

LUBRICATING OILS FOR ELECTRIC VEHICLES**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of U.S. Provisional Application No. 63/607,626, filed December 8, 2023, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] A major challenge in lubricating electric vehicles is balancing the electrical resistance with other performance requirements such as antiwear properties, oxidation resistance, and stability. Electric resistance may be impacted by the amount of dispersants, detergents, antiwear agents, extreme pressure agents, and other additives in lubricating oils. Typically, electrical resistance can be enhanced by reducing the treat rate of additives, and in particularly additives containing metals. However, this approach may also lead to increased wear, as well as scuffing, and poor oxidative resistance of the lubricant.

SUMMARY

[0003] Provided herein is a lubricating composition for an electrical vehicle (EV) or hybrid electric vehicle (HEV) with an electric motor and/or generator, comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a phosphorylated dispersant, which is a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

[0004] In another embodiment, provided herein is a method of reducing wear in an electric vehicle (EV) or a hybrid vehicle (HV) with an electric motor and/or generator, the method comprising lubricating the powertrain with a lubricating composition comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

DETAILED DESCRIPTION

[0005] 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.

Definitions

[0006] To facilitate the understanding of the subject matter disclosed herein, a number of terms, abbreviations or other shorthand as used herein are defined below. Any term, abbreviation or shorthand not defined is understood to have the ordinary meaning used by a skilled artisan contemporaneous with the submission of this application.

[0007] 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.

[0008] 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).

[0009] 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).

[0010] A “major amount” means in excess of 50 weight % of a composition.

[0011] 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.

[0012] “Active ingredients” or “actives” or “oil free” refer to additive material that is not diluent or solvent.

[0013] All percentages reported are weight % on an active ingredient basis (i.e., without regard to carrier or diluent oil) unless otherwise stated.

[0014] The abbreviation “ppm” means parts per million by weight, based on the total weight of the lubricating composition.

[0015] The term “metal” refers to transition metals, alkali metals, alkaline earth metals, or mixtures thereof. Transition metals include any metal found in Groups 3-12 of the periodic table, including titanium, iron, copper, zinc, molybdenum, palladium, and platinum. When an alkali metal is employed,

the alkali metal is lithium, sodium or potassium. When an alkaline earth metal is employed, the alkaline earth metal can be selected from the group consisting of calcium, barium, magnesium and strontium.

[0016] 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 composition.

[0017] The term “electric vehicle” as used herein refers to a vehicle that uses one or more electric motors for propulsion. The one or more electric motors may rely, in part, on electric current from a battery. Electric vehicles (EV) can be battery electric vehicles (BEV), sometimes known as all-electric vehicle (AEV). Alternatively, the electric vehicles may be a hybrid electric vehicle (HEV), such as a plug-in hybrid electric vehicle (PHEV) or a fuel cell electric vehicle (FCEV). BEVs/AEVs generally run entirely on a battery-powered electric drivetrain and have no additional fuel source. HEVs and PHEVs generally operate on both an internal combustion engine, or other power source, in addition to a rechargeable battery pack. In a PHEV, the battery can be externally recharged. FCEVs generally do not operate on a combustion engine, but instead, use a fuel cell to generate electricity.

[0018] “Free of zinc” or “substantially free of zinc” is understood to mean a composition comprising an extremely negligible amount of zinc or zinc derivatives. In general, “substantially free of zinc” indicates that a composition contains 10 ppm or less of zinc as measured by ASTM D5185 method.

[0019] 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 D2896 test.

[0020] Boron, calcium, magnesium, molybdenum, phosphorus, sulfur, and zinc contents were determined in accordance with ASTM D5185.

[0021] Volume resistivity values were measured in accordance with JIS C2101-24.

[0022] Dielectric breakdown voltage values were measured in accordance with ASTM D1816.

[0023] All ASTM standards referred to herein are the most current versions as of the filing date of the present application.

[0024] Unless otherwise specified, all percentages are in weight percent.

[0025] The present disclosure relates to lubricating compositions for electric vehicles comprising dispersants that have been treated with dialkyl dithiophosphoric acids (DTPA), which demonstrates enhanced antiwear performance. The phosphorylated dispersant replaces traditional metal-based antiwear agents such as zinc dithiophosphate (ZnDTP), and thus leads to improved electrical resistivity as well, making these lubricant compositions particularly suitable for use in electric or hybrid electric vehicle.

[0026] The present disclosure relates to a lubricant composition suitable for use in electric vehicles and hybrid electric vehicles with an electric motor and/or a generator. The composition provides good

antiwear and electrical properties and eliminates the need for metal-based wear inhibitors such as zinc dithiophosphates (ZnDTP).

[0027] In one embodiment, provided herein is lubricating composition for an electrical vehicle (EV) or hybrid electric vehicle (HEV) with an electric motor and/or generator, comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a phosphorylated dispersant, which is a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

[0028] In another embodiment, provided herein is a method of reducing wear in an electric vehicle (EV) or a hybrid vehicle (HV) with an electric motor and/or generator, the method comprising lubricating the powertrain with a lubricating composition comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

Oil of lubricating viscosity

[0029] 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, for example to produce a final lubricant (or lubricant composition). A base oil is useful for making concentrates as well as for making lubricating compositions therefrom, and may be selected from natural and synthetic lubricating oils and combinations thereof.

[0030] Natural oils include animal and vegetable oils, liquid petroleum oils and hydrotreated, 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 base oils.

[0031] Synthetic lubricating oils include hydrocarbon oils such as polymerized and interpolymers of 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.

[0032] 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.

[0033] 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. Esters from bio-derived sources may also be useful as synthetic oils.

[0034] 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.

[0035] The base oil may be a renewable or bio-derived engine oil. Examples of such engine oils are disclosed in WO2016061050 and US20190338211, which is incorporated herein by reference.

According to some embodiments, the renewable or bio-derived base oil includes a biobased hydrocarbon, such as an isoparaffinic hydrocarbon derived from hydrocarbon terpenes, such as myrcene, ocimene, and farnesene. In some embodiments, the biobased hydrocarbon is produced from fatty acids or fatty esters.

[0036] Unrefined, refined and re-refined oils can be used in the present lubricating 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.

[0037] By applying similar refining processes to already-refined oils that have been used in service as those processes that are used to obtain those refined oils in the first place, re-refined oils may be obtained. 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.

[0038] Hence, the base oil which may be used to make the present lubricating 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

	Base Oil Properties		
Group	Saturates ^(a) , wt. %	Sulfur ^(b) , wt. %	Viscosity Index ^(c)

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) Determined in accordance with ASTM D2007.

(b) Determined in accordance with ASTM D2622, ASTM D3120, ASTM D4294 or ASTM D4927.

(c) Determined in accordance with ASTM D2270.

[0039] 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. In one embodiment, the base oil is a Group I base oil or a blend of two or more different Group I base oils. 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.

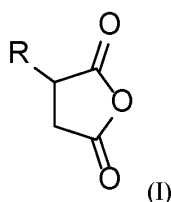
[0040] In one embodiment, the base oil is a Group II base oil or a blend of two or more different Group II base oils. Suitable Group II base oils include, for example, paraffinic mineral oils obtained by a suitable combination of refining processes such as hydrotreating and dewaxing in respect of lubricating oil fractions obtained by atmospheric distillation of crude oil.

