers, such as ethylene-propylene copolymers, styrene-isoprene copolymers, hydrated styrene-isoprene copolymers, polybutene, polyisobutylene, polymethacrylates, vinylpyrrolidone and methacrylate copolymers and

dispersant type viscosity index improvers. These viscosity modifiers can optionally be grafted with grafting materials such as, for example, maleic anhydride, and the grafted material can be reacted with, for example, amines, amides, nitrogen-containing heterocyclic compounds or alcohol, to form multifunctional viscosity modifiers (dispersant-viscosity modifiers). Other examples of viscosity modifiers include star polymers (e.g., a star polymer comprising isoprene/styrene/isoprene triblock). Yet other examples of viscosity modifiers include poly alkyl(meth)acrylates of low Brookfield viscosity and high shear stability, functionalized poly alkyl(meth)acrylates with dispersant properties of high Brookfield viscosity and high shear stability, polyisobutylene having a weight average molecular weight ranging from 700 to 2,500 Daltons and mixtures thereof. The amount of the viscosity index improvers may vary from about 0.01 wt. % to about 25 wt. %, from about 0.05 wt. % to about 20 wt. %, or from about 0.3 wt. % to about 15 wt. %, based on the total weight of the lubricating oil composition.

Thickeners

[00145] The lubricating oil composition of the present invention can contain one or more thickener. Thickeners such as polyisobutylene (PIB) and polyisobutenyl succinic anhydride (PIBSA) can be used to thicken lubricants. PIB and PIBSA are commercially available materials from several manufacturers. The PIB can be used in the manufacture of PIBSA and is typically a viscous oil-miscible liquid, having a weight average molecular weight in the range of 1000 to 8000 Daltons (e.g., 1500 to 6000 Daltons) and a kinematic viscosity at 100°C in a range of 2000 to 6,000 mm²/s. can be present at 1 to 20 wt. % of the lubricating oil composition.

Metal Deactivators

[00146] The lubricating oil composition of the present invention can contain one or more metal deactivators. Non-limiting examples of suitable metal deactivators include disalicylidene propylenediamine, triazole derivatives, thiadiazole derivatives, and mercaptobenzimidazoles.

[00147] Each of the foregoing additives, when used, is used at a functionally effective amount to impart the desired properties to the lubricant. Thus, for example, if an additive is a friction modifier, a functionally effective amount of this friction modifier would be an amount sufficient to impart the desired friction modifying characteristics to the lubricant. Generally, the concentration of each of these additives, when used, may range, unless otherwise specified, from about 0.001 wt.% to about 10 wt.%, in one embodiment from about 0.005 wt.% to about

5 wt.%, or in one embodiment from about 0.1 wt.% to about 2.5 wt.%, based on the total weight of the lubricating oil composition. Further, the total amount of the additives in the lubricating oil composition may range from about 0.001 wt.% to about 20 wt.%, from about 0.01 wt.% to about 10 wt.%, or from about 0.1 wt.% to about 5 wt.%, based on the total weight of the lubricating oil composition.

[00148] In the preparation of lubricating oil formulations, it is common practice to introduce the additives in the form of 10 to 100 wt. % active ingredient concentrates in hydrocarbon oil, e.g. mineral lubricating oil, or other suitable solvent.

[00149] Usually these concentrates may be diluted with 3 to 100, e.g., 5 to 40, parts by weight of lubricating oil per part by weight of the additive package in forming finished lubricants, e.g. crankcase motor oils. The purpose of concentrates, of course, is to make the handling of the various materials less difficult and awkward as well as to facilitate solution or dispersion in the final blend.

[00150] The following examples are presented to exemplify embodiments of the invention but are not intended to limit the invention to the specific embodiments set forth. Unless indicated to the contrary, all parts and percentages are by weight. All numerical values are approximate. When numerical ranges are given, it should be understood that embodiments outside the stated ranges may still fall within the scope of the invention. Specific details described in each example should not be construed as necessary features of the invention.

[00151] It will be understood that various modifications may be made to the embodiments disclosed herein. Therefore, the above description should not be construed as limiting, but merely as exemplifications of preferred embodiments. For example, the functions described above and implemented as the best mode for operating the present invention are for illustration purposes only. Other arrangements and methods may be implemented by those skilled in the art without departing from the scope and spirit of this invention. Moreover, those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

EXAMPLES

[00152] The following examples are intended for illustrative purposes only and do not limit in any way the scope of the present invention.

Automotive Formulations

[00153] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the

additive to provide its desired function. Representative effective amounts of such additives, when used in crankcase lubricants, are listed below in Table 4. All the values listed are stated as wt.% active ingredient (A.I).

TABLE 4: TEST COMPOSITION(S)

Description of Additive	Wt. % (Broad) ⁽¹⁾	Wt. % (Preferred) ⁽¹⁾
Dispersants	0.1 to 20	1 to 10
Detergents (Metal or ashless)	0.1 to 15	0.1 to 9.0
Corrosion Inhibitor	0 to 5.0	0 to 1.0
Metal dihydrocarbyl dithiophosphate	0 to 6.0	0 to 4.0
Antioxidant	0 to 5.0	0 to 4.0
Pour Point Depressant	0.01 to 5.0	0.01 to 1.0
Friction Modifier	0 to 5.0	0 to 1.5
Antifoam Agent	0 to 5.0	0.001 to 0.15
Viscosity Modifier	0 to 10	0.10 to 3
Supplemental Antiwear Agents	0 to 1.0	0 to 0.5
Metal Decativator	0 to 5.0	0 to 1.0
Bio Based Base Oil	10 to 99.9	10 to 99.9
Secondary Base Oil	0 to 90	0 to 90

(1) Such that the composition adds up to 100%

[00154] More specific representative automotive formations that will be evaluated in the tests outlined below are the following:

Representative Formulation(s)

[00155] A lubricating oil composition will be prepared that contain one or more of the following additives and base oil to provide a finished oil having an SAE viscosity grade of 0W-

12, 0W-16, 0W-20, 0W-26, 0W-30, 0W-40, 0W-50, 0W-60, 5W, 5W-20, 5W-30, 5W-40, 5W-50, 5W-60, 10W, 10W-20, 10W-30, 10W-40, 10W-50, 15W, 15W-20, 15W-30, or 15W-40:

- (1) a succinimide or ethylene carbonate post-treated bis-succinimide;
- (2) a borated bis-succinimide dispersant;
- (3) 0 to 3500 ppm in terms of calcium content of one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, borated calcium sulfonate detergent, borated calcium salicylate, calcium salicylate detergent, calcium Mannich type, or calcium phenate detergent;
- (4) 0 to 2500 ppm in terms of magnesium content of an overbased magnesium sulfonate or overbased magnesium salicylate detergent;
- (5) 0 to 1200 ppm in terms of phosphorus content, of a primary zinc dialkyldithiophosphate and/or a secondary zinc dialkyldithiophosphate;
- (6) a sulfurized or unsulfurized molybdenum succinimide complex;
- (7) MoDTC or MoDTP;
- (8) a borated or unborated amine, amide, or ester type organic friction modifier;
- (9) one or more of an alkylated diphenylamine or hindered phenol antioxidant;
- (10) one or more ashless sulfur or ashless phosphorus based antiwear agents;
- (11) one or more sulfur or nitrogen based corrosion inhibitor or metal deactivator;
- (12) a silicon, fluorine, or polyalkylmethacrylate (PMA) based foam inhibitor;
- (13) one or more of a dispersant or non-dispersant type PMA, olefin copolymer (OCP), or diene-based viscosity modifier having block, di-block, tri-block and linear, star, or comb architecture;
- (14) a PMA or OCP based PPD; and
- (15) the remainder bio-based base oil and optional secondary base oil as described above.

[00156] The lubricating oils will be evaluated by the methods below to demonstrate the properties as described herein.

JIS K2246

[00157] Based on JIS K2246, a test piece coated with the sample oil in a predetermined procedure, the temperature 49 ° C., in a humidity cabinet above 95% RH and allowed to stand for 50 hours, the test piece taken out, and evaluated for rust by the with the naked eye. The JIS K2246 test is a Japanese Industrial Standard test. It is used to assess the ability of oils to prevent

rust on metal materials or metal products, mainly consisting of iron and steel. The evaluation criteria is whether rust is seen or not. The ASTM D1748 test (Humidity cabinet rust test) is run in a similar fashion.

ASTM D7563

[00158] The samples will be tested in accordance with a modified ASTM D7563 method. ASTM D7563 measures the ability of an oil to emulsify water and E85 fuel. In this modification the lubricating oil is mixed with 25% E10 fuel and 10% water and emulsion stability will be tracked after 24 hrs. at 25° C. Afterwards, the amount of oil, water, and emulsion will be observed and reported. In ASTM D7563, an emulsion is desirable (i.e., no observable aqueous layer at the bottom of the container). This is a test to check and evaluate the stability of engine oil in respect of whether any (condensed) water or E85 fuel and the like that has become mixed with it does not deposit out on surfaces but remains incorporated in emulsion form without separating out, so that the individual engine components do not rust or corrode.

VW TDI

[00159] The lubricating oil compositions of the invention will be prepared and tested for piston cleanliness and tendency to piston ring sticking according to the Volkswagen Turbocharged DI test, a European passenger car diesel engine test (CEC-L-78-T-99), which is part of the ACEA A/B and C specifications promulgated by the European Automobile Manufacturers Association in 2004. This test will be used to simulate repeated cycles of high-speed operation followed by idling. A Volkswagen 1.9 liter, inline, four-cylinder turbocharged direct injection automotive diesel engine (VW TDi) will be mounted on an engine dynamometer stand. A 54-hour, 2-phased procedure that cycles between 30 minutes of 40° C oil sump at idle and 150 minutes of 145°C oil sump at full power (4150 rpm) will be carried out without interim oil top-ups. After the procedure, the pistons will be rated for carbon and lacquer deposits, as well for groove carbon filling. The piston rings will be evaluated for ring sticking.

[00160] The pass/fail score according to ACEA standards B4, B5, C3, and VW limits are listed in the following Table 5.

TABLE 5

	ACEA A3/B4 limits	ACEA A5/B5 limits	ACEA C3 limits	VW 504/507 limits
Piston Merit, Avg	$\geq$ RL206	$(\geq$ RL206)	$(\geq$ RL206)	$(\geq$ Avg, RL206+std)
Ring Sticking Avg, of all 8 rings, ASF	$\leq$ 1.0	$\leq$ 1.0	$\leq$ 1.0	$\leq$ 1.0
Max for any 1st ring, ASF	$\leq$ 1.0	$\leq$ 1.0	$\leq$ 1.0	$\leq$ 1.0
Max for any 2nd ring, ASF	$\leq$ 0.0	$\leq$ 0.0	$\leq$ 0.0	$\leq$ 0.0
TBN at EOT	$\geq$ 6.0	$\geq$ 4.0	Report	Report
TAN at EOT	Report	Report	Report	Report

DD13 Fuel Economy Test

[00161] The DD13 fuel economy test's objective is to quantify the efficiency benefit of an engine over a prescribed test cycle. The standard test cycle consists of 13 discrete modes (i.e. specific engine load and RPM) run for seven minutes to stabilize temperatures and pressures to a high level of consistency. The cycle is repeated a total of eight times with the last seven used for statistical evaluations of operation. A flush process between lubricants ensures no carryover occurs. The test fixture is a modified Detroit diesel DD13 engine. Results are given as a percentage improvement in fuel consumption between a baseline and candidate lubricants. The test is run at Southwest Research Institute. For further details see: <https://www.swri.org/sites/default/files/dd13-fuel-economy-test.pdf>

The abovementioned standard DD13 fuel economy test will be modified by the addition of 8 modes at 25%, 50%, 75%, and 100% of maximum engine torque at 700 and 1000 RPM. The additional modes provide for a wider range of tribological conditions. Each mode is identified by a quasi-Stribeck number which is, for the purposes of this program, is defined as the RPM/load at that mode.

Oxidator Bx test

[00162] A 25 g sample will be weighted into a special glass oxidator cell. A catalyst will be added, followed by inserting a glass stirrer. The cell will then sealed and placed in an oil bath maintained at 340 °F and connected to the oxygen supply. One liter of oxygen will be fed

into the cell while the stirrer agitated the oil sample. The test will run until 1 liter of oxygen is consumed by the sample and the total time, in hours, of the sample run will be reported. Higher hours to 1 Liter means better oxidation performance.

Komatsu Hot Tube Test (KHTT)

[00163] The Komatsu Hot Tube Test (KHTT) is used for screening and quality control of deposit formation performance for engine oils and other oils subjected to high temperatures.

[00164] Detergency and thermal and oxidative stability are performance areas that are generally accepted in the industry as being essential to satisfactory overall performance of a lubricating oil. The Komatsu Hot Tube test is a lubrication industry bench test (JPI 5S-55-99) that measures the detergency and thermal and oxidative stability of a lubricating oil. During the test, a specified amount of test oil is pumped upwards through a glass tube that is placed inside an oven set at a certain temperature. Air is introduced in the oil stream before the oil enters the glass tube, and flows upward with the oil. Evaluations of the lubricating oils will be conducted at a temperature of 280°C. The test result is determined by comparing the amount of lacquer deposited on the glass test tube to a rating scale ranging from 1.0 (very black) to 10.0 (perfectly clean).

TEOST MHT4

[00165] TEOST MHT4 (ASTM D7097-16a) is designed to predict the deposit-forming tendencies of engine oil in the piston ring belt and upper piston crown area. Correlation has been shown between the TEOST MHT procedure and the TU3MH Peugeot engine test in deposit formation. This test determines the mass of deposit formed on a specially constructed test rod exposed to repetitive passage of 8.5 g of engine oil over the rod in a thin film under oxidative and catalytic conditions at 285°C. Deposit-forming tendencies of an engine oil under oxidative conditions are determined by circulating an oil-catalyst mixture comprising a small sample (8.4 g) of the oil and a very small (0.1 g) amount of an organo-metallic catalyst. This mixture is circulated for 24 hours in the TEOST MHT instrument over a special wire-wound depositor rod heated by electrical current to a controlled temperature of 285°C at the hottest location on the rod. The rod is weighed before and after the test. Deposit weight of 45 mg is considered as pass/fail criteria.

[00166] A copy of this test method can be obtained from ASTM International at 100 Barr Harbor Drive, PO Box 0700, West Conshohocken, Pa. 19428-2959 and is herein incorporated for all purposes.

LSPI Testing

[00167] Low Speed Pre-ignition events will be measured in a Ford 2.0L Ecoboost engine. This engine is a turbocharged gasoline direct injection (GDI) engine. The Ford Ecoboost engine is operated in four-roughly 4 hours iterations. The engine is operated at 1750 rpm and 1.7 MPa break mean effective pressure (BMEP) with an oil sump temperature of 95 °C. The engine is run for 175,000 combustion cycles in each stage, and LSPI events are counted. LSPI events are determined by monitoring peak cylinder pressure (PP) and mass fraction burn (MFB) of the fuel charge in the cylinder. When either or both criteria are met, it can be said that an LSPI event has occurred. The threshold for peak cylinder pressure varies by test, but is typically 4-5 standard deviations above the average cylinder pressure. Likewise, the MFB threshold is typically 4-5 standard deviations earlier than the average MFB (represented in crank angle degrees). LSPI events can be reported as average events per test, events per 100,000 combustion cycles, events per cycle, and/or combustion cycles per event. Similar testing can be conducted on aged oil.

Ball Rust Test (BRT) - ASTM D6557

[00168] The Ball Rust test referred to herein is conducted using the method of ASTM-D-6557. The Ball Rust Test (BRT) is a procedure for evaluating the anti-corrosion ability of fluid lubricants. In accordance with ASTM D6557, a ball bearing is immersed in an oil. Air saturated with acidic contaminants is bubbled through the oil for 18 hours at 49° C. After the 18-hour reaction period, the ball is removed from the test oil and the amount of corrosion on the ball is quantified using a light reflectance technique. The amount of reflected light is reported as an average gray value (AGV). The AGV for a fresh un-corroded ball is approximately 140. A totally corroded ball has an AGV result of less than 20. A lubricating oil composition which gives an AGV of at least 100 passes the BRT. A lubricating oil composition which gives an AGV of less than 100 fails the BRT.

FZG Wear

[00169] The following bench test will be performed to measure wear: FZG Wear Scuffing Load Carrying Capacity Test. In order to evaluate wear performance of the automotive engine oils, the load carrying characteristics of various engine oils having different chemistries will be evaluated on an FZG test rig (FZG four-square test machine) using A10 gears according to CEC-L-84-A-02. This method is useful for evaluating the scuffing load capacity potential of oils typically used with highly stressed cylindrical gearing found in many

vehicle and stationary applications. The minimum load stage fail will be 8 for the A10 gears at 16.6 m/s and 130 °C.

Fuel Economy Testing in a Toyota 2ZR-FE Motored Engine

[00170] The lubricating oil compositions will be tested for their fuel economy performance in a gasoline motored engine test. Gasoline engines are known to produce very little if any measurable amounts of soot during operation. The engine is a Toyota 2ZR-FE 1.8L in-line 4-cylinder arrangement. The torque meter is positioned between the motor and the crank shaft of the engine and the % torque change is measured between a reference and candidate oil. % torque change data at oil temperatures of 100 °C, 80 °C, and 60 °C and engine speeds of 400 to 2000 RPM are measured. Lower % torque change (i.e., more negative) reflects better fuel economy. The configuration of the motored engine friction torque test and its test conditions are further described in SAE Paper 2013-01-2606.

ASTM D6594 HTCBT (High Temperature Corrosion Bench Test)

[00171] The ASTM D6594 HTCBT test is used to test diesel engine lubricants to determine their tendency to corrode various metals, specifically alloys of lead and copper commonly used in cam followers and bearings. Four metal specimens of copper (Cu), lead (Pb), tin (Sn) and phosphor bronze are immersed in a measured amount of engine oil. The oil, at an elevated temperature (170 °C), is blown with air (5 l/h) for a period of time (168 h). When the test is completed, the copper specimen and the stressed oil are examined to detect corrosion and corrosion products, respectively. The concentrations of copper, lead, and tin in the new oil and stressed oil and the respective changes in metal concentrations are reported. To be a pass for API heavy duty categories, the concentration of lead should not exceed 120 ppm and copper should not exceed 20 ppm. A copy of this test method can be obtained from ASTM International at 100 Barr Harbor Drive, PO Box 0700, West Conshohocken, Pa. 19428-2959 and is herein incorporated for all purposes.

Copper Strip Corrosion Test - ASTM D130

[00172] Crude petroleum contains sulfur compounds, most of which are removed during refining. However, of the sulfur compounds remaining in the petroleum product, some can have a corroding action on various metals and this corrosivity is not necessarily related directly to the total sulfur content. The effect can vary according to the chemical types of sulfur compounds present. The copper strip corrosion test is designed to assess the relative degree of corrosivity of a petroleum product. In this test, a polished copper strip is immersed in a specific volume of the sample being tested and heated under conditions of temperature and time that

are specific to the class of material being tested. At the end of the heating period, the copper strip is removed, washed and the color and tarnish level assessed against the ASTM Copper Strip Corrosion Standard summarized below (Table 6).

TABLE 6

Classification	Designation	Description ¹
Freshly polished strip ²		
1	Slight tarnish	a. Light orange
		b. Dark Orange
2	Moderate tarnish	a. Claret red
		b. Lavender
		c. Multicolored with lavender blue or silver or both, overlaid on claret red
		d. Silvery
		e. Brassy or Gold
3	Dark tarnish	a. Magenta overcast on brassy strip
		b. Multicolored with red and green showing (peacock), but no gray
4	Corrosion	a. Transparent black, dark gray or brown with peacock green barely showing
		b. Glossy or jet black

¹The ASTM Copper Strip Corrosion Standard is a colored reproduction of strips characteristic of these descriptions.

²The freshly polished strip is included in the series only as an indication of the appearance of a properly polished strip before a test run; it is not possible to duplicate this appearance after a test even with a completely noncorrosive sample.

MTU Seals

[00173] The lubricating oil compositions of the invention will be tested for compatibility with seals in a MTU bench test by suspending a Viton® fluorocarbon test piece in an oil-based solution heated for 168 hours. The variation in the percent volume change, points hardness change, tensile strength and the elongation rupture of each sample will be measured. For tensile strength and elongation rupture, results closer to zero indicate better seal compatibility.

Sequence IVA

[00174] The Sequence IVA test evaluates a lubricant's performance in preventing camshaft lobe wear in an overhead camshaft engine. More specifically, the test measures the ability of crankcase oil to control camshaft lobe wear for spark-ignition engines equipped with an overhead valve-train and sliding cam followers. This test is to simulate service for taxicab, light-delivery truck, or commuter vehicles. Pass/fail criteria include average cam wear of 90 μm maximum for GF-4/5. The Sequence IVA test method is a 100-hour test involving 100 hourly cycles; each cycle consists of two operating modes or stages. Unleaded "Haltermann KA24E Green" fuel is used. The test fixture is a KA24E Nissan 2.4-liter, water-cooled, fuel-injected engine, 4-cylinder in-line, overhead camshaft with two intake valves, and one exhaust valve per cylinder.

OM646LA

[00175] While the Sequence IVA test is the key wear test in the API test sequences, it is not applicable for European ACEA specifications. The key engine wear test for ACEA specifications is the diesel OM646LA test. OM646LA is a 300 hour cyclic test uses a 4 cylinder 2.2L diesel OM646 DE 22 LA engine to evaluate engine lubricant performance with respect to engine wear and overall cleanliness, as well as piston cleanliness and ring sticking, under severe operating conditions. The primary result is cam wear, although bore polish, cylinder wear and tappet wear may also be measured.

Oxidation Test for Engine Oils Operating in the Presence of Biodiesel Fuel: CEC L-109-14

[00176] Oxidation Test for Engine Oils Operating in the Presence of Biodiesel Fuel is a standard test method for evaluation of viscosity increase and oxidation level of an aged oil in the presence of biodiesel. The test is conducted at 150 °C by blowing 10l/h air through the heated sample for 168 and/or 216 hrs in the presence of 7 wt% B100. Viscosity versus time is measured. The test can be found at www.cectests.org. The examples of the invention will be evaluated in the Oxidation Test for Engine Oils Operating in the Presence of Biodiesel Fuel, CEC L-109-14, which is incorporated herein by reference.

Soot Thickening Bench Test

[00177] The lubricating oil compositions of the invention will be evaluated for dynamic viscosity using a soot test which measures the ability of the formulation to disperse and control viscosity increase resulting from the addition of carbon black, a soot surrogate. In this test, glass tubes will be charged with 40 g of lubricating oil and affixed to a condenser. Each oil will be heated at 200°C with 115 mL/min of air flow bubbling through the oil for 8 hours. Then, 0.5 g of VULCAN[®] XC72R carbon black (Cabot Corporation) will be added to 12 g of each oxidized oil. The resulting mixture will be heated in a 60°C oven for 16 hours. After removal from the oven, the mixture will be stirred for 1 minute and then homogenized using a paint shaker for 30 minutes to completely disperse the carbon black. The mixture will then be heated in a vacuum oven (full vacuum, <25 mm Hg) at 100°C for 30 minutes. The mixture will be removed from the vacuum oven and stirred using a vortex mixer for 30 seconds just prior to measuring viscosity. The dynamic viscosity of each lubricating oil containing carbon black will then be measured at 100°C for 900 seconds at a shear rate of 0.65 s⁻¹ on a TA Instruments AR-G2 rheometer using a cone and plate geometry, wherein the cone is stainless steel with a 60 mm diameter and a 2° angle. Sample temperature will be controlled with a Peltier plate temperature control system. The dynamic viscosity reported is the value at the end of test (EOT). Lower dynamic viscosity indicates improved soot dispersion.

ASTM D4684 Mini-Rotary Viscometer Test (MRV)

[00178] In this test, a test oil is first heated, and then cooled to test temperature, in this case -40° C., in a mini-rotary viscometer cell. Each cell contains a calibrated rotor-stator set, in which the rotor is rotated by means of a string wound around the rotor shaft and attached to a weight. A series of increasing weights are applied to the string starting with a 10 g weight until rotation occurs to determine the yield stress. Results are reported as Yield Stress as the applied force in Pascals. A 150 g weight is then applied to determine the apparent viscosity of the oil. The larger the apparent viscosity, the more likely it is that the oil will not be continuously and adequately supplied to the oil pump inlet. Results are reported as Viscosity in centipoise.

Scanning Brookfield

[00179] Scanning Brookfield Viscosity: ASTM D 5133 is used to measure the low temperature, low shear rate, viscosity/temperature dependence of engine oils. The low temperature, low shear viscometric behavior of an engine oil determines whether the oil will flow to the sump inlet screen, then to the oil pump, then to the sites in the engine requiring

lubrication in sufficient quantity to prevent engine damage immediately or ultimately after cold temperature starting. ASTM D 5133, the Scanning Brookfield Viscosity technique, measures the Brookfield viscosity of a sample as it is cooled at a constant rate of 1° C./hour. Like the MRV, ASTM D 5133 is intended to relate to an oil's pumpability at low temperatures. The test reports the temperature at which the sample reaches 40,000 cP or the viscosity at – 40 °C. The gelation index is also reported, and is defined as the largest rate of change of viscosity increase from –5° C. to the lowest test temperature. The current API SL/ILSAC GF-5 specifications for passenger car engine oils require a maximum gelation index of 12.

Pour Point (JIS K 2269)

[00180] A 45 ml sample is warmed in a test tube up to 45 °C and cooled by a specified method. The test tube is taken from the cooling bath each time the temperature of the sample drops by 2.5 °C, the temperature at which the sample stays thoroughly motionless for 5 sec. is read and 2.5 °C is added to this value and the result is taken as the pour point.

Plint TE 77 High Frequency Friction Machine

[00181] Boundary friction coefficient measurements will be obtained using a Plint TE-77 High Frequency Friction Machine (commercially available from Phoenix Tribology). A 5mL sample of test oil will be placed in the apparatus for each test. The TE-77 will be run at 100 °C and 56N of load will be placed on the testing specimen. The reciprocating speed will be swept from 10Hz to 1Hz, and coefficient of friction data will be collected throughout the test.

SRV Friction Test

[00182] The friction reducing performance of each lubricating oil composition will be evaluated by means of a cylinder-on-desk reciprocating sliding tester (SRV manufactured by Optimol) under conditions of 400 N of load, 0.4 GPa of surface pressure (maximum Hertz stress), 10 Hz of frequency, 1.50 mm of amplitude, 100°C of temperature, 60 minutes of testing time. The friction characteristic will be evaluated by calculating the average friction coefficient which is an averaged friction coefficient for the time of 30 to 60 minutes after beginning of the test. This measurement conditions correspond to the conditions of boundary lubrication.

Shell Four Ball Wear Test

[00183] The wear preventative performance of each lubricating oil composition will be determined in accordance with ASTM D4172 under conditions of 1200 rpm, oil temperature of 80°C and load of 30 kgf for periods of 30 minutes. After testing, the test balls will be removed, the wear scars will be measured and the diameter shown as the result.

Ford Chain Wear Test

[00184] The Ford Chain Wear Test is a method of evaluating the timing chain stretch in an engine. The Ford Chain Wear Test employs a 2012 Ford 2.0 Liter EcoBoost TGD_i Four-cylinder test engine. The engine will run at the low to moderate speed and load at low and normal running temperatures in a two stage test. The test cycle consists of an 8 hour break-in period followed by 216 hours of cyclic test conditions. The timing chain is measured after the break-in period and this measurement is used as the baseline measurement for the end-of-test chain elongation calculation. Stage 1 of the test runs at low speed, low load and low temperatures with an enriched combustion cycle. Stage 2 runs at moderate speed, moderate load and moderate temperatures using stoichiometric conditions. Between Stage 1 and Stage 2, the temperatures, speeds, and loads are ramped at specified rates.

Oil mist separator (OMS) compatibility

[00185] The lubricating compositions are evaluated for oil mist separator fouling and soot handling. Oil mist separator compatibility will be evaluated in diesel trucks equipped with 2010EC DD15 engines manufactured by Detroit Diesel Corporation (DDC). The engines will be equipped with Alfdex® centrifugal oil mist separators. The oils will be evaluated in field trials ranging from 250,000 miles to nearly 600,000 miles. All of the oil mist separator (OMS) units will be inspected after the field trials will be completed and rated for sludge deposit formation and drain hole plugging. OMS sludge deposit rating is assigned as follows in Table 7:

TABLE 7

Rating Number	Description	Impact
0	No sludge	No problem
1	Beginning of sludge deposits	Reliability not endangered
2	Light sludge	Reliability not endangered
3	Severe Sludge, no drain holes plugged	Reliability not endangered
4	2 of 4 drain holes plugged	Separator efficiency endangered
5	All drain holes plugged with sludge	100% oil carryover to T/C inlet

PDSC Test

[00186] Pressure differential scanning calorimetry (PDSC) is a way of raising the temperature of a test substance and a standard substance at equal rates and of measuring, under pressure, the amount of energy necessary to maintain at zero the temperature difference between the two test specimens which occurs due to generation of heat and absorption of heat by the test substance. In this case, the PDSC value is a way of evaluating, in terms of oxidative life, the period (known as the oxidation induction time) till a specified temperature is reached, keeping the specimen at a fixed temperature (210°C) at atmospheric pressure (0.69 MPa). A longer oxidation induction time shows a better performance in preventing oxidation.

ASTM D3427

[00187] The present invention tested for the air release of lubricating oil as measured by ASTM D3427. In the test, compressed air is blown into a lubricating oil heated to a temperature of 50 ° C. After the air flow is stopped, the time required for the air mixed into the oil to be reduced to 0.2% of the volume is recorded as the venting time. Desirable venting values are generally less than 3 minutes, preferably less than 60 seconds, and most preferably less than 20 seconds.

ASTM D5800

[00188] Standard Test Method for Evaporation Loss of Lubricating Oils by the Noack Method. Noack volatility of engine oil, as measured by ASTM D5800-15, has been found to correlate with oil consumption in passenger car engines. Strict requirements for low volatility are important aspects of several recent engine oil specifications, such as, for example, ACEA A-3 and B-3 in Europe, and SAE J300, ILSAC GF-5, and future ILSAC GF-6, in North America.

TPEO Formulations

[00189] A Trunk Piston Engine Oil (TPEO) may employ 5-35 wt. %, preferably 10-28 wt.%, more preferably 12-24 wt. % of a concentrate or additives package, the remainder being base stock(s) (oil of lubricating viscosity). Preferably, the TPEO has a compositional TBN (ASTM D2896) of 10-70, preferably 10-60, preferably 15-60 or preferably 15-55 mg KOH/g.

[00190] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 8. All the values listed are stated as wt.% active ingredient (A.I).

[00191] The following table (Table 8) may demonstrate typical proportions of additives in a traditional TPEO composition:

TABLE 8

Description of Additive	Wt. %
Dispersants	0.1 to 10.0
Detergents (Metal or ashless)	0 to 30.0
Corrosion Inhibitor	0 to 5.0
Metal dihydrocarbyl dithiophosphate	0 to 6.0
Antioxidant	0 to 5.0
Pour Point Depressant	0 to 5.0
Friction Modifier	0 to 10.0
Antifoam Agent	0.001 to 5.0
Viscosity Modifier/Thickener	0 to 20
Emulsifier/Demulsifier	0 to 1.0
Bio Based Base Oil	10 to 99.9
Secondary Base Oil	0 to 90

Representative TPEO Formulation(s)

[00192] A TPEO lubricating oil composition will be prepared that contains one or more of the following additives and base oil to provide a finished oil having an SAE 30 or SAE 40 viscosity grade and TBN of 15 to 60 mgKOH/g:

- (1) 0-10.0 wt.% of a succinimide, borated bis-succinimide dispersant or an ethylene carbonate post-treated bis-succinimide
- (2) 1.0-30.0 wt.% of one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, calcium salicylate, calcium carboxylate or calcium phenate detergent;

- (3) 0.1 to 4.0 wt.% of a primary zinc dialkyldithiophosphate and/or a secondary zinc dialkyldithiophosphate;
- (4) 0 to 5.0 wt.% of an alkylated diphenylamine or phenolic antioxidant;
- (5) 0 to 1.0 wt.% of an emulsifier
- (6) 0.001 to 1.0 wt.% of a silicon, fluorine, or polyalkylmethacrylate (PMA) based foam inhibitor;
- (7) the remainder bio-based base oil and optional secondary base oil as described above.

MCL Formulations

[00193] A Marine Cylinder Lubricant (MCL) may employ 5-45 wt.%, preferably 10-40 wt. % of a concentrate or additives package, the remainder being base stock(s) (oil of lubricating viscosity). Preferably, the MCL has a compositional TBN (ASTM D2896) of 5-200, preferably 5-150, preferably 15 to 150, preferably 10 to 100, preferably 20 to 80, or preferably 30 to 80, or preferably 30 to 60, or preferably 30 to 50 mgKOH/g.

[00194] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 9. All the values listed are stated as wt.% active ingredient (A.I).

[00195] The following table (Table 9) may demonstrate typical proportions of additives in a traditional MCL composition:

TABLE 9

Description of Additive	Wt. %
Dispersants	0.1 to 10.0
Detergents (Metal or ashless)	0 to 45
Metal dihydrocarbyl dithiophosphate	0 to 6.0
Antioxidant	0 to 10.0
Friction Modifier	0 to 10.0
Antifoam Agent	0.001 to 5.0
Viscosity Modifier/Thickener	0 to 20
Bio Based Base Oil	10 to 99.9
Secondary Base Oil	0 to 90

Representative MCL Formulation(s)

[00196] A MCL lubricating oil composition will be prepared that contains one or more of the following additives and base oil to provide a finished oil having an SAE 40 or SAE 50 viscosity grade and TBN of 25 to 200 mg KOH/g:

- (1) 0-10.0 wt.% of a succinimide, borated bis-succinimide dispersant or an ethylene carbonate post-treated bis-succinimide
- (2) 1.0-45.0 wt.% of one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, calcium salicylate, calcium carboxylate or calcium phenate detergent;
- (3) 0.1 to 6.0 wt.% of a primary zinc dialkyldithiophosphate and/or a secondary zinc dialkyldithiophosphate;
- (4) 0 to 10.0 wt.% of an alkylated diphenylamine or phenolic antioxidant;
- (5) 0 to 1.0 wt.% of an emulsifier

(6) 0.001 to 1.0 wt.% of a silicon, fluorine, or polyalkylmethacrylate (PMA) based foam inhibitor;

(7) the remainder bio-based base oil and optional secondary base oil as described above.

System Oil Formulations

[00197] A Marine System Oil (SO) may employ 1-25 wt. % of a concentrate or additives package, the remainder being base stock(s) (oil of lubricating viscosity). Preferably, the SO has a compositional TBN (ASTM D2896) of 4-15, preferably 5-10 mgKOH/g.

[00198] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 10. All the values listed are stated as wt.% active ingredient (A.I).

[00199] The following table (Table 10) may demonstrate typical proportions of additives in a traditional System Oil composition:

TABLE 10

Description of Additive	Wt. %
Dispersants	0.1 to 10.0
Detergents (Metal or ashless)	0 to 20
Corrosion Inhibitor	0 to 5.0
Metal dihydrocarbyl dithiophosphate	0 to 6.0
Antioxidant	0 to 5.0
Pour Point Depressant	0 to 5.0
Friction Modifier	0 to 10.0
Antifoam Agent	0.001 to 5.0
Viscosity Modifier/Thickener	0 to 20
Emulsifier/Demulsifier	0 to 1.0
Bio Based Base Oil	10 to 99.9
Secondary Base Oil	0 to 90

Representative System Oil Formulation(s)

[00200] A system oil lubricating oil composition will be prepared that contains one or more of the following additives and base oil to provide a finished oil having an SAE 20 or SAE 30 viscosity grade and TBN of 5 to 15 mgKOH/g:

- (1) 0-5.0 wt.% of a succinimide, borated bis-succinimide dispersant or an ethylene carbonate post-treated bis-succinimide
- (2) 1.0-20.0 wt.% of one or more of a neutral, low overbased, medium overbased, high overbased or high high overbased calcium sulfonate, calcium salicylate, calcium carboxylate or calcium phenate detergent;
- (3) 0.1 to 5.0 wt.% of a primary zinc dialkyldithiophosphate and/or a secondary zinc dialkyldithiophosphate;

- (4) 0 to 5.0 wt.% of an alkylated diphenylamine or phenolic antioxidant;
- (5) 0 to 1.0 wt.% of an emulsifier
- (6) 0.001 to 1.0 wt.% of a silicon, fluorine, or polyalkylmethacrylate (PMA) based foam inhibitor;
- (7) the remainder bio-based base oil and optional secondary base oil as described above.

TEST METHODS

Low Temp Performance

[00201] Low temperature performance of the lubricants will be evaluated by pour point, according to ASTM D6749.

DSC Oxidation Test

[00202] The DSC oxidation test will be used to evaluate thin film oxidation stability of test oils, in accordance with ASTM D-6186. Heat flow to and from a test oil in a sample cup is compared to a reference cup during the test. The Oxidation Onset Temperature is the temperature at which the oxidation of the test oil starts. The Oxidation Induction Time is the time at which the oxidation of the test oil starts. A higher oxidation induction time means better performance. The oxidation reaction results in an exothermic reaction which is clearly shown by the heat flow. The Oxidation Induction Time is calculated to evaluate the thin film oxidation stability of the test oil.

Determining Oxidation-based Viscosity Increase and TBN Depletion

[00203] Institute of Petroleum 48 (MIP-48) Test

[00204] The degree of stability against oxidation-based viscosity increase and BN depletion of the marine lubricating oil compositions of the present invention will be evaluated using the Modified Institute of Petroleum 48 ("MIP-48") Test. The MIP-48 Test consists of a thermal and an oxidative part. During both parts of the test, the test samples are heated for a period of time. In the thermal part of the test, nitrogen is passed through a heated oil sample for 24 hours and in parallel during the oxidative part of the test, air is passed through a heated oil sample for 24 hours. The samples will be cooled and the viscosities of both samples will be determined. The viscosity increase of the test oil caused by oxidation will be determined and corrected for the thermal effect. The BN depletion and oxidation-based viscosity increase

for each marine lubricating oil composition will be calculated by subtracting the kinematic viscosity at 200 °C for the nitrogen-blown sample from the kinematic viscosity at 200 °C for the air-blown sample, and dividing the subtraction product by the kinematic viscosity at 200 °C for the nitrogen blown sample. This will be done to correct for potential evaporation effects during the test, or any other thermal effect, thereby focusing on the impact of oxidation. This correction may result in a negative value. Test oils which exhibit better stability against oxidation-based viscosity increase will result in a lower % value.

Foam Performance

[00205] This test method covers the determination of the foaming characteristics of lubricating oils at 24°C and 93.5°C. The sample, maintained at a temperature of 24°C (75°F) will be blown with air at a constant rate for 5 min, then allowed to settle for 10 min (“Sequence I”). The volume of foam will be measured at the end of both periods. The test will be repeated on a second sample at 93.5°C (200°F) (“Sequence II”), and then, after collapsing the foam, at 24°C (75°F) (“Sequence III”). The tendency of oils to foam can be a serious problem in systems such as high-speed gearing, high-volume pumping, and splash lubrication. Inadequate lubrication, cavitation, and overflow loss of lubricant can lead to mechanical failure. This test method will be used in the evaluation of oils for such operating conditions.

Deposit Control

[00206] Deposit control will be measured by the Komatsu Hot Tube (KHT) test, which will employ heated glass tubes through which sample lubricant is pumped, approximately 5 mL total sample, typically at 0.31 mL/hour for an extended period of time, such as 16 hours, with an air flow of 10 mL/minute. The glass tube will be rated at the end of test for deposits on a scale of 1.0 (very heavy varnish) to 10 (no varnish). Test results will be reported in multiples of 0.5. In the case the glass tubes are completely blocked with deposits, the test result will be recorded as “blocked”. Blockage is deposition below a 1.0 result, in which case the lacquer is very thick and dark but still allows fluid flow. The test will be run at 310°C and 325°C and is described in SAE Technical Paper 840262.

Sludge Formation

[00207] The Black Sludge Deposit (BSD) test will be used to evaluate the ability of lubricants to cope with instable – unburned asphaltenes in residual fuel oil. The test measures the tendency of lubricants to cause deposits on a test strip, by applying oxidative thermal strain on a mixture of heavy fuel oil and lubricant. A sample of a lubricating oil composition will be mixed with a specific amount of residual fuel to form test mixtures. The test mixture is then dispensed during the test as a thin film over a metal test strip, which is controlled at test temperature (200°C) for a period of time (12 hours). The test oil-fuel mixture is recycled into the sample vessel. After the test, the test strip is cooled and then washed and dried. The test plates are then weighed. In this manner, the weight of the deposit remaining on the test plates will be measured and recorded as the change in weight of the test plate.

Focused Beam Reflectance Method (FBRM)

[00208] Lubricants will be evaluated for asphaltene dispersancy using light scattering according to the Focused Beam Reflectance Method (“FBRM”), which predicts asphaltene agglomeration and hence ‘black sludge’ formation. The FBRM test method was disclosed at the 7th International Symposium on Marine Engineering, Tokyo, 24-28 Oct. 2005, and was published in ‘The Benefits of Salicylate Detergents in TPEO Applications with a Variety of Base Stocks’, in the Conference Proceedings. Further details were disclosed at the CIMAC Congress, Vienna, 21-24 May 2007 and published in “Meeting the Challenge of New Base Fluids for the Lubrication of Medium Speed Marine Engines—An Additive Approach” in the Congress Proceedings.

Dispersion Test

[00209] This test evaluates the ability of marine system oils to keep asphaltenic and carbonaceous materials dispersed by measuring the dispersion of oil and black matter on filter paper. Dispersions are measured on both fresh and aged oils, with different treatment heating conditions and with and without water addition.

[00210] The fresh sample consists of a mixture of a majority of fresh marine system oil, heavy fuel oil, and carbon black. The aged sample consists of a mixture of fresh marine system oil and heavy fuel oil which is aged by heating at elevated temperature under oxidizing conditions. Carbon black is added to the aged sample after the aging step.

[00211] Both fresh and aged oil samples are then subjected to three different heat treatments, both with and without water addition, making a total of six different treatments. A drop of treated sample is then placed on a piece of filter paper and developed in an incubator for 48 hours. After development, the drops form a small, dark circular sludge area surrounded by a light oil area. The diameters of the oil and sludge areas are measured and the ratio of the oil:sludge diameters calculated. The test results are reported as $6\times$, which is the sum of the ratio of oil:sludge diameters from the six different treatments.

FZG Wear

[00212] The FZG bench test will evaluate wear performance. The FZG test is an industry standard identified variously under the codes CEC L-07-A-95, ASTM D5182 and ISO 14635-1:2000.

Natural Gas Engine Formulations

[00213] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 11. All the values listed are stated as wt.% active ingredient (A.I).

[00214] The following table (Table 11) may demonstrate typical proportions of additives in a natural gas engine oil composition:

TABLE 11: NCEO TEST COMPOSITION(S)

Description of Additive	Wt. %
Dispersants	0.1 to 20
Detergents (Metal or ashless)	0.1 to 15
Metal dihydrocarbyl dithiophosphate	0 to 6.0
Antioxidant	0 to 5.0
Pour Point Depressant	0 to 5.0
Friction Modifier	0 to 5.0
Antifoam Agent	0 to 5.0
Viscosity Modifier	0 to 10
Thickener	0 to 10
Metal Decativator	0 to 5.0
Other additives	0 to 5.0
Biobased Base Oil	10 to 99.9
Other Base Oil	0 to 90

[00215] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 12. All the values listed are stated as wt.% active ingredient (A.I).

[00216] The following table (Table 12) may demonstrate typical proportions of additives in a rail road engine oil composition:

TABLE 12: RAILROAD TEST COMPOSITION(S)

Description of Additive	Wt. %
Dispersants	0.1 to 20
Detergents (Metal or ashless)	0.1 to 15
Antioxidant	0 to 5.0
Pour Point Depressant	0 to 5.0
Friction Modifier	0 to 5.0
Antifoam Agent	0 to 5.0
Viscosity Modifier	0 to 10
Antiwear Agents	0 to 5.0
Other additives	0 to 5.0
Biobased Base Oil	10 to 99.9
Other Base Oil	0 to 90

[00217] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 13. All the values listed are stated as wt.% active ingredient (A.I).

[00218] The following table (Table 13) may demonstrate typical proportions of additives in a functional fluid composition:

TABLE 13: FUNCTIONAL FLUID TEST COMPOSITION(S)

Description of Additive	Wt. %
Dispersants	0 to 20
Detergents (Metal or ashless)	0 to 15
Antioxidant	0 to 5.0
Pour Point Depressant	0 to 5.0
Friction Modifier	0 to 5.0
Antifoam Agent	0 to 5.0
Viscosity Modifier	0 to 10
Antiwear Agents	0 to 5.0
Other additives	0 to 5.0
Biobased Base Oil	10 to 99.9
Other Base Oil	0 to 90

[00219] When lubricating compositions contain one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. Representative effective amounts of such additives are listed below in Table 14. All the values listed are stated as wt.% active ingredient (A.I).

[00220] The following table (Table 14) may demonstrate typical proportions of additives in a gasoline additive composition:

Penn State Micro-Oxidation Test

[00221] Deposit performance of the lubricant oil compositions will be measured using the Penn State Micro-Oxidation Test after 35 minutes at 260°C (SAE Technical Paper 801362).

Oxidator Bx test

[00222] A 25 g sample will be weighted into a special glass oxidator cell. A catalyst will be added, followed by inserting a glass stirrer. The cell will then be sealed and placed in an oil bath maintained at 340 °F and connected to the oxygen supply. One liter of oxygen will be fed into the cell while the stirrer agitates the oil sample. The test will be run until 1 liter of oxygen is consumed by the same and the total time, in hours, of the sample run is reported.

PDSC Test

[00223] Pressure differential scanning calorimetry (PDSC) is a way of raising the temperature of a test substance and a standard substance at equal rates and of measuring, under pressure, the amount of energy necessary to maintain at zero the temperature difference between the two test specimens which occurs due to generation of heat and absorption of heat by the test substance. In this case, the PDSC value is a way of evaluating, in terms of oxidative life, the period (known as the oxidation induction time) till a specified temperature is reached, keeping the specimen at a fixed temperature (210°C) at atmospheric pressure (0.69 MPa). A longer oxidation induction time shows a better performance in preventing oxidation.

TEOST MHT4 test - ASTM 7097

[00224] TEOST MHT4 (ASTM D7097-16a) is designed to predict the deposit-forming tendencies of engine oil in the piston ring belt and upper piston crown area. Correlation has been shown between the TEOST MHT procedure and the TU3MH Peugeot engine test in deposit formation. This test determines the mass of deposit formed on a specially constructed test rod exposed to repetitive passage of 8.5 g of engine oil over the rod in a thin film under oxidative and catalytic conditions at 285°C. Deposit-forming tendencies of an engine oil under oxidative conditions are determined by circulating an oil-catalyst mixture comprising a small sample (8.4 g) of the oil and a very small (0.1 g) amount of an organo-metallic catalyst. This mixture is circulated for 24 hours in the TEOST MHT instrument over a special wire-wound depositor rod heated by electrical current to a controlled temperature of 285°C at the hottest location on the rod. The rod is weighed before and after the test. Deposit weight of 45 mg is considered as pass/fail criteria.

[00225] A copy of this test method can be obtained from *ASTM* International at 100 Barr Harbor Drive, PO Box 0700, West Conshohocken, Pa. 19428-2959 and is herein incorporated for all purposes.

B2-7 Test/Union Pacific Oxidation Test

[00226] The B2-7 test is an oxidation test with the following conditions in Table 14:

TABLE 14

UP Oxidation (B2)	
Temp	149 C. (300 F.)
Duration	96 hr
Coupons	Cu, Fe, Pb
Flow	oxygen
Replenishing oil	At 48 hr (50 mL)
	72 hr (50 mL)
Comments	Trend data of BN, AN, pH and Pb ppm

[00227] According to the B2-7 test, the oil to be tested is heated at 300 °F for 96 hours with bubbling of oxygen. Copper, iron and lead coupons are suspended in the oil. Fifty milliliter samples are taken at 48, 72 and 96 hours. The samples at 48 and 72 hours are replenished with fresh oil. The oil test samples are evaluated for base number, acid number, pH and lead.

**Silver Wear Evaluation Using a Silver Disk Wear and Friction TestAmoco Modified
Silver Disc Wear and Friction Test**

[00228] Formulations will be tested in what is known to those skilled in the art as the Amoco modified Silver Disc Wear and Friction Test. This wear test procedure is a laboratory test for determining the anti-wear properties of lubricant oil. The test machine comprises a system wherein a one-half inch diameter 52100 steel ball is placed in assembly with three one-quarter inch silver discs of like size and of a quality identical to that employed in the plating of the silver pin insert bearing or railway diesel engines manufactured by the Electromotive Division (EMD) of General Motors, Inc. These discs are in a fixed triangular position in a reservoir containing the oil sample to be tested for its silver antiwear properties. The steel ball is positioned above and in contact with the three silver discs. In carrying out these tests, the ball is rotated while it is pressed against the three discs at the pressure specified and by means of a suitable weight applied to a lever arm. The test results are determined by using a low power microscope to examine and measure the scars on the discs. A wear scar diameter of 2.2 mm or less is considered to indicate adequate silver wear protection. The rotation of the steel ball on the silver discs proceeds for a period of 30 min at 600 revolutions per minute under a 23 kilogram static load. Each oil will be tested at 500 F. The coefficient of friction is measured for each formulation.

R20 Friction Test

[00229] The R20 friction testing will be performed to compare the low speed brake torque variation performance of formulations containing Phenate 1 (Ca phenate derived from C20-24 isomerized olefin) versus analogous formulations containing Phenate 2 (Ca phenate derived from tetrapropylene). The results of R20 testing demonstrate that formulations containing 3.0 - 10.0 millimoles of Phenate 1 show reduced low speed brake torque variation as compared to formulations containing 3.0 – 10.0 millimoles of Phenate 2. This means that formulations containing phenate 1 improved clutch and brake capacity while maintaining low torque variation at low speed. The benefit of mitigated low speed brake torque variation is decreased energy loss and vibration, which correlates to lower risk of damage to mechanical parts, decreased operator discomfort, and less tendency for brake noise.

SAE No. 2 Friction Test

[00230] The compositions described above will be assessed using the SAE No. 2 Friction test under the following conditions:

- Disk: Paper disk
- Plate: Steel plate
- Motor rotating speed: 2940 rpm
- Applied pressure: 20 kg/cm²
- Lubricant Temperature: 80° C.

[00231] Measurements will be carried out by taking the value of 1200 rpm as the dynamic friction coefficient (μ_d) and the friction coefficient at the engaging point of the clutch as the break-away friction coefficient (μ_0). The maximum friction coefficient at the engaging point at 0.7 rpm will be measured as the static friction coefficient (μ_s).

Brake Noise Test

[00232] A tractor will be operated in low gear (low-I gear, low-II gear, and low-III gear) at 1200-1800 rpm with straight double brake, straight alternating brake, and turn single brake applications. Noise level will be determined by ear as “no noise”, “noise”, and “heavy noise.” Initially, the tractor with new test oil will be tested at 0% vol water. Water will then be added

by the amount of 0.1 vol. %, and the tractor will be tested the driving/braking conditions. The cycle will be repeated until brake noise occurs or water contamination becomes 0.2 vol. %.

ZF V3 Test

[00233] Slow speed gear performance is evaluated using ZF Group's ZF V3 test, which is also known as the S19-5 test. In this test, an FZG stand is operated for 120 hours under controlled conditions of speed (9 rpm input speed, 13 rpm pinion speed), load (tenth stage) and temperature (90° C. for 40 hours, 120° C. for 40 hours and 90° C. for 40 hours). The test gears are lubricated with the test oil. The gear and pinion are weighed before and after the test. The gear weight loss and pinion weight loss are used to evaluate the wear obtained with the test fluid. In order to pass the test, the total weight loss (gear weight loss+pinion weight loss) must be less than 30 mg.

MAO 23 Compatibility Test

[00234] The MAO 23 Compatibility Test is used to evaluate the storage *stability* of lubricating oils. The formulated oil is placed in an oven at 80 °C for a period of a month, then the appearance and the sediment are rated after a month comparatively to standard samples. The ratings are as follows: Appearance: clear and bright (1), cloud (3), very cloud (6) Sediment: no sediment (0), light (1), medium (2), high (3) Rating 1/0 means: appearance clear and bright (1)/no sediment (0). The lower the rating of the appearance and the lower the rating of the sediment, the better the product. A good result is an appearance of 2 max and a sediment rating of 1 max.

Emulsification Performance Test – ASTM D1401

[00235] The water separability of antiwear hydraulic fluids is characterized in the *ASTM D 1401* test method. In this method, a 40 mL volume of the sample material will be emulsified with a 40 mL volume of distilled water by stirring the combined liquids in a graduated cylinder at 54 °C for 5 minutes. The separation of the emulsion into organic and aqueous layers will be characterized by monitoring the relative volumes of the respective fluid, water and emulsion layers after cessation of stirring. Results are set forth as the respective mL fluid-mL water-mL emulsion observed at minutes after cessation of stirring.

Rust Inhibition Performance Test – ASTM D665

[00236] Rust inhibition of antiwear hydraulic fluids will be determined using *ASTM D 665*, which is incorporated herein by reference. *ASTM D 665* is directed at a test for

determining the ability of fluid to aid in preventing the rusting of ferrous parts should water become mixed with the fluid. For the determining the rust prevention properties in the instant invention, Procedure B of *ASTM D 665* will be employed. In this test, a mixture of 300 mL of the test fluid is stirred with 30 mL of synthetic sea water at a temperature of 60 °C with a cylindrical steel specimen completely immersed therein for 24 hours. The rust test results are reported as either a "pass" or a "fail."

Shell 4-ball WL Test

[00237] The welding point is evaluated by means of the Shell 4-ball test. This test is operated with one steel ball under load rotating against three steel balls held stationary in the form of a cradle. Test examples cover the lower three balls. The rotating speed is 1760 ± 40 rpm. A series of tests of 10 s duration are made at increasing load until welding occurs. The target welding load is 1960 N. The weld point is greatly influenced by the types of phosphorus compounds and those dosage.

Komatsu Micro Clutch Test KES 07.802

[00238] Measurement of Friction Coefficients Friction coefficients of the test fluids prepared in Example will be measured using a micro-clutch apparatus made by Komatsu Engineering and following the Komatsu KES 07.802 procedure. That is, the disc and the plates as specified in the procedure will be contacted with the pressure of 4 kgf/cm² against the disc rotating at 20 rpm in presence of additive component dissolved in mineral oil. The friction coefficient will be measured at room temperature (25 °C), 60 °C, 80 °C, 100 °C, 120 °C, and 140 °C. The test criteria for friction coefficient is 0.130 minimum.

ASTM D-5704

[00239] In this test, a sample of the lubricant will be placed in a heated gear case containing two spur gears, a test bearing, and a copper catalyst. The lubricant will be heated to 325.degree. F. and the gears will be operated for 50 hours at predetermined load and speed conditions. Air will be bubbled through the lubricant at a specified rate and the bulk oil temperature of the lubricant will be controlled throughout the test. Parameters used for evaluating oil degradation after testing are viscosity increase, insolubles in the used oil, and gear cleanliness. Also, as part of the test report, the copper catalyst percent weight loss based upon the original weight of the copper strip will be reported. The copper weight loss result indicates the copper activity of the test lubricants.

[00240] A copy of this test method can be obtained from *ASTM* International at 100 Barr Harbor Drive, PO Box 0700, West Conshohocken, Pa. 19428-2959 and is herein incorporated for all purposes.

Determination of Friction Coefficient

[00241] The friction coefficient will be determined in terms of a metal-metal friction coefficient by means of a block-on-ring tester according to "Standard test method for metal on metal friction characteristics of belt CVT fluids" described in JASO M358:2005. Details of the testing method are described below.

Testing conditions

Ring: Falex S-10 Test Ring (SAE 4620 Steel)

Block: Falex H-60 Test Block (SAE 01 Steel)

Amount of oil

150 mL

Break-in Conditions

Oil temperature: 110 °C

Load: 5 min. under 890 N and 25 min. under 1112 N

Sliding velocity: 5 min. at 0.5 m/s--25 min. at 1.0 m/s

Testing Conditions

Oil temperature: 110 °C

Load: 1112 N

Sliding velocity: 5 min. each at 1.0, 0.5, 0.25, 0.125, 0.075, 0.025 m/s

Friction coefficient: a friction coefficient for 30 sec. before the change of the sliding velocity

Determination of Anti-Shudder Performance Durability

[00242] The anti-shudder performance durability will be determined by means of a low velocity friction apparatus according to "Road vehicles--Test method for anti-shudder performance of automatic transmission fluids" described in JASO M-349:2001. Details of the testing method are described below.

Testing conditions

Friction material: cellulose disc/steel plate

Amount of oil: 150 mL

Break-in conditions

Contact pressure: 1 MPa

Oil temperature: 80 °C

Sliding velocity: 0.6 m/s

Sliding time: 30 minutes

μ -V Performance test conditions

Contact pressure: 1 MPa

Oil temperature: 40, 80, 120 °C

Sliding velocity: continuously increasing and decreasing between 0 m/s to 1.5 m/s

Durability test conditions

Contact pressure: 1 MPa

Oil temperature: 120 °C

Sliding rate: 0.9 m/s

Time: 30 minutes

Rest time: 1 minute

Performance measurement time: μ -V characteristics will be measured every 24 hour from 0 hour

Note: The anti-shudder performance will be evaluated by determining a period of time until $\mu d/dV$ at 0.9 m/s reached 0. The longer the determined period of time the better the anti-shudder performance.

Wear Scar Test

[00243] The antiwear performance of each lubricating oil compositions will be determined in accordance with the 4 ball wear scar test ASTM D4172 under conditions of 1800rpm, oil temperature of 80°C, and a load of 392N for 60 min. After testing, the test balls will be removed and the wear scars will be measured. Specifically, when the wear scar diameter is equal to or smaller than 0.55mm, the sample oil exhibits favorable wear performance.

Extreme Pressure Wear Test

[00244] The extreme pressure wear performance of the lubricating oil compositions will be determined using the Falex Pin and Vee Block Test (ASTM D3233, Method B, Pin material: SAE 3135 steel, Block: AISI-C-1137 steel). This method comprises running a rotating steel journal at 290 rpm against two stationary V-blocks immersed in the lubricant sample. Load is applied to the V-blocks by a ratchet mechanism. In Test Method B, load is applied in 250-lbf (1112-N) increments with load maintained constant for 1 min at each load increment. The fail load value obtained is the criteria for the level of load-carrying properties. Specifically, when the failure load is equal to or greater than 1000lbs, the sample oil exhibits favorable wear performance.

Cu Corrosion Test

[00245] The Cu corrosion resistance of the lubricating oil compositions will be determined using the Indiana Stirring Oxidation Test (ISOT, Test method JIS K 2514 Two catalyst plates (copper and steel) and a glass varnish rod are immersed in test oil, and the test oil is heated to 165.5°C and aerated by stirring for 150 hours.. When Cu content of the oil is 50ppm or less, the sample oil exhibits favorable anti-corrosion performance. Additionally, the appearance of sludge or varnish formation is indicative of poor oxidative corrosion performance.

Volume Resistivity

[00246] The electrical insulating ability of the lubricating oil compositions will be determined in accordance with JIS C2101-1999-24. The volume resistivity of the test oils at 80°C and an applied voltage of 250V will be measured and is reported in units of $\Omega \cdot \text{cm}$. A volume resistivity of $1.0 \times 10^9 \Omega \cdot \text{cm}$ or greater is sufficiently high for electric vehicle applications.