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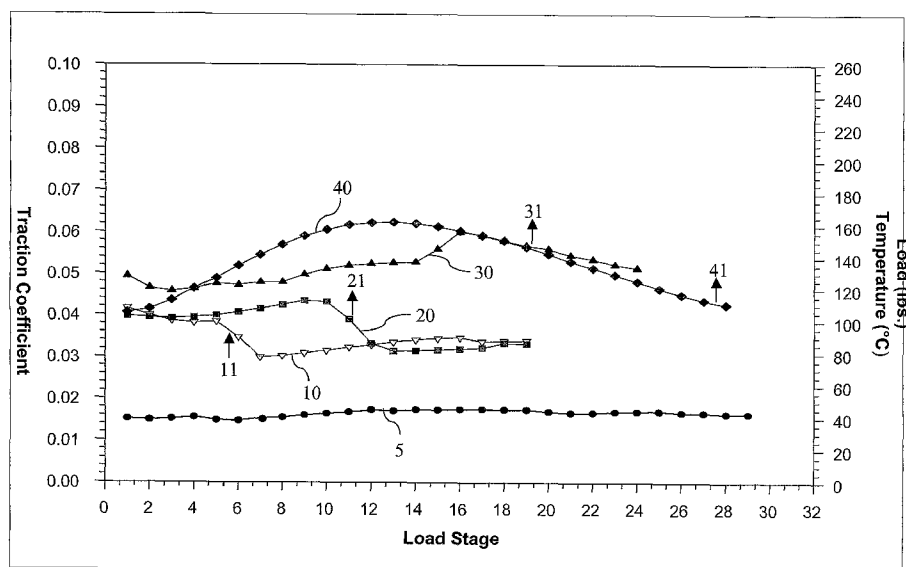
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(54) Title: LUBRICANT ADDITIVE PACKAGES FOR IMPROVING LOAD-CARRYING CAPACITY AND SURFACE FATIGUE LIFE



(57) Abstract: The present invention provides a multifunctional lubricant additive package or composition for improving load-carrying capacity, pressure resistance, surface fatigue life, and other performance characteristics of a lubricant or base oil. The composition typically includes four components: (a) an alkyl or aryl neutral phosphate, (b) a long-chain organic partial ester, (c) an aryl or alkyl phosphite, and (d) a phenol group. The present invention further provides a multifunctional lubricant having improved performance characteristics, which are obtained by mixing a lubricant with the above-described multifunctional lubricant additive package or composition.

WO 2007/001443 A2

## **LUBRICANT ADDITIVE PACKAGES FOR IMPROVING LOAD-CARRYING CAPACITY AND SURFACE FATIGUE LIFE**

### **CROSS-REFERENCE TO RELATED APPLICATIONS**

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The present application claims the benefit of U.S. Provisional Application No. 60/625,416 filed November 4, 2004, and is related to the following co-pending and commonly-owned applications which were filed herewith and are hereby incorporated by reference in full: "Multifunctional Lubricant Additive Package" (Attorney Docket No. 0002291WOU, EH-11679), U.S. Serial No. \_\_\_\_\_; "Lubricants Containing Multifunctional Additive Packages Therein for Improving Load-Carrying Capacity, Increasing Surface Fatigue Life and Reducing Friction" (Attorney Docket No. 0002294WOU, EH-11697), U.S. Serial No. \_\_\_\_\_; and "Multifunctional Lubricant Additive Package for a Rough Mechanical Component Surface" (Attorney Docket No. 0002295WOU, EH-11698), U.S. Serial No. \_\_\_\_\_.

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### **GOVERNMENT RIGHTS IN THE INVENTION**

The invention was made by, or under contract with the National Institute of Standards and Technology of the United States Government under contract number: 70NANB0H3048.

25

### **BACKGROUND OF THE INVENTION**

#### **1. Field of the Invention**

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The present invention relates to a multifunctional lubricant additive composition or package for improving the performance characteristics of a lubricant. More particularly, the present invention relates to a multifunctional lubricant additive composition or package for providing a lubricant with superior performance characteristics such as improved load-carrying ability, anti-scuffing (anti-scoring) capacity, friction reduction, and improved surface-fatigue life.

## 2. Description of Related Art

Mechanical systems such as manual or automatic transmissions; single and multi-speed aviation transmissions, including but not limited to those used to propel rotorcraft and those used to alter the rotational speed of sections within gas turbine engines; push-belt type continuous variable transmissions; and traction drive continuous variable transmissions, have large surface areas of contact zones. These contact portions or zones, such as drive rolling surfaces, and gear and ball-and roller bearings, are known to be susceptible to high surface pressures. In addition, internal combustion engines and other propulsion devices, especially those that are common for high-performance and racing applications, are subject to taxing demands in the form of inertial loading, high sliding and/or rolling speeds, and marginal lubrication. Moreover, the need for reducing friction resistance and fatigue within larger contact zones of mechanical systems is increased by many recently developed transmission systems that are designed to be miniaturized or weight-reduced to maximize transmission throughput capacity.

