

LOW VISCOSITY LUBRICATING OIL

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] This application claims the benefit of U.S. Provisional Application No. 63/321,791, filed March 21, 2022, which is hereby incorporated herein by reference.

TECHNICAL FIELD

[002] This disclosure relates to low viscosity lubricating oil composition that improves fuel economy.

BACKGROUND

[003] Modern car and engine designs aim to improve fuel economy without sacrificing performance or durability. As such, the use of roller follower type valvetrains has become prevalent in modern automobiles as this newer design greatly reduces frictional loss in valvetrains compared to older designs.

[004] While these performance gains are encouraging, new lubricant formulations are being designed to further improve fuel efficiency and meet the demands of the newer engine designs.

[005] One potential area of improvement involves the use of friction modifiers. It is known that conventional friction modifiers such as molybdenum dithiocarbamate (MoDTC) reduce the surface friction of the lubricating oil and allow for better fuel economy. However, these friction modifiers can cause unwanted side effects. For example, MoDTC can increase deposit formation, and seal degradation. MoDTC can also out-compete anti-wear components for surface sites (which can be limited), not allowing the formation of an anti-wear film which leads to increased wear.

SUMMARY

[006] In one aspect, there is provided a lubricating oil composition for internal combustion engine with a roller follower type valvetrain, comprising: a) major amount

of an oil of lubricating viscosity; b) one or more magnesium detergents in an amount to provide 100 to 1000 ppm of magnesium to the lubricating oil composition; c) 0.1 to 0.5 wt% of organic friction modifier; and d) optionally a viscosity modifier present at no more 0.5 wt%, wherein the lubricating oil composition is substantially free of molybdenum friction modifier and has a total boron content ranging from 20 to 200 ppm.

[007] In another aspect, there is provided a method of improving fuel efficiency of an internal combustion engine, wherein the method comprises: lubricating the internal combustion engine with a lubricating oil composition comprising: a) major amount of an oil of lubricating viscosity; b) one or more magnesium detergent in an amount to provide 100 to 1000 ppm of magnesium to the lubricating oil composition; c) 0.1 to 0.5 wt% of organic friction modifier; and d) optionally a viscosity modifier present at no more 0.5 wt%; wherein the lubricating oil composition is substantially free of molybdenum friction modifier and has a total boron content ranging from 20 to 200 ppm.

DETAILED DESCRIPTION

[008] In this specification, the following words and expressions, if and when used, have the meanings ascribed below.

[009] The terms "oil soluble" means that for a given additive, the 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 0.001% by weight of the additive can be incorporated in a lubricating oil composition.

[010] A "major amount" means in excess of 50 weight % of a composition based on total lubricating oil composition.

[011] A "minor amount" means less than 50 weight % of a composition based on total lubricating oil composition.

[012] An "engine" or a "combustion engine" is a heat engine where the combustion of fuel occurs in a combustion chamber. An "internal combustion engine" is a heat engine where the combustion of fuel occurs in a confined space ("combustion chamber").

[013] It has now been discovered that significant improvements in fuel economy can be achieved in internal combustion engines (including engines with roller follower type valvetrain) via low viscosity lubricating oil compositions without the use of molybdenum friction modifiers.

[014] The lubricating oil composition generally includes 1) a major amount of an oil of lubricating viscosity, 2) a magnesium detergent, 3) an organic friction modifier, and 4) optionally a viscosity modifier. The lubricating oil composition is characterized by limited amounts or being substantially free (less than about 50 ppm) of molybdenum friction modifier.

[015] The lubricating oil composition is characterized by relatively low viscosity and has a kinematic viscosity at 100°C ranging from 4.0 cSt and 4.5 cSt, such as from 4.1 cSt to 4.4 cSt, and from 4.2 cSt to 4.3 cSt. Contrary to some or many conventional lubricants, this low viscosity is achieved in the absence of viscosity modifiers or using very small amounts of viscosity modifiers.

[016] The lubricating oil composition has a total boron content ranging from 20 to 200 ppm.

Magnesium Detergent

[017] The lubricating oil composition includes one or more magnesium detergents present in an amount to provide 100 to 1000 ppm of magnesium to the lubricating oil composition, such as from 100 to 900 ppm, 100 to 800 ppm, 100 to 700 ppm, 100 to 600 ppm, 100 to 500 ppm, 200 to 1000 ppm, 200 to 900 ppm, 200 to 800 ppm, 200 to 700 ppm, 200 to 600 ppm, 200 to 500 ppm, 300 to 1000 ppm, 300 to 900 ppm, 300 to 800 ppm, 300 to 700 ppm, 300 to 600 ppm, 300 to 500 ppm, 400 to 1000 ppm, 400 to 900 ppm, 400 to 800 ppm, 400 to 700 ppm, 400 to 600 ppm, 400 to 500 ppm.