Phosphorylated Dispersant

[0041] The lubricating composition of the present disclosure contains a phosphorylated dispersant, which is a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid.

[0042] In some embodiments, the phosphorylated dispersant is a reaction product of a polyalkenyl bis-succinimide and a dialkyl dithiophosphoric acid.

[0043] In one embodiment, a polyalkenyl bis-succinimide can be obtained by reacting a polyamine with the polyalkenyl-substituted succinic anhydride below:



wherein R is a polyalkenyl substituent derived from a polyalkene group having a number average molecular weight of from about 200 g/mol to about 3000 g/mol, such as from about 200 g/mol to 2900 g/mol, about 200 g/mol to about 2800 g/mol, about 200 g/mol to about 2700 g/mol, about 200 g/mol to about 2600 g/mol, about 200 g/mol to about 2500 g/mol, about 200 g/mol to about 2400 g/mol, about 200 g/mol to about 2300 g/mol, about 200 g/mol to about 2200 g/mol, about 200 g/mol to about 2100 g/mol,

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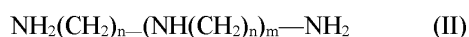
g/mol to about 7500 g/mol, about 700 g/mol to about 2400 g/mol, about 700 g/mol to about 2300 g/mol, about 700 g/mol to about 2200 g/mol, about 700 g/mol to about 2100 g/mol, about 700 g/mol to about 2000 g/mol, about 700 g/mol to about 1900 g/mol, about 700 g/mol to about 1800 g/mol, about 700 g/mol to about 1700 g/mol, about 700 g/mol to about 1600 g/mol, about 700 g/mol to about 1500 g/mol, about 700 g/mol to about 1400 g/mol, about 700 g/mol to about 1300 g/mol, about 700 g/mol to about 1200 g/mol, about 700 g/mol to about 1100 g/mol, about 700 g/mol to about 1000 g/mol, about 800 g/mol to about 3000 g/mol, about 800 g/mol to about 2900 g/mol, about 800 g/mol to about 2800 g/mol, about 800 g/mol to about 2700 g/mol, about 800 g/mol to about 2600 g/mol, about 800 g/mol to about 2500 g/mol, about 800 g/mol to about 2400 g/mol, about 800 g/mol to about 2300 g/mol, about 800 g/mol to about 2200 g/mol, about 800 g/mol to about 2100 g/mol, about 800 g/mol to about 2000 g/mol, about 800 g/mol to about 1900 g/mol, about 800 g/mol to about 1800 g/mol, about 800 g/mol to about 1700 g/mol, about 800 g/mol to about 1600 g/mol, about 800 g/mol to about 1500 g/mol, about 800 g/mol to about 1400 g/mol, about 800 g/mol to about 1300 g/mol, about 800 g/mol to about 1200 g/mol, about 800 g/mol to about 1100 g/mol, about 800 g/mol to about 1000 g/mol, about 900 g/mol to about 3000 g/mol, about 900 g/mol to about 2900 g/mol, about 900 g/mol to about 2800 g/mol, about 900 g/mol to about 2700 g/mol, about 900 g/mol to about 2600 g/mol, about 900 g/mol to about 2500 g/mol, about 900 g/mol to about 2400 g/mol, about 900 g/mol to about 2300 g/mol, about 900 g/mol to about 2200 g/mol, about 900 g/mol to about 2100 g/mol, about 900 g/mol to about 2000 g/mol, about 900 g/mol to about 1900 g/mol, about 900 g/mol to about 1800 g/mol, about 900 g/mol to about 1700 g/mol, about 900 g/mol to about 1600 g/mol, about 900 g/mol to about 1500 g/mol, about 900 g/mol to about 1400 g/mol, about 900 g/mol to about 1300 g/mol, about 900 g/mol to about 1200 g/mol, about 900 g/mol to about 1100 g/mol, or about 900 g/mol to about 1000 g/mol.

[0044] In some embodiments, the polyalkenyl substituent is a polyisobutenyl substituent. In one embodiment, R is a polyisobutenyl substituent derived from a polyisobutene. r.

[0045] In some embodiments R is a polyisobutenyl substituent derived from a polyisobutene having a number average molecular weight of 3000 g/mol or less, 2000 g/mol or less, 1500 g/mol or less, 1200 g/mol or less, 1000 g/mol or less, 900 g/mol or less, 800 g/mol or less, 750 g/mol or less, 700 g/mol or less, 650 g/mol or less, or 600 g/mol or less.

[0046] Suitable polyisobutenes for use herein include those formed from conventional polyisobutylene or highly reactive polyisobutylene having at least 60%, such as 70% to 90% and above, terminal vinylidene content. Suitable polyisobutenes may include those prepared using BF₃ catalysts.

[0047] In some embodiments, the amines for reaction to form the succinimide are polyamines having from 2 to 60 carbon atoms and from 2 to 12 nitrogen atoms per molecule. Polyamines include polyalkyleneamines represented by the formula:



wherein n is 2 to 3 and m is 0 to 10. Illustrative examples include ethylene diamine, diethylene triamine, triethylene tetramine, tetraethylene pentamine, tetrapropylene pentamine, pentaethylene hexamine and

the like, as well as the commercially available mixtures of such polyamines. Amines including other groups such as hydroxy, alkoxy, amide, nitride and imidazoline groups may also be used, as may polyoxyalkylene polyamines. Suitable polyalkylene polyamines are those having the formula: $H_2N-(R'NH)_x-H$ 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). Cyclic polyalkylene polyamines such as aminoethylpiperazine, bis(aminoethylpiperazine), piperazinoethylethylenediamine, and other piperazinyll derivatives may also be considered.

[0048] The amines may be reacted with the alkenyl succinic acid or anhydride in ratios of about 1:1 to 10:1, 1:1 to 5:1, or 1:1 to 3:1, moles of alkenyl succinic acid or anhydride to polyamine, typically by heating the reactants to from about 100 °C to about 250 °C, or about 125 °C to about 175 °C for between 1 to 10 hours, or between 2 to 6 hours.

[0049] The dispersant may also be post-treated by reacting with a number of phosphorus compounds or sulfur-phosphorus compounds to provide phosphorylated dispersants. Suitable phosphorus compounds for forming the dispersants herein include phosphorus compounds or mixtures of phosphorus compounds capable of introducing a phosphorus-containing species into the dispersant. Any phosphorus compound, organic or inorganic, capable of undergoing the reaction can be used. Suitable phosphorylating agents include organic or inorganic phosphorus compounds such as mono-, di-, or triesters of phosphoric acid, mono-, di-, or triesters of thiophosphoric acid, mono-, di-, or triesters of dithiophosphoric acid, mono-, di-, or triesters of trithiophosphoric acid, mono-, di-, or triesters of phosphorous acid, mono-, di-, or triesters of thiophosphorous acid, mono-, di-, or triesters of dithiophosphorous acid, mono-, di-, or triesters of trithiophosphorous acid, mono-, di-, tri-, or tetraesters of bisphosphonates, inorganic phosphorus halides such as PCl_3 , PBr_3 , $POCl_3$, $PSCl_3$, and the like.

[0050] The phosphorylated dispersant is a reaction product of a bis-succinimide as described herein and a dialkyl dithiophosphoric acid. Dialkyl dithiophosphoric acids are prepared by reacting phosphorus pentasulfide with linear or branched alcohols of varying chain lengths.

[0051] In some embodiments, the dialkyl dithiophosphoric acid is derived from linear or branched C_1 - C_{40} alcohols, linear or branched C_2 - C_{20} alcohols, linear or branched C_2 - C_{12} alcohols, linear or branched C_3 - C_8 alcohols, or mixtures thereof. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of linear or branched C_2 - C_{12} alcohols. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of linear or branched C_3 - C_8 alcohols. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of linear C_2 - C_{12} alcohols. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of branched C_2 - C_{12} alcohols. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of branched C_4 - C_8 alcohols.

[0052] In some embodiments, the dialkyl dithiophosphoric acid is derived from methanol, ethanol, *n*-propanol, isopropanol, linear or branched C₄ alcohols (such as *n*-butanol, 2-butanol, isobutanol, or *tert*-butanol), linear or branched C₅ alcohols (such as *n*-pentanol, 2-pentanol, 3-pentanol, isopentanol (isoamyl alcohol), 2-methylbutan-2-ol (*tert*-amyl alcohol), neopentyl alcohol, and the like), linear or branched C₆ alcohols (such as *n*-hexanol, hexan-2-ol, hexan-3-ol, 2-methylpentan-1-ol, 3-methylpentan-1-ol, 4-methylpentan-1-ol, 2,2-dimethylbutan-1-ol, and the like), linear or branched C₇ alcohols (such as *n*-heptanol, 2-heptanol, 3-heptanol, and the like), linear or branched C₈ alcohols (such as *n*-octanol, 2-octanol, 3-octanol, 2-ethylhexanol, and the like), linear or branched C₉ alcohols (such as *n*-nonanol), linear or branched C₁₀ alcohols (such as *n*-decanol), linear or branched C₁₁ alcohols (such as *n*-undecanol), or linear or branched C₁₂ alcohols (such as *n*-dodecanol), or mixtures thereof.

[0053] In some embodiments, the dialkyl dithiophosphoric acid is derived from linear or branched fatty alcohols, including capric alcohol, lauryl alcohol, myristyl alcohol, cetyl alcohol, palmitoleyl alcohol, stearyl alcohol, oleyl alcohol, or mixtures thereof.

[0054] In some embodiments, the dialkyl dithiophosphoric acid is derived from C₄-C₁₂ primary or secondary alcohols, or mixtures thereof. In some embodiments, the dialkyl dithiophosphoric acid is derived from *n*-butanol, 2-butanol, *n*-hexanol, 2-methylpentanol, *n*-octanol, 2-ethylhexanol, nonanol, decanol, undecanol, lauryl alcohol, or mixtures thereof. In some embodiments, the dialkyl dithiophosphoric acid is derived from 2-butanol, 2-methylpentanol, 2-ethylhexanol, or mixtures thereof. In some embodiments, the dialkyl dithiophosphoric acid is derived from 2-butanol. In some embodiments, the dialkyl dithiophosphoric acid is derived from 2-methylpentanol. In some embodiments, the dialkyl dithiophosphoric acid is derived from 2-ethylhexanol. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of 2-butanol and 2-ethylhexanol. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of 2-butanol and 2-methylpentanol. In some embodiments, the dialkyl dithiophosphoric acid is derived from a mixture of 2-methylpentanol and 2-ethylhexanol.

[0055] The Charge Mole Ratio (CMR) of the dialkyl dithiophosphoric acid to the bis-succinimide may be important to ensure correct reaction product. In some embodiments, the CMR of the bis-succinimide to the dialkyl dithiophosphoric acid ester is about 1:1. In some embodiments, an excess of the dialkyl dithiophosphoric acid ester is used such that the CMR of bis-succinimide to the acid ester is about 1:2. Other CMR may also yield suitable phosphorylated dispersants.

[0056] In some embodiments, the phosphorylated dispersant contains about 0.5 wt.% to about 6.0 wt.% of sulfur, such as from about 0.5 wt.% to about 5.5 wt.%, about 0.5 wt.% to about 5.0 wt.%, about 0.5 wt.% to about 4.5 wt.%, about 0.5 wt.% to about 4.0 wt.%, about 0.5 wt.% to about 3.9 wt.%, about 0.5 wt.% to about 3.8 wt.%, about 0.5 wt.% to about 3.7 wt.%, about 0.5 wt.% to about 3.6 wt.%, about 0.5 wt.% to about 3.5 wt.%, about 1.0 wt.% to about 5.5 wt.%, about 1.0 wt.% to about 5.0 wt.%, about 1.0 wt.% to about 4.5 wt.%, about 1.0 wt.% to about 4.0 wt.%, about 1.0 wt.% to about 3.9 wt.%, about 1.0 wt.% to about 3.8 wt.%, about 1.0 wt.% to about 3.7 wt.%, about 1.0 wt.% to about 3.6 wt.%, about 1.0

wt.% to about 3.5 wt.%, about 1.5 wt.% to about 5.5 wt.%, about 1.5 wt.% to about 5.0 wt.%, about 1.5 wt.% to about 4.5 wt.%, about 1.5 wt.% to about 4.0 wt.%, about 1.5 wt.% to about 3.9 wt.%, about 1.5 wt.% to about 3.8 wt.%, about 1.5 wt.% to about 3.7 wt.%, about 1.5 wt.% to about 3.6 wt.%, about 1.5 wt.% to about 3.5 wt.%, about 2.0 wt.% to about 5.5 wt.%, about 2.0 wt.% to about 5.0 wt.%, about 2.0 wt.% to about 4.5 wt.%, about 2.0 wt.% to about 4.0 wt.%, about 2.0 wt.% to about 3.9 wt.%, about 2.0 wt.% to about 3.8 wt.%, about 2.0 wt.% to about 3.7 wt.%, about 2.0 wt.% to about 3.6 wt.%, about 2.0 wt.% to about 3.5 wt.%, about 2.1 wt.% to about 5.5 wt.%, about 2.1 wt.% to about 5.0 wt.%, about 2.1 wt.% to about 4.5 wt.%, about 2.1 wt.% to about 4.0 wt.%, about 2.1 wt.% to about 3.9 wt.%, about 2.1 wt.% to about 3.8 wt.%, about 2.1 wt.% to about 3.7 wt.%, about 2.1 wt.% to about 3.6 wt.%, about 2.1 wt.% to about 3.5 wt.%, about 2.2 wt.% to about 5.5 wt.%, about 2.2 wt.% to about 5.0 wt.%, about 2.2 wt.% to about 4.5 wt.%, about 2.2 wt.% to about 4.0 wt.%, about 2.2 wt.% to about 3.9 wt.%, about 2.2 wt.% to about 3.8 wt.%, about 2.2 wt.% to about 3.7 wt.%, about 2.2 wt.% to about 3.6 wt.%, about 2.2 wt.% to about 3.5 wt.%, about 2.3 wt.% to about 5.5 wt.%, about 2.3 wt.% to about 5.0 wt.%, about 2.3 wt.% to about 4.5 wt.%, about 2.3 wt.% to about 4.0 wt.%, about 2.3 wt.% to about 3.9 wt.%, about 2.3 wt.% to about 3.8 wt.%, about 2.3 wt.% to about 3.7 wt.%, about 2.3 wt.% to about 3.6 wt.%, about 2.3 wt.% to about 3.5 wt.%, about 2.4 wt.% to about 5.5 wt.%, about 2.4 wt.% to about 5.0 wt.%, about 2.4 wt.% to about 4.5 wt.%, about 2.4 wt.% to about 4.0 wt.%, about 2.4 wt.% to about 3.9 wt.%, about 2.4 wt.% to about 3.8 wt.%, about 2.4 wt.% to about 3.7 wt.%, about 2.4 wt.% to about 3.6 wt.%, about 2.4 wt.% to about 3.5 wt.%, about 2.5 wt.% to about 5.5 wt.%, about 2.5 wt.% to about 5.0 wt.%, about 2.5 wt.% to about 4.5 wt.%, about 2.5 wt.% to about 4.0 wt.%, about 2.5 wt.% to about 3.9 wt.%, about 2.5 wt.% to about 3.8 wt.%, about 2.5 wt.% to about 3.7 wt.%, about 2.5 wt.% to about 3.6 wt.%, or about 2.5 wt.% to about 3.5 wt.%.

[0057] In some embodiments, the phosphorylated dispersant contains about 0.3 wt.% to about 3.0 wt.% of phosphorus, such as from about 0.3 wt.% to about 2.9 wt.%, about 0.3 wt.% to about 2.8 wt.%, about 0.3 wt.% to about 2.7 wt.%, about 0.3 wt.% to about 2.6 wt.%, about 0.3 wt.% to about 2.5 wt.%, about 0.3 wt.% to about 2.4 wt.%, about 0.3 wt.% to about 2.3 wt.%, about 0.3 wt.% to about 2.2 wt.%, about 0.3 wt.% to about 2.1 wt.%, about 0.3 wt.% to about 2.0 wt.%, about 0.4 wt.% to about 2.9 wt.%, about 0.4 wt.% to about 2.8 wt.%, about 0.4 wt.% to about 2.7 wt.%, about 0.4 wt.% to about 2.6 wt.%, about 0.4 wt.% to about 2.5 wt.%, about 0.4 wt.% to about 2.4 wt.%, about 0.4 wt.% to about 2.3 wt.%, about 0.4 wt.% to about 2.2 wt.%, about 0.4 wt.% to about 2.1 wt.%, about 0.4 wt.% to about 2.0 wt.%, about 0.5 wt.% to about 2.9 wt.%, about 0.5 wt.% to about 2.8 wt.%, about 0.5 wt.% to about 2.7 wt.%, about 0.5 wt.% to about 2.6 wt.%, about 0.5 wt.% to about 2.5 wt.%, about 0.5 wt.% to about 2.4 wt.%, about 0.5 wt.% to about 2.3 wt.%, about 0.5 wt.% to about 2.2 wt.%, about 0.5 wt.% to about 2.1 wt.%, about 0.5 wt.% to about 2.0 wt.%, about 0.6 wt.% to about 2.9 wt.%, about 0.6 wt.% to about 2.8 wt.%, about 0.6 wt.% to about 2.7 wt.%, about 0.6 wt.% to about 2.6 wt.%, about 0.6 wt.% to about 2.5 wt.%, about 0.6 wt.% to about 2.4 wt.%, about 0.6 wt.% to about 2.3 wt.%, about 0.6 wt.% to about 2.2 wt.%, about 0.6 wt.% to about 2.1 wt.%, about 0.6 wt.% to about 2.0 wt.%, about 0.7 wt.% to about 2.9 wt.%, about

0.7 wt.% to about 2.8 wt.%, about 0.7 wt.% to about 2.7 wt.%, about 0.7 wt.% to about 2.6 wt.%, about 0.7 wt.% to about 2.5 wt.%, about 0.7 wt.% to about 2.4 wt.%, about 0.7 wt.% to about 2.3 wt.%, about 0.7 wt.% to about 2.2 wt.%, about 0.7 wt.% to about 2.1 wt.%, about 0.7 wt.% to about 2.0 wt.%, about 0.8 wt.% to about 2.9 wt.%, about 0.8 wt.% to about 2.8 wt.%, about 0.8 wt.% to about 2.7 wt.%, about 0.8 wt.% to about 2.6 wt.%, about 0.8 wt.% to about 2.5 wt.%, about 0.8 wt.% to about 2.4 wt.%, about 0.8 wt.% to about 2.3 wt.%, about 0.8 wt.% to about 2.2 wt.%, about 0.8 wt.% to about 2.1 wt.%, about 0.8 wt.% to about 2.0 wt.%, about 0.9 wt.% to about 2.9 wt.%, about 0.9 wt.% to about 2.8 wt.%, about 0.9 wt.% to about 2.7 wt.%, about 0.9 wt.% to about 2.6 wt.%, about 0.9 wt.% to about 2.5 wt.%, about 0.9 wt.% to about 2.4 wt.%, about 0.9 wt.% to about 2.3 wt.%, about 0.9 wt.% to about 2.2 wt.%, about 0.9 wt.% to about 2.1 wt.%, about 0.9 wt.% to about 2.0 wt.%, about 1.0 wt.% to about 2.9 wt.%, about 1.0 wt.% to about 2.8 wt.%, about 1.0 wt.% to about 2.7 wt.%, about 1.0 wt.% to about 2.6 wt.%, about 1.0 wt.% to about 2.5 wt.%, about 1.0 wt.% to about 2.4 wt.%, about 1.0 wt.% to about 2.3 wt.%, about 1.0 wt.% to about 2.2 wt.%, about 1.0 wt.% to about 2.1 wt.%, or about 1.0 wt.% to about 2.0 wt.%.

[0058] In some embodiments, the lubricating composition of the present disclosure contains about 0.1 wt.% to about 15 wt.%, about 0.5 wt.% to about 10 wt.%, or about 1.0 wt.% to about 5.0 wt.% of a phosphorylated dispersant. In some embodiments, the lubricating composition of the present disclosure contains about 1.25 wt.% to about 4.0 wt.% of a phosphorylated dispersant. In some embodiments, the lubricating composition of the present disclosure contains about 1.5 wt.% to about 3.5 wt.% of a phosphorylated dispersant.

[0059] In some embodiments, the phosphorylated dispersant provides about 50 ppm to about 2000 ppm of sulfur to the lubricating composition. In some embodiments, the phosphorylated dispersant provides about 50 ppm to about 2000 ppm of sulfur, such as from about 50 ppm to about 1800 ppm, about 50 ppm to about 1600 ppm, about 50 ppm to about 1400 ppm, about 50 ppm to about 1200 ppm, about 50 ppm to about 1000 ppm, about 50 ppm to about 900 ppm, about 50 ppm to about 800 ppm, about 100 ppm to about 2000 ppm, about 100 ppm to about 1800 ppm, about 100 ppm to about 1600 ppm, about 100 ppm to about 1400 ppm, about 100 ppm to about 1200 ppm, about 100 ppm to about 1000 ppm, about 100 ppm to about 900 ppm, about 100 ppm to about 800 ppm, 150 ppm to about 2000 ppm, about 150 ppm to about 1800 ppm, about 150 ppm to about 1600 ppm, about 150 ppm to about 1400 ppm, about 150 ppm to about 1200 ppm, about 150 ppm to about 1000 ppm, about 150 ppm to about 900 ppm, about 150 ppm to about 800 ppm, about 200 ppm to about 2000 ppm, about 200 ppm to about 1800 ppm, about 200 ppm to about 1600 ppm, about 200 ppm to about 1400 ppm, about 200 ppm to about 1200 ppm, about 200 ppm to about 1000 ppm, about 200 ppm to about 900 ppm, about 200 ppm to about 800 ppm, about 250 ppm to about 2000 ppm, about 250 ppm to about 1800 ppm, about 250 ppm to about 1600 ppm, about 250 ppm to about 1400 ppm, about 250 ppm to about 1200 ppm, about 250 ppm to about 1000 ppm, about 250 ppm to about 900 ppm, about 250 ppm to about 800 ppm, about 300 ppm to about 2000 ppm, about 300 ppm to about 1800 ppm, about 300 ppm to about 1600 ppm, about 300 ppm to about 1400 ppm, about 300 ppm to about 1200 ppm, about 300 ppm to about 1000 ppm, about 300 ppm to about 900 ppm.

ppm, about 300 ppm to about 800 ppm, about 350 ppm to about 2000 ppm, about 350 ppm to about 1800 ppm, about 350 ppm to about 1600 ppm, about 350 ppm to about 1400 ppm, about 350 ppm to about 1200 ppm, about 350 ppm to about 1000 ppm, about 350 ppm to about 900 ppm, about 350 ppm to about 800 ppm, about 400 ppm to about 2000 ppm, about 400 ppm to about 1800 ppm, about 400 ppm to about 1600 ppm, about 400 ppm to about 1400 ppm, about 400 ppm to about 1200 ppm, about 400 ppm to about 1000 ppm, about 400 ppm to about 900 ppm, about 400 ppm to about 800 ppm of sulfur to the lubricating composition

[0060] In some embodiments, the phosphorylated dispersant provides at least about 50 ppm, such as at least about 100 ppm, at least about 150 ppm, at least about 200 ppm, at least about 250 ppm, at least about 300 ppm, at least about 350 ppm, at least about 400 ppm, at least about 450 ppm, or at least about 500 ppm of sulfur to the lubricating composition.

[0061] In some embodiments, the phosphorylated dispersant provides about 50 ppm to about 1000 ppm of phosphorus to the lubricating composition. In some embodiments, the phosphorylated dispersant provides about 50 ppm to about 1000 ppm, such as from about 50 ppm to about 900 ppm, about 50 ppm to about 800 ppm, about 50 ppm to about 700 ppm, about 50 ppm to about 600 ppm, about 50 ppm to about 400 ppm, about 100 ppm to about 100 ppm, about 100 ppm to about 900 ppm, about 100 ppm to about 800 ppm, about 100 ppm to about 700 ppm, about 100 ppm to about 600 ppm, about 100 ppm to about 500 ppm, about 100 ppm to about 400 ppm, about 150 ppm to about 1000 ppm, about 150 ppm to about 900 ppm, about 150 ppm to about 800 ppm, about 150 ppm to about 700 ppm, about 150 ppm to about 600 ppm, about 150 ppm to about 500 ppm, about 150 ppm to about 400 ppm, about 200 ppm to about 1000 ppm, about 200 ppm to about 900 ppm, about 200 ppm to about 800 ppm, about 200 ppm to about 700 ppm, about 200 ppm to about 600 ppm, about 200 ppm to about 500 ppm, or about 200 ppm to about 400 ppm of phosphorus to the lubricating composition.

[0062] In some embodiments, the phosphorylated dispersant provides at least about 50 ppm of phosphorus, such as at least about 60 ppm, at least about 70 ppm, at least about 80 ppm, at least about 90 ppm, at least about 100 ppm, at least about 110 ppm, at least about 120 ppm, at least about 130 ppm, at least about 140 ppm, at least about 150 ppm, at least about 160 ppm, at least about 170 ppm, at least about 180 ppm, at least about 190 ppm, or at least about 200 ppm of phosphorus to the lubricating composition.

Lubricating Composition

[0063] The lubricating composition of the present disclosure is suitable for use in EV and HEV, including BEV/AEV, PHEV, FCEV. Fluids suitable for use in electric and/or hybrid electric vehicles must meet the requirements of a standard transmission fluid (such as good antiwear and friction characteristics), while also minimizing electrical conductivity as the fluid is in contact with various electric components during operation.

[0064] Electrical resistivity, or volume resistivity, is a measure of a material's ability to resist electric current and is a critical property for electric vehicle lubricants. Generally, a value of $10^8 \Omega \cdot \text{cm}$ or higher at operating temperatures ranging from 20°C to 120°C is considered suitable for use in automatic and manual transmissions.

[0065] Dielectric breakdown voltage is also a useful metric for electric vehicle lubricants. The dielectric breakdown voltage of an insulating liquid is of importance as a measure of the liquid's ability to withstand electric stress without failure.

[0066] In some embodiments, the lubricating composition of the present disclosure has a volume resistivity value of $5.0 \times 10^7 \Omega \cdot \text{cm}$ or greater, $1.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, $5.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, or $1.0 \times 10^9 \Omega \cdot \text{cm}$ or greater, as measured by JIS C2101-24. In some embodiments, the lubricating composition of the present disclosure has a volume resistivity value of between $1.0 \times 10^7 \Omega \cdot \text{cm}$ to $1.0 \times 10^{11} \Omega \cdot \text{cm}$, $5.0 \times 10^7 \Omega \cdot \text{cm}$ to $5.0 \times 10^{10} \Omega \cdot \text{cm}$, $1.0 \times 10^8 \Omega \cdot \text{cm}$ to $1.0 \times 10^{10} \Omega \cdot \text{cm}$, or $1.0 \times 10^8 \Omega \cdot \text{cm}$ to $5.0 \times 10^9 \Omega \cdot \text{cm}$, as measured by JIS C2101-24.

[0067] In some embodiments, the lubricating composition of the present disclosure has a volume resistivity value of $5.0 \times 10^7 \Omega \cdot \text{cm}$ or greater, $1.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, $5.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, or $1.0 \times 10^9 \Omega \cdot \text{cm}$ or greater, as measured by JIS C2101-24 at a temperature of 40°C , 60°C , 80°C , 100°C , or 120°C . In some embodiments, the lubricating composition of the present disclosure has a volume resistivity value of $1.0 \times 10^7 \Omega \cdot \text{cm}$ or greater, $5.0 \times 10^7 \Omega \cdot \text{cm}$ or greater, $1.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, $3.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, or $5.0 \times 10^8 \Omega \cdot \text{cm}$ or greater, as measured by JIS C2101-24 at a temperature of 40°C , 60°C , 80°C , 100°C , or 120°C after aging at 165.5°C for 150 hours in accordance with ISOT protocol.

[0068] In some embodiments, the lubricating composition of the present disclosure has a dielectric breakdown voltage of 20 kV or greater, 30 kV or greater, 40 kV or greater, 50 kV or greater, or 60 kV as measured by ASTM D1816 using a 2 mm electrode gap. In some embodiments, the lubricating composition of the present disclosure has a dielectric breakdown voltage of 5 kV or greater, 10 kV or greater, 15 kV or greater, 20 kV or greater, or 25 kV as measured by ASTM D1816 using a 2 mm electrode gap, after aging at 165.5°C for 150 hours in accordance with ISOT protocol.

[0069] Typically, the presence of metals can decrease volume resistivity and thus is desirable to minimize the use of metal-containing additive such as ZnDTP and MoDTC in electric vehicle lubricants.

[0070] In some embodiments, the lubricating composition of the present disclosure is substantially free of zinc.

[0071] In order to meet desired antiwear and frictional properties, lubricating compositions for electric vehicles may contain phosphorus and/or sulfur-phosphorus additives that impart antiwear properties. In some embodiments, the lubricating composition of the present disclosure contains metal-free phosphorus and/or sulfur-phosphorus antiwear agents.

[0072] In some embodiments, the lubricating composition of the present disclosure contains about 50 ppm to about 2000 ppm, about 100 ppm to about 1500 ppm, about 100 ppm to about 1200 ppm, about 100 ppm to about 1000 ppm, about 150 ppm to about 1000 ppm, about 200 ppm to about 1000 ppm,

about 250 ppm to about 1000 ppm, about 250 ppm to about 900 ppm, about 300 ppm to about 800 ppm, about 350 ppm to about 700 ppm, or about 400 ppm to about 700 ppm of phosphorus.

[0073] In some embodiments, the lubricating composition of the present disclosure contains about 100 ppm to about 1500 ppm of phosphorus. In some embodiments, the lubricating composition of the present disclosure contains about 200 ppm to about 1000 ppm of phosphorus. In some embodiments, the lubricating composition of the present disclosure contains about 300 ppm to about 800 ppm of phosphorus. In some embodiments, the lubricating composition of the present disclosure contains about 400 ppm to about 700 ppm of phosphorus.

[0074] The lubricating composition of the present disclosure is suitable for use in EV or HEV with an electric motor or generator. As such, also provided herein is a method of lubricating an EV or HEV with an electric motor or generator, the method comprising supplying to the powertrain a lubricating composition comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

[0075] Also provided herein is a method of reducing wear in an electric vehicle (EV) or a hybrid vehicle (HV) with an electric motor and/or generator, the method comprising lubricating the powertrain with a lubricating composition comprising: (a) a major amount of an oil of lubricating viscosity; (b) about 1.0 wt.% to about 5.0 wt.% of a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid; wherein the lubricating composition is substantially free of zinc; and wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.

Other Additives

[0076] The lubricating compositions of the present disclosure may also contain other additives that can impart or improve any desirable property of the lubricating 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 compositions disclosed herein. Some examples of 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 compositions can be blended with antioxidants, antiwear agents, detergents such as metal detergents, rust inhibitors, dehazing agents, demulsifying agents, metal deactivating agents, friction modifiers, pour point depressants, antifoaming agents, co-solvents, corrosion-inhibitors, dispersants, multifunctional agents, 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 compositions of the disclosure by the usual blending procedures.

Detergents

[0077] In some embodiments, the lubricating composition comprises one or more detergents. Detergents utilized in lubricating compositions generally comprise a polar head with a long hydrophobic, oil-soluble tail where the polar head comprises a metal salt of an organic acid. The salts may comprise a substantially stoichiometric amount of metal to the acid, resulting in neutral detergents with TBN values of between 0 to about 50. When a large amount of excess metal is used, the resulting detergent is overbased, and may have TBN values of 100 or greater. When formulating with detergents, in particular highly overbased detergents which can contribute a significant amount of metals to the formulation, care must be taken to avoid negatively impacting volume resistivity.

[0078] Suitable detergents include oil-soluble overbased sulfonate, non-sulfonate containing phenate, sulfurized phenate, salixarate, salicylate, saligenin, complex detergents and naphthenate detergents and other oil-soluble alkylhydroxybenzoates 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.

Corrosion inhibitors

[0079] In some embodiments, the lubricating composition comprises one or more rust or corrosion inhibitors. Metal passivators are a type of corrosion inhibitor that binds to the surface of a metal to form a protective film, thereby passivating the metal surface.

[0080] Suitable examples of rust or corrosion inhibitors include ether amines, polyethoxylated compounds, mono- and polycarboxylic acids derived from fatty acids, and the like. Suitable examples of metal passivators include thiazoles, triazoles, and thiadiazoles such as benzotriazole, tolyltriazole, decyltriazole, dodecyltriazole, 2-mercaptobenzotriazole, 2,5-dimercapto-1,3,4-thiadiazoles, and the like.

Dispersants

[0081] In some embodiments, the lubricating composition comprises one or more additional dispersants. Suitable dispersants may include hydrocarbyl succinimides, mixed ester/amides of hydrocarbyl-substituted succinic acid, hydroxyesters of hydrocarbyl-substituted succinic acids, and Mannich condensation products of hydrocarbyl-substituted phenols, formaldehydes, and polyamines. Also suitable are condensation products of polyamines and hydrocarbyl-substituted phenyl acids. Mixtures of these dispersants can also be used.

[0082] Suitable examples of dispersants may be bis-succinimide dispersants derived from polyalkenyl succinic anhydrides, such as polyisobutyl succinic anhydride (PIBSA).

[0083] The dispersant may also be post-treated by conventional methods by reaction with any of a variety of agents. Among these agents are boron compounds (e.g., boric acid) and cyclic carbonates (ethylene carbonate).

Antiwear agents

[0084] In some embodiments, the lubricating composition comprises one or more antiwear agents. Suitable examples of antiwear agents include metal thiosphosphates, metal dialkyldithiophosphates,

phosphoric acid esters or salts thereof, phosphate esters, phosphites, phosphonates, sulfurized olefins, thiocarbamate-containing compounds including, thiocarbamate esters, alkylene-coupled thiocarbamates, and bis(S-alkyldithiocarbamyl) disulfides.

Friction Modifiers

[0085] In some embodiments, the lubricating composition comprises one or more friction modifiers. Suitable friction modifiers may comprise metal containing and metal-free friction modifiers and may include, but are not limited to, imidazolines, aliphatic fatty acid amides, aliphatic amines, succinimides, alkoxyated aliphatic amines, ether amines, alkoxyated ether amines, amine oxides, amidoamines, nitriles, betaines, quaternary amines, imines, amine salts, amino guanidine, alkanolamides, phosphonates, metal-containing compounds, glycerol esters, sulfurized fatty compounds and olefins, sunflower oil other naturally occurring plant or animal oils, dicarboxylic acid esters, esters or partial esters of a polyol and one or more aliphatic or aromatic carboxylic acids, and the like. As metal species can negatively impact volume resistivity, it is desirable to minimize the amount of metal-containing friction modifiers in lubricating compositions for EVs and other applications where the lubricant may come into contact with electrical components.

Antioxidants

[0086] In some embodiments, the lubricating composition comprises one or more antioxidants. Suitable antioxidants include alkylated phenols or diarylamines, as well as sulfur-containing antioxidants. Suitable examples of phenolic antioxidants include 2,6-di-*tert*-butylphenol, mixtures of *tert*-butylated phenols, 2,6-di-*tert*-butyl-4-methylphenol, 4,4'-methylenebis(2,6-di-*tert*-butylphenol), 2,2'-methylenebis(4-methyl-6-*tert*-butylphenol), and mixed methylene-bridged polyalkyl phenols, and 4,4'-thiobis(2-methyl-6-*tert*-butylphenol). Examples of aminic antioxidants include 3-hydroxydiphenylamine, *N*-phenyl-1,2-phenylenediamine, *N*-phenyl-1,4-phenylenediamine, mono/dibutyldiphenylamine, mono/dioctyldiphenylamine, mono/dinonyldiphenylamine, mono/ditetradecyldiphenylamine, phenyl- α -naphthylamine, and the like. Exemplary sulfur containing antioxidants include, sulfurized olefins derived from C₄-C₂₅ alpha-olefins and a sulfur source such as elemental sulfur, sulfur monochloride, sulfur dichloride, sodium sulfide, sodium polysulfide, and combinations thereof.

Foam inhibitors

[0087] In some embodiments, the lubricating composition comprises one or more foam inhibitors. Foam inhibitors are used to reduce or prevent stable foams in the lubricating composition, and includes silicon-based polymers such as polysiloxanes. Other suitable examples of foam inhibitors include non-silicon-based organic polymers such as polyacrylates such as ethyl acrylate/2-ethylhexylacrylate copolymers.

Seal Swell Agents

[0088] In some embodiments, the lubricating composition comprises one or more seal swell agents. Seal swell agents are used to condition hard or shrunken seals and gaskets to prevent leakage. Suitable

seal swell agents include esters, adipates, sebacates, azealates, phthalates, sulfones, alcohols, alkylbenzenes, and substituted sulfolanes.

Viscosity Modifiers

[0089] In some embodiments, the lubricating composition comprises one or more viscosity modifiers. Suitable viscosity modifiers may include polyolefins, olefin copolymers, ethylene/propylene copolymers, polyisobutenes, hydrogenated styrene-isoprene polymers, styrene/maleic ester copolymers, hydrogenated styrene/butadiene copolymers, hydrogenated isoprene polymers, alpha-olefin maleic anhydride copolymers, polymethacrylates, polyacrylates, polyalkyl styrenes, hydrogenated alkenyl aryl conjugated diene copolymers, or mixtures thereof.

[0090] In the preparation of lubricating formulations, it is common practice to introduce the additives in the form of about 10 wt. % to about 100 wt. % active ingredient concentrates in hydrocarbon oil, e.g. mineral lubricating oil, or other suitable solvent.

[0091] Usually these concentrates may be diluted with about 3 to about 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.

[0092] 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.

[0093] In general, the concentration of each of the additives in the lubricating composition, when used, may range from about 0.001 wt. % to about 20 wt. %, from about 0.01 wt. % to about 15 wt. %, from about 0.1 wt. % to about 10 wt. %, from about 0.005 wt.% to about 5 wt.%, or from about 0.1 wt.% to about 2.5 wt.%, based on the total weight of the lubricating composition. Further, the total amount of the additives in the lubricating 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 composition.

EXAMPLES

[0094] The following examples are intended for illustrative purposes only and do not limit in any way the scope of the present disclosure.

[0095] A general synthesis of the phosphorylated dispersant is described in PCT Patent Application No. WO 2023/156989 which is herein incorporated by reference in its entirety.

[0096] Examples 1 and 2 contain phosphorylated dispersant, which is a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid. The bis-succinimide was synthesized from polyisobutylene succinic anhydride (PIBSA) with a molecular weight of about 550 g/mol and diethylenetriamine (DETA). The bis-succinimide was then treated with dialkyl dithiophosphoric acid

derived from a mixture of 2-butanol and 2-methylpentanol. The phosphorylated dispersant contains 1.65 wt.% of phosphorus and 3.18 wt.% of sulfur.

[0097] Comparative examples 1 and 2 contain primary or secondary ZnDTP. Comparative examples 3 contains di(2-ethylhexyl)dithiophosphate.

[0098] All examples additionally contain 2.8 wt.% of a viscosity modifier and 7.0 wt.% total of other additives, including corrosion inhibitor, borated dispersant, metal detergent, antioxidant, friction modifier, foam inhibitor, and seal swell agent. The remainder of the lubricating composition comprises Group 2 base oil.

[0099] The following examples were formulated according to the amounts and concentrations provided in Table 1.

FZG step load Test (A10/16.6R/90:120, CEC L-84-02)

[0100] In the FZG Step Load test, a defined load is applied to a pair of spur wheels, which is increased after a certain run time. After each load stage (12 load stages in total), the gear wheels are inspected visually, and wear is measured. If wear exceeds a certain limit, the test is terminated, and the last load stage documented as scuffing load step conditions. The FZG Step Load Test (FZG (A10/16.6R/90)), also known as CEC L-84-02, is particularly demanding on lubricating oils as the sense of rotation is reversed (gear wheel driving the pinion) and a narrower pinion is used (A10). This change of operating conditions increases pressure and makes it more difficult for the lubricant to reach the friction points.

[0101] This test procedure is for industrial or automotive gear lubricants that exceed the load-carrying capacity of the standard FZG load stage test (A20/8.3/90).

[0102] The smaller 10 mm wide gears were run in the reverse direction at 2910 rpm through a dozen 7.5-minute stages with incremental increases in load until failure or until the test sequence was complete. The test was run at 90 °C (194 °F) for the lubricating compositions provided in Table 1. Ten millimeters of tooth scuffing indicates test failure. A pass in load stage nine at 90 °C (194 °F) indicates GL-5 or better performance. The results are provided in Table 1.

Table 1

Additive (wt.%)	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3	Ex. 1	Ex. 2
Viscosity modifier	2.8	2.8	2.8	2.8	2.8
Other additives	7.0	7.0	7.0	7.0	7.0
Phosphorylated dispersant	0	0	0	1.897	3.109
Secondary ZnDTP	0.435	0	0	0	0
Primary ZnDTP	0	0.430	0	0	0
di(2-ethylhexyl) dithiophosphate	0	0	0.356	0	0

FZG Step Load					
A10/16.6R/90, Fail Load Stage	5	4	4	6	7

Volume Resistivity

[0103] The electrical insulating ability of the lubricating oil compositions was determined in accordance with JIS C2101-24. The volume resistivity of the test oils was measured and reported in units of $\Omega \cdot \text{cm}$. Fresh oil samples were measured in accordance with JIS C2101-24 at 40 °C, 60 °C, 80 °C, 100 °C, and 120 °C. The samples were also aged at 165.5 °C for 150 hours in accordance with a modified Indiana Stirring Oxidation Test (ISOT) protocol JIS K2514-4, and evaluated for volume resistivity. The measured volume resistivity values are provided in Table 1.

Breakdown Voltage

[0104] The dielectric breakdown voltage of an insulating liquid is of importance as a measure of the liquid's ability to withstand electric stress without failure. The breakdown voltage was measured in accordance with ASTM D1816. A test cell is filled with the sample fluid, and two electrodes are submerged into the fluid, spaced at either 1 mm or 2 mm apart. Increasing voltage is applied a rate of 0.5 kV/s $\pm$ 5% until breakdown occurs as indicated by operation of the circuit-interrupting equipment. The highest rms voltage value that occurred immediately prior to each breakdown is reported.

[0105] The breakdown voltage of each sample was measured at room temperature with 2 mm electrode gap spacing, and averaged over 5 runs. The average value of the fresh oil sample as well as aged oil sample (aged at 165.5 °C for 150 hours in accordance with ISOT protocol) are provided in Table 2.

Table 2

	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3	Ex. 1	Ex. 2
Volume resistivity					
$\Omega \cdot \text{cm}$ Fresh oil 40 °C	-	-	-	3.3E+09	1.3E+09
$\Omega \cdot \text{cm}$ Fresh oil 60 °C	-	-	-	2.5E+09	8.3E+08
$\Omega \cdot \text{cm}$ Fresh oil 80 °C	-	-	-	1.1E+09	5.0E+08
$\Omega \cdot \text{cm}$ Fresh oil 100 °C	-	-	-	7.0E+08	3.7E+08
$\Omega \cdot \text{cm}$ Fresh oil 120 °C	-	-	-	4.5E+08	2.9E+08
$\Omega \cdot \text{cm}$ Aged oil 40 °C	-	-	-	9.74E+08	8.34E+08
$\Omega \cdot \text{cm}$ Aged oil 60 °C	-	-	-	6.48E+08	4.20E+08
$\Omega \cdot \text{cm}$ Aged oil 80 °C	-	-	-	3.59E+08	2.28E+08

$\Omega \cdot \text{cm}$ Aged oil 100 °C	-	-	-	2.67E+08	1.51E+08
$\Omega \cdot \text{cm}$ Aged oil 120 °C	-	-	-	2.10E+08	1.01E+08
Breakdown voltage					
kV (2mm gap, RT, average)	-	-	-	43.7	60.9
kV Aged oil (2mm gap, RT, average)	-	-	-	20.9	26.9

[0106] The examples containing phosphorylated dispersants exhibited higher scores in the FZG step load test, compared to the examples containing ZnDTP or di(2-ethylhexyl) dithiophosphate. In addition, the examples exhibited suitable volume resistivity and dielectric breakdown voltage values both before and after aging.

[0107] 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.

[0108] 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.

[0109] 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.

[0110] The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments.

[0111] 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 subcombination. 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.

What is claimed is:

1. A lubricating composition for an electrical vehicle (EV) or hybrid electric vehicle (HEV) with an electric motor and/or generator, comprising:
 - (a) a major amount of an oil of lubricating viscosity;
 - (b) about 0.5 wt.% to about 5.0 wt.% of a phosphorylated dispersant, which is a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid;wherein the lubricating composition is substantially free of zinc;
wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.
2. The lubricating composition of claim 1, wherein the bis-succinimide is derived from polyisobutylene having a number average molecular weight of 900 g/mol or less.
3. The lubricating composition of claim 1, wherein the bis-succinimide is derived from polyisobutylene having a number average molecular weight of between 400 g/mol to 700 g/mol.
4. The lubricating composition of claim 1, wherein the dialkyl dithiophosphoric acid is derived from C₂-C₁₂ alcohols.
5. The lubricating composition of claim 5, wherein the dialkyl dithiophosphoric acid is derived from *n*-butanol, 2-butanol, *n*-hexanol, 2-methylpentanol, *n*-octanol, 2-ethylhexanol, nonanol, decanol, undecanol, lauryl alcohol (dodecanol), or mixtures thereof.
6. The lubricating composition of claim 1, wherein the phosphorylated dispersant provides at least 300 ppm of sulfur to the lubricating composition.
7. The lubricating composition of claim 1, wherein the phosphorylated dispersant contains about 0.5 wt.% to about 6.0 wt.% of sulfur.
8. The lubricating composition of claim 1, wherein the phosphorylated dispersant provides at least 100 ppm of phosphorus to the lubricating composition.
9. The lubricating composition of claim 1, wherein the lubricating composition contains about 100 ppm to about 1500 ppm of phosphorus.
10. The lubricating composition of claim 1, wherein the lubricating composition contains about 300 ppm to about 800 ppm of phosphorus.

11. The lubricating composition of claim 1, wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C after the fluid has been aged at 165.5 °C for 150 hours according to ISOT protocol JIS K2514-4.
12. The lubricating composition of claim 1, wherein the dielectric breakdown voltage of the lubricating composition, as determined by ASTM D1816, is at least 40 kV.
13. A method of reducing wear in an electric vehicle (EV) or a hybrid vehicle (HV) with an electric motor and/or generator, the method comprising lubricating the powertrain with a lubricating composition comprising:
- (a) a major amount of an oil of lubricating viscosity;
 - (b) about 0.5wt.% to about 5.0 wt.% of a reaction product of a bis-succinimide and a dialkyl dithiophosphoric acid;
- wherein the lubricating composition is substantially free of zinc; and
- wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C.
14. The method of claim 13, wherein the bis-succinimide is derived from polyisobutylene having a number average molecular weight of 900 g/mol or less.
15. The method of claim 14, wherein the bis-succinimide is derived from polyisobutylene having a number average molecular weight of between 400 g/mol to 700 g/mol.
16. The method of claim 14, wherein the dialkyl dithiophosphoric acid is derived from $\text{C}_2\text{-C}_{12}$ alcohols.
17. The method of claim 16, wherein the dialkyl dithiophosphoric acid is derived from *n*-butanol, 2-butanol, *n*-hexanol, 2-methylpentanol, *n*-octanol, 2-ethylhexanol, nonanol, decanol, undecanol, lauryl alcohol (dodecanol), or mixtures thereof.
18. The method of claim 14, wherein the phosphorylated dispersant provides at least 300 ppm of sulfur to the lubricating composition.
19. The method of claim 14, wherein the volume resistivity of the lubricating composition, as determined by JIS C2101-24, is $1 \times 10^8 \Omega \cdot \text{cm}$ or greater at 120 °C after the fluid has been aged at 165.5 °C for 150 hours according to ISOT protocol JIS K2514-4.
20. The method of claim 14, wherein the dielectric breakdown voltage of the lubricating composition, as determined by ASTM D1816, is at least 40 kV.