To address these severe application demands, lubricants, especially those containing specific additives, play a critical role in protecting and minimizing the wear and scuffing (scoring) of surfaces. The lubricants generally reduce principal damage accumulation mechanisms of lubricated components caused by surface fatigue and overloading.

Examples of known lubricants are discussed in the following publications, which are hereby incorporated in full by reference: Phillips, W. D., Ashless phosphorus-containing lubricating oil additives; Lubricant Additives Chemistry and Application 45-111 (L. R. Rudick, Marcel Dekker, Inc. 2003); and Kenbeck, D., and T. F. Buenemann, Organic Modifiers; Lubricant Additives Chemistry and Application 203-222 (L. R. Rudick, Marcel Dekker, Inc. 2003).

Recently developed system-optimization approaches for increasing overall power throughput of mechanical systems underscore the need for new and better performing lubricant additives. By reducing friction, wear, and pressure, and improving scoring resistance, these additives prolong surface fatigue life for lubricated contacts within transmission systems and propulsive devices.

The present invention provides lubricant additives for improving the performance characteristics (i.e, load-carrying capacity and/or surface fatigue life, etc.) of mechanical systems. Combining the additive compositions provided by this invention with lubricant stocks, and optionally other additives, results in a fully formulated lubricant with many performance advantages such as reduction in friction and wear and increase in surface fatigue life.

#### **SUMMARY OF THE INVENTION**

The present invention provides lubricant additives comprising elements or components that are intended to enhance the performance characteristics, such as scuffing (scoring) resistance and surface-fatigue life of a lubricant base stock or fully formulated lubricant including anti-wear (AW), extreme pressure (EP), and friction modifying (FM) compositions.

In a preferred embodiment, this invention provides a multifunctional lubricant additive composition for improving the performance characteristics of a natural or synthetic lubricant for use in transmission fluid products that meet both civil and military specifications.

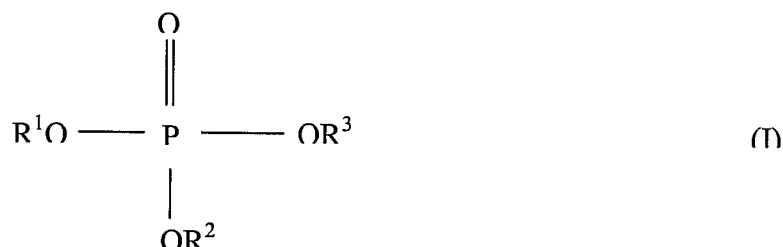
In another embodiment, the present invention provides a multifunctional composition for use in improving the performance of metals and alloys of power transmission components, including but not limited to gears, bearings, splines, shafts and springs.

In another embodiment, this invention provides a multifunctional lubricant additive composition for improving the performance characteristics of engines and related propulsive devices used to power automobiles, both stock (production) and specialty (e.g. racing and other high performance) varieties, and heavy on- and off-road equipment, such as farm implements and construction equipment.

In another embodiment, the present invention provides a multifunctional lubricant additive composition capable of being combined with lubricant stocks and other additives to produce a fully formulated lubricant that beneficially reduces friction and scuffing (scoring), and improves resistance to surface damage and surface degradation through fatigue, including micro- and macro-pitting, and wear.

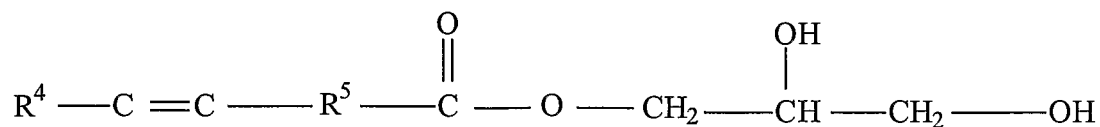
In yet another embodiment, the present invention provides a multifunctional lubricant additive composition, for improving the performance characteristics of a lubricant, which includes one or more of the following components:

(a) a compound consisting of an aryl or alkyl neutral phosphate having the general formula:



wherein  $\text{R}^1$ ,  $\text{R}^2$ , and  $\text{R}^3$  are each  $\text{C}_n\text{H}_{2n+1}$  alkyl groups of an alkyl neutral phosphate or  $(\text{C}_6\text{H}_5\text{C}_m\text{H}_{2m+1})$  aryl groups of an aryl neutral phosphate,  $n$  is an integer of about  $2 \leq n \leq 10$ ,  $m$  is an integer of about  $0 \leq m \leq 8$ ;