[018] Any detergent that can coordinate with magnesium is generally compatible with the present invention. Particularly useful detergents include oil-soluble sulfonates (e.g., alkaryl sulfonates), hydroxyaromatic carboxylates (e.g., salicylates, alkylhydroxybenzoates, etc.), and phenates. The detergent of the present invention may have a wide range of TBN values. For example, the detergent may be a neutral detergent, low overbased detergent, medium overbased detergent, high overbased detergent, and so forth.

[019] Synthesis of various magnesium detergents are generally known and disclosed in, for example, U.S. Publication No. 20110136711, which is hereby incorporated by reference. By way of illustration, magnesium sulfonates can be prepared by reacting alkyltoluene sulfonic acid with a source of magnesium (e.g., magnesium oxide, magnesium hydroxide, magnesium alkoxide, etc.) in the presence of an organic solvent and low molecular weight alcohol. The reaction product is contacted with at least one promoter and water and then an overbasing acid and distilled.

[020] Sulfonates may be prepared from sulfonic acids which are often obtained by the sulfonation of alkyl-substituted aromatic compounds such as those obtained from the fractionation of petroleum or by the alkylation of aromatic compounds. Examples include those obtained by alkylating benzene, toluene, xylene, naphthalene, diphenyl or their halogen derivatives. The alkylation may be carried out in the presence of a catalyst with alkylating agents having from about 3 to more than 70 carbon atoms. The alkaryl sulfonates usually contain from about 9 to about 80 or more carbon atoms, preferably from about 16 to about 60 carbon atoms, preferably about 16 to about 30 carbon atoms, and more preferably 20-24 carbon atoms per alkyl substituted aromatic moiety.

[021] According to an embodiment, the detergent may include one or more magnesium salts of hydroxyaromatic carboxylate. Suitable hydroxyaromatic compounds include mononuclear monohydroxy and polyhydroxy aromatic hydrocarbons having 1 to 4, and preferably 1 to 3 hydroxyl groups. Suitable

hydroxyaromatic compounds include phenol, catechol, resorcinol, hydroquinone, pyrogallol, cresol, and the like.

[022] According to an embodiment, the detergent may include one or more magnesium salts of phenate. Suitable phenates can be prepared by reacting an magnesium hydroxide or oxide with an alkyl phenol or sulfurized alkylphenol. Useful alkyl groups include straight or branched chain C1 to C30 (e.g., C4 to C20) alkyl groups, or mixtures thereof. Examples of suitable phenols include isobutylphenol, 2-ethylhexylphenol, nonylphenol, dodecyl phenol, and the like. It should be noted that starting alkylphenols may contain more than one alkyl substituent that are each independently straight chain or branched chain. When a non-sulfurized alkylphenol is used, the sulfurized product may be obtained by methods well known in the art. These methods include heating a mixture of alkylphenol and sulfurizing agent (e.g., elemental sulfur, sulfur halides such as sulfur dichloride, and the like) and then reacting the sulfurized phenol with magnesium base.

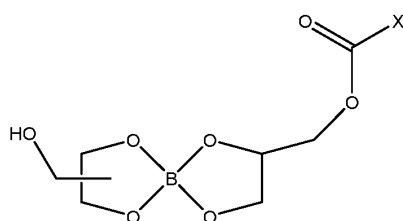
Organic Friction Modifier

[023] The lubricating oil composition is substantially free of molybdenum friction modifiers. Examples of molybdenum friction modifiers include, for example, molybdenum dithiocarbamates, molybdenum dithiophosphates, and trinuclear molybdenum compounds containing sulfur such as those described in U.S. Patent No. 6,232,276, which is hereby incorporated by reference.

[024] Instead, the lubricating oil composition of the present invention includes an organic friction modifier. In some embodiments, the organic friction modifier is borated (borated organic friction modifier) and contributes to the overall boron content of the lubricating oil composition. In other embodiments, the organic friction modifier is not borated. In cases where non-borated organic friction modifier is used, other borated components (e.g., borated dispersants) are needed to meet the boron content requirement of the lubricating oil composition.

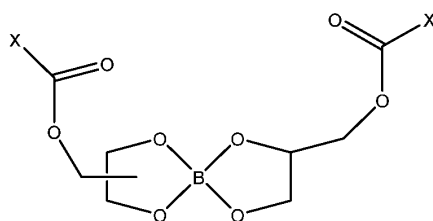
[025] As an illustrative non-limiting example, borated organic friction modifiers (e.g., borated glycerol monooleate) compatible with the present invention

may be represented by, for example, Structure 1, wherein each X is independently a hydrocarbonyl group that has 10 to 20 carbon atoms, such as from 10 to 18 carbon atoms, 10 to 16 carbon atoms, 12 to 20 carbon atoms, 12 to 18 carbon atoms, 12 to 16 carbon atoms, 14 to 20 carbon atoms, 14 to 18 carbon atoms, and 14 to 16 carbon atoms. X may be saturated or unsaturated. In some embodiments, X is branched. In other embodiments, X is linear.



Structure 1

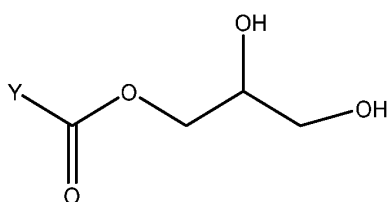
[026] A borated organic friction modifier (e.g., borated glycerol dioleate) may be a diester such as the one represented by Structure 2 below:



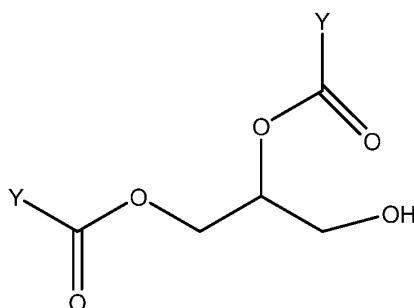
Structure 2

[027] Borated organic friction modifiers such as the one represented by Structure 1 and 2 are generally known and may be commercially available or prepared using known methods. Conventional synthesis involves a reaction of glycerol, boric acid, and fatty acid (e.g., oleic acid). A more detailed description of borated friction modifiers can be found U.S. Pat. No. 4,530,771 and 5,629,272, which are hereby incorporated by reference.

[028] Non-borated organic friction modifiers (e.g., glycerol monooleate) may be represented by, for example, Structure 3 and 4, wherein each Y is independently a hydrocarbyl group that has 10 to 20 carbon atoms, such as from 10 to 18 carbon atoms, 10 to 16 carbon atoms, 12 to 20 carbon atoms, 12 to 18 carbon atoms, 12 to 16 carbon atoms, 14 to 20 carbon atoms, 14 to 18 carbon atoms, and 14 to 16 carbon atoms. Y may be saturated or unsaturated. In some embodiments, Y is branched. In other embodiments, Y is linear.



Structure 3



Structure 4

[029] The organic friction modifier is incorporated in the lubricating oil composition in an amount ranging from 0.1 to 0.5 wt% based on total lubricating oil composition, such as from 0.15 to 0.45 wt%, from 0.18 to 0.42 wt%, from 0.20 to 0.40 wt%, and from 0.25 to 0.35 wt%.

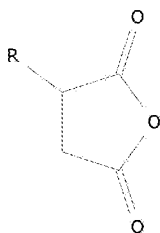
[030] When present, the borated organic friction modifier contributes to boron content of the lubricating oil composition such that the total boron content of the

lubricating oil composition is 20 to 200 ppm, such as from 20 to 180 ppm, 20 to 160 ppm, 20 to 140 ppm, 20 to 120 ppm, 20 to 100 ppm, 40 to 200 ppm, 40 to 180 ppm, 40 to 160 ppm, 40 to 140 ppm, 40 to 120 ppm, 40 to 100 ppm, 60 to 200 ppm, 60 to 180 ppm, 60 to 160 ppm, 60 to 140 ppm, 60 to 120 ppm, 60 to 100 ppm, 80 to 200 ppm, 80 to 180 ppm, 80 to 160 ppm, 80 to 140 ppm, 80 to 120 ppm, and 80 to 100 ppm.

Dispersant

[031] The lubricating oil composition may include non-borated and/or borated dispersants. Dispersants include, for example, polyalkenyl succinimide dispersants which can be post-treated by a boron-containing reagent to form borated components that contribute to the total boron content of the lubricating oil composition.

[032] In one embodiment, a polyalkenyl bis-succinimide can be obtained by reacting a polyalkenyl-substituted succinic anhydride below

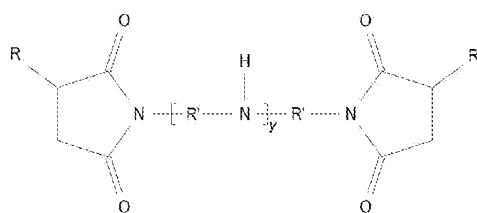


wherein R is a polyalkenyl substituent is derived from a polyalkene group having a number average molecular weight of from about 500 to about 3000, with a polyamine. In one embodiment, R is a polyalkenyl substituent derived from a polyalkene group having a number average molecular weight of from about 1000 to about 2500. In one embodiment, R is a polyisobutenyl substituent derived from a polyisobutene having a number average molecular weight of from about 500 to about 3000. In another embodiment, R is a polyisobutenyl substituent derived from a polyisobutene having a number average molecular weight of from about 1000 to about 2500.

[033] Suitable polyamines for use in preparing the bis-succinimide dispersants include polyalkylene polyamines. Such polyalkylene polyamines will typically contain about 2 to about 12 nitrogen atoms and about 2 to 24 carbon atoms. Particularly suitable polyalkylene polyamines are those having the formula: $\text{H}_2\text{N}-(\text{R}'\text{NH})_x-\text{H}$ wherein R' is a straight- or branched-chain alkylene group having 2 or 3 carbon atoms and x is 1 to 9. Representative examples of suitable polyalkylene polyamines include ethylenediamine, diethylenetriamine, triethylenetetraamine, tetraethylenepentamine, pentaethylene hexamine, and heavy polyamines (e.g., Ethyleneamine E-100, available from Huntsman Company).

[034] Generally, the polyalkenyl-substituted succinic anhydride is reacted with the polyamine at a temperature of about 130°C to about 220°C (e.g., 145°C to 175°C). The reaction can be carried out under an inert atmosphere, such as nitrogen or argon. Generally, a suitable molar charge of polyamine to polyalkenyl-substituted succinic anhydride is from about 0.35:1 to about 0.6:1 (e.g., 0.4:1 to 0.5:1). As used herein, the “molar charge of polyamine to polyalkenyl-substituted succinic anhydride” means the ratio of the number of moles of polyamine to the number of succinic groups in the succinic anhydride reactant.

[035] One class of suitable polyalkenyl succinimides may be represented by the following:



wherein R and R' are as described herein above and y is 1 to 11.

Post-Treatment of Polyalkenyl Succinimide

[036] The succinimide dispersant may be post-treated by a reactive boron compound. Suitable boron compounds that can be used as a source of boron include,

for example, boric acid, a boric acid salt, a boric acid ester, and the like. Representative examples of a boric acid include orthoboric acid, metaboric acid, paraboric acid, and the like. Representative examples of a boric acid salt include ammonium borates, such as ammonium metaborate, ammonium tetraborate, ammonium pentaborate, ammonium octaborate, and the like. Representative examples of a boric acid ester include monomethyl borate, dimethyl borate, trimethyl borate, monoethyl borate, diethyl borate, triethyl borate, monopropyl borate, dipropyl borate, tripropyl borate, monobutyl borate, dibutyl borate, tributyl borate, and the like.

Viscosity Modifier

[037] The lubricating oil composition may optionally include a viscosity modifier. Well-known viscosity modifiers that may be compatible with the present invention include polymethacrylate (PMA), olefin copolymer (OCP), and hydrogenated styrene-diene type (HSD) polymeric viscosity modifiers.

[038] The viscosity modifier may be present in about 0.5 wt% or less, such as from 0.4 wt% or less, 0.3 wt% or less, and 0.2 wt% or less.

[039] In some embodiments, the polymethacrylate may be a non-dispersant comb polymethacrylate which is described in US 2017/0298287A1 and JP2019014802, the disclosures of which is incorporated herein by reference. The non-dispersant comb PMA can be provided by Viscoplex® Viscosity Index Improver 3-201 and/or 3-162, which are available from Evonik.

[040] According to one embodiment, the non-dispersant comb PMA is provided by the compound referred to as Viscoplex® 3-201, which includes, as a main resin component, a comb PMA. This non-dispersant comb PMA has a weight average molecular weight (Mw) of 420,000 g/mol, a number average molecular weight (Mn) of 70,946 g/mol, and a Mw/Mn of 5.92. The compound has at least a constituent unit derived from a macromonomer having a Mn of 500 or more. The non-dispersant comb PMA is present in an amount of 19 wt. %, based on the total weight of the compound.

[041] According to another embodiment, the non-dispersant comb PMA is provided by the compound referred to as Viscoplex® 3-162, which also includes, as a

main resin component, a comb PMA. This non-dispersant comb PMA has a weight average molecular weight (Mw) of 399,292 g/mol, a number average molecular weight (Mn) of 205,952 g/mol, a Mw/Mn of 1.94, and a Shear Stability Index (SSI) of 0.6.

[042] According to another embodiment, the non-dispersant comb PMA is provided by a combination of compounds, for example a combination of the Viscoplex® 3-201 and the Viscoplex® 3-162.

[043] Other suitable viscosity modifiers include linear polymethacrylates which are described in U.S. Patent No. 3,607,749 and 8,778,857 which are hereby incorporated by reference.

[044] Olefin copolymers are also well-known and described in, for example, U.S. Patent No. 7,402,235 and 5,391,617, which are hereby incorporated by reference.

[045] Styrene-diene type viscosity modifiers can be prepared by copolymerizing styrene and butadiene and hydrogenating the unsaturated copolymers and are described in U.S. Patent No. 4,116,917, 3,772,196 and 4,788,316, which are hereby incorporated by reference.

Oil of Lubricating Viscosity

[046] The oil of lubricating viscosity (sometimes referred to as “base stock” or “base oil”) is the primary liquid constituent of a lubricant, into which additives and possibly other oils are blended to produce a final lubricant (or lubricant composition). A base oil is useful for making concentrates as well as for making lubricating oil compositions therefrom, and may be selected from natural and synthetic lubricating oils and combinations thereof.

[047] Natural oils include animal and vegetable oils, liquid petroleum oils and hydrorefined, solvent-treated mineral lubricating oils of the paraffinic, naphthenic and mixed paraffinic-naphthenic types. Oils of lubricating viscosity derived from coal or shale are also useful as base oils.

[048] Synthetic lubricating oils include hydrocarbon oils such as polymerized and interpolymerized olefins (e.g., polybutylenes, polypropylenes, propylene-isobutylene copolymers, chlorinated polybutylenes, poly(1-hexenes), poly(1-octenes),

poly(1-decenes); alkylbenzenes (e.g., dodecylbenzenes, tetradecylbenzenes, dinonylbenzenes, di(2-ethylhexyl)benzenes; polyphenols (e.g., biphenyls, terphenyls, alkylated polyphenols); and alkylated diphenyl ethers and alkylated diphenyl sulfides and the derivatives, analogues and homologues thereof. Polymerized olefins can also be derived from bio-derived sources such as hydrocarbon terpenes such as myrcene, ocimene and farnesene which can also be co-polymerized with other olefins and further isomerized if desired.

[049] Another suitable class of synthetic lubricating oils comprises the esters of dicarboxylic acids (e.g., malonic acid, alkyl malonic acids, alkenyl malonic acids, succinic acid, alkyl succinic acids and alkenyl succinic acids, maleic acid, fumaric acid, azelaic acid, suberic acid, sebacic acid, adipic acid, linoleic acid dimer, phthalic acid) with a variety of alcohols (e.g., butyl alcohol, hexyl alcohol, dodecyl alcohol, 2-ethylhexyl alcohol, ethylene glycol, diethylene glycol monoether, propylene glycol). Specific 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 complex ester formed by reacting one mole of sebacic acid with two moles of tetraethylene glycol and two moles of 2-ethylhexanoic acid.

[050] Esters useful as synthetic oils also include those made from C₅ to C₁₂ monocarboxylic acids and polyols, and polyol ethers such as neopentyl glycol, trimethylolpropane, pentaerythritol, dipentaerythritol and tripentaerythritol.

[051] Also, esters from bio-derived sources are also useful as synthetic oils.

[052] The base oil may be derived from Fischer-Tropsch synthesized hydrocarbons. Fischer-Tropsch synthesized hydrocarbons are made from synthesis gas containing H₂ and CO using a Fischer-Tropsch catalyst. Such hydrocarbons typically require further processing in order to be useful as the base oil. For example, the hydrocarbons may be hydroisomerized; hydrocracked and hydroisomerized; dewaxed; or hydroisomerized and dewaxed; using processes known to those skilled in the art.

[053] Unrefined, refined and re-refined oils can be used in the present lubricating oil composition. Unrefined oils are those obtained directly from a natural or synthetic source without further purification treatment. For example, a shale oil obtained directly from retorting operations, a petroleum oil obtained directly from distillation or ester oil obtained directly from an esterification process and used without further treatment would be unrefined oil. Refined oils are similar to the unrefined oils except they have been further treated in one or more purification steps to improve one or more properties. Many such purification techniques, such as distillation, solvent extraction, acid or base extraction, filtration and percolation are known to those skilled in the art.

[054] Re-refined oils are obtained by processes similar to those used to obtain refined oils applied to refined oils which have been already used in service. Such re-refined oils are also known as reclaimed or reprocessed oils and often are additionally processed by techniques for approval of spent additive and oil breakdown products.

[055] Hence, the base oil which may be used to make the present lubricating oil composition may be selected from any of the base oils in Groups I-V as specified in the American Petroleum Institute (API) Base Oil Interchangeability Guidelines (API Publication 1509). Such base oil groups are summarized in Table 1 below:

Table 1

	<u>Base Oil Properties</u>		
Group ^(a)	Saturates ^(b) , wt. %	Sulfur ^(c) , wt. %	Viscosity Index ^(d)
Group I	<90 and/or	>0.03	80 to <120
Group II	≥90	≤0.03	80 to <120
Group III	≥90	≤0.03	≥120
Group IV	Polyalphaolefins (PAOs)		
Group V	All other base stocks not included in Groups I, II, III or IV		

^(a) Groups I-III are mineral oil base stocks.

^(b) Determined in accordance with ASTM D2007.

- (c) Determined in accordance with ASTM D2622, ASTM D3120, ASTM D4294 or ASTM D4927.
- (d) Determined in accordance with ASTM D2270.

[056] Base oils suitable for use herein are any of the variety corresponding to API Group II, Group III, Group IV, and Group V oils and combinations thereof, preferably the Group III to Group V oils due to their exceptional volatility, stability, viscometric and cleanliness features.

[057] The oil of lubricating viscosity for use in the lubricating oil compositions of this disclosure, also referred to as a base oil, is typically present in a major amount, e.g., an amount of greater than 50 wt %, such as greater than about 70 wt %, greater than about about 80 wt %, greater than 90 wt % based on the total weight of the composition. The expression "base oil" as used herein shall be understood to mean a base stock or blend of base stocks which is a lubricant component that is produced by a single manufacturer to the same specifications (independent of feed source or manufacturer's location); that meets the same manufacturer's specification; and that is identified by a unique formula, product identification number, or both. The base oil for use herein can be any presently known or later-discovered oil of lubricating viscosity used in formulating lubricating oil compositions for any and all such applications, e.g., engine oils, marine cylinder oils, functional fluids such as hydraulic oils, gear oils, transmission fluids, etc. Additionally, the base oils for use herein can optionally contain additional viscosity modifiers or viscosity index improvers, e.g., comb-shaped polymethacrylate polymers/polyalkyl methacrylate polymers, olefinic copolymers, an ethylene-propylene copolymer or a styrene-butadiene copolymer; and the like and mixtures thereof.

[058] As one skilled in the art would readily appreciate, the viscosity of the base oil is dependent upon the application. Generally, individually the base oils used as engine oils will have a kinematic viscosity range at 100° C of about 4 cSt to about 8 cSt and will be selected or blended depending on the desired end use and the

additives in the finished oil to give the desired grade of engine oil, e.g., a lubricating oil composition having an SAE Viscosity Grade of 0W, 0W-8, 0W-12, 0W-16, 0W-20, 0W-30, 0W-40, 0W-50, 0W-60, 5W, 5W-16, 5W-20, 5W-30, 5W-40, 5W-50, 5W-60, 10W, 10W-20, 10W-30, 10W-40, 10W-50, 15W, 15W-20, 15W-30, 15W-40, 30, 40 and the like. The lubricating oil composition also has a viscosity index of about 200 or less.

Lubricant Additives

[059] The present lubricating oil compositions may also contain conventional lubricant additives for imparting auxiliary functions to give a finished lubricating oil composition in which these additives are dispersed or dissolved. For example, the lubricating oil compositions can be blended with antioxidants, ashless dispersants, anti-wear agents, detergents such as metal detergents, rust inhibitors, dehazing agents, demulsifying agents, friction modifiers, metal deactivating agents, pour point depressants, viscosity modifiers, antifoaming agents, co-solvents, package compatibilizers, corrosion-inhibitors, 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.

[060] 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 an ashless dispersant, a functionally effective amount of this ashless dispersant would be an amount sufficient to impart the desired dispersancy characteristics to the lubricant. Generally, the concentration of each of these additives, when used, may range, unless otherwise specified, from about 0.001 to about 20 wt %, such as about 0.010 to about 10 wt %.

EXAMPLES

[061] The following non-limiting examples are provided.

EXAMPLE 1

[062] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1240 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 450 ppm in terms of magnesium content of an overbased magnesium sulfonate (TBN=400 mg KOH/g)
- d) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- e) 270 ppm in terms of molybdenum of a molybdated succinimide
- f) 0.3 wt% of an organic friction modifier (borated glycerol monooleate)
- g) minor amounts of antioxidant, foam inhibitor, and pour point depressant

EXAMPLE 2

[063] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1240 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 450 ppm in terms of magnesium content of an overbased magnesium sulfonate (TBN=400 mg KOH/g)
- d) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- e) 270 ppm in terms of molybdenum of a molybdated succinimide
- f) 0.3 wt% of an organic friction modifier (non-borated glycerol monooleate)

- g) minor amounts of antioxidant, foam inhibitor, and pour point depressant

EXAMPLE 3

[064] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1240 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 450 ppm in terms of magnesium content of an overbased magnesium sulfonate (TBN=400 mg KOH/g)
- d) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- e) 150 ppm in terms of molybdenum of a molybdated succinimide
- f) 0.255 wt% of an organic friction modifier (borated glycerol monooleate)
- g) minor amounts of antioxidant, foam inhibitor, and pour point depressant

COMPARATIVE EXAMPLE 1

[065] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1240 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 450ppm in terms of magnesium content of an overbased magnesium sulfonate (TBN=400 mg KOH/g)
- d) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- e) 270 ppm in terms of molybdenum of a molybdated succinimide

- f) 0.3 wt% of an organic friction modifier (borated glycerol monooleate)
- g) 0.7 wt% of MoDTC (10 wt% Mo)
- h) minor amounts of antioxidant, foam inhibitor, and pour point depressant

COMPARATIVE EXAMPLE 2

[066] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1690 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- d) 150 ppm in terms of molybdenum of a molybdated succinimide
- e) 0.255 wt% of an organic friction modifier (borated glycerol monooleate)
- f) minor amounts of antioxidant, foam inhibitor, and pour point depressant

COMPARATIVE EXAMPLE 3

[067] SAE 0W-8 lubricating oil was preparing by blending the following components together in a Group III base oil with a KV100 of 4 cSt:

- a) 3.3 wt% of a mixture of borated and non-borated succinimide dispersant
- b) 1690 ppm in terms of calcium content of a mixture of a neutral calcium sulfonate (TBN=17 mg KOH/g), an overbased calcium sulfonate (TBN=410 mg KOH/g), and an overbased calcium phenate (TBN=260 mg KOH/g)
- c) 660 ppm in terms of phosphorus content of a mixture of primary and secondary alkyl ZnDTP
- d) 150 ppm in terms of molybdenum of a molybdated succinimide
- e) 0.255 wt% of an organic friction modifier (borated glycerol monooleate)
- f) 0.7 wt% of MoDTC

- g) minor amounts of antioxidant, foam inhibitor, and pour point depressant

Fuel Economy Tests

[068] The lubricating oil compositions above were tested for their fuel economy performance in 1) a gasoline motored engine with roller follower valvetrain (Toyota 2ZR-FXE) and 2) a mechanical motored engine with direct acting valvetrain (Nissan MR20).

[069] The detailed configuration of equipment and conditions of the Toyota 2ZR-FXE test can be found in SAE paper 2019-01-2296. The test oils are pre-conditioned in the engine operating at 1350 rpm for 10 hours at an oil temperature of 88 °C. The fuel consumption of the test oils are measured over a 4-hour period in the engine operating at 2100 rpm and 100 Nm at an oil temperature of 85°C for 15 minutes, and compared against the fuel consumption of a baseline calibration (BC) oil. The viscometric values of the BC oil used in the test method is shown below:

Table 2

Typical value	Modified BC oil
KV100 (cSt)	7.5
KV40 (cSt)	43.4
HTHS150 (mPas)	2.6
HTHS100 (mPas)	6.0

The fuel economy improvement (FEI) is calculated for the candidate oil test as relative improvement (% change) to the average of two BC oils as shown below. A higher FEI value indicates overall better fuel economy performance.

$$\{FEI(\%)\} = \frac{(\{FCBCB\} + \{FCBCA\}) \div 2 - \{FCCAN\}}{(\{FCBCB\} + \{FCBCA\}) \div 2} \times 100$$

FEI : Fuel Economy Improvement (%)

FCBCB : Fuel consumption of the BC oil before the candidate test oil (kg/h)

FCCAN : Fuel consumption of the candidate test oil (kg/h)

FCBCA : Fuel consumption of the BC oil after the candidate test oil (kg/h)

[070] The detailed test procedure of the Nissan MR20 test can be found in JASO M365.

Table 3

	Example 1	Example 2	Example 3	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3
Ca content (ppm)	1240	1240	1200	1240	1900	1900
Mg content (ppm)	450	450	430	450	-	-
Organic FM (wt%)	0.3	0.3	0.255	0.3	0.255	0.255
MoDTC	-	-	-	0.7	-	0.7
Mo content (ppm)	270	270	150	970	150	850
Boron content (ppm)	110	40	90	110	90	90
KV100	5.08	5.09	5.04	5.12	5.03	5.04
KV40	24.38	24.57	24.23	24.5	24.3	24.56
HTHS150	1.82	1.85	1.82	1.83	1.81	1.81
Viscosity Index	141	140	140	143	138	136
Toyota 2ZR FXE FEI (%)	1.07%	1.31%	1.11%	0.79%	0.85%	0.88%

[071] The Toyota 2ZR FXE FEI results of Table 3 show that the inventive examples demonstrate excellent fuel economy performance in an engine using a roller-follower type valvetrain, even in the absence of MoDTC. By contrast, when MoDTC was added to the formulation, the fuel economy performance worsened noticeably (comparative examples 1 and 3). Magnesium was also shown to contribute to fuel economy and the lubricating oil containing only calcium detergents showed poor performance (comparative examples 2 and 3). When tested in the Nissan MR20 engine which uses a direct acting valvetrain rather than a roller-follower type

valvetrain, the fuel economy performance was slightly improved by addition of MoDTC.

[072] 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.

CLAIMS

1. A lubricating oil composition for internal combustion engine with a roller follower type valvetrain, comprising:
 - a) major amount of an oil of lubricating viscosity;
 - b) one or more magnesium detergents in an amount to provide 100 to 1000 ppm of magnesium to the lubricating oil composition;
 - c) 0.1 to 0.5 wt% of organic friction modifier; and
 - d) optionally a viscosity modifier present at no more 0.5 wt%wherein the lubricating oil composition is substantially free of molybdenum friction modifier and has a total boron content ranging from 20 to 200 ppm.
2. The lubricating oil composition of claim 1, wherein the oil of lubricating viscosity is a group III base oil having a kinematic viscosity at 100°C ranging from 4 cSt to 4.5 cSt.
3. The lubricating oil composition of claim 1, where the organic friction modifier is glycerol monooleate or borated glycerol monooleate.
4. The lubricating oil composition of claim 2, wherein the viscosity modifier is a non-dispersant comb polymethacrylate, linear polymethacrylate, olefin copolymer, or hydrogenated styrene-diene type copolymer.
5. The lubricating oil composition of claim 1, further comprising a dispersant.
6. The lubricating oil composition of claim 5, wherein the dispersant is borated or non-borated.
7. The lubricating oil composition of claim 5, wherein the dispersant is a succinimide dispersant.

8. A method of improving fuel efficiency of an internal combustion engine, wherein the method comprises:

lubricating the internal combustion engine with a lubricating oil composition comprising:

- a) major amount of an oil of lubricating viscosity;
- b) one or more magnesium detergent in an amount to provide 100 to 1000 ppm of magnesium to the lubricating oil composition;
- c) 0.1 to 0.5 wt% of organic friction modifier; and
- d) optionally a viscosity modifier present at no more 0.5 wt%;

wherein the lubricating oil composition is substantially free of molybdenum friction modifier and has a total boron content ranging from 20 to 200 ppm.

9. The method of claim 8, wherein the oil of lubricating viscosity is a group III base oil having a kinematic viscosity at 100°C ranging from 4 cSt to 4.5 cSt.

10. The method of claim 8, where the organic friction modifier is glycerol monooleate or borated glycerol monooleate.

11. The method of claim 8, wherein the viscosity modifier is a non-dispersant comb polymethacrylate, linear polymethacrylate, olefin copolymer, or hydrogenated styrene-diene type copolymer.

12. The method of claim 8 wherein the internal combustion engine includes roller follower type valvetrain.

13. The method of claim 8, wherein the lubricating oil composition further comprises a dispersant.

14. The method of claim 13, wherein the dispersant is borated or non-borated.
15. The method of claim 15, wherein the dispersant is a succinimide dispersant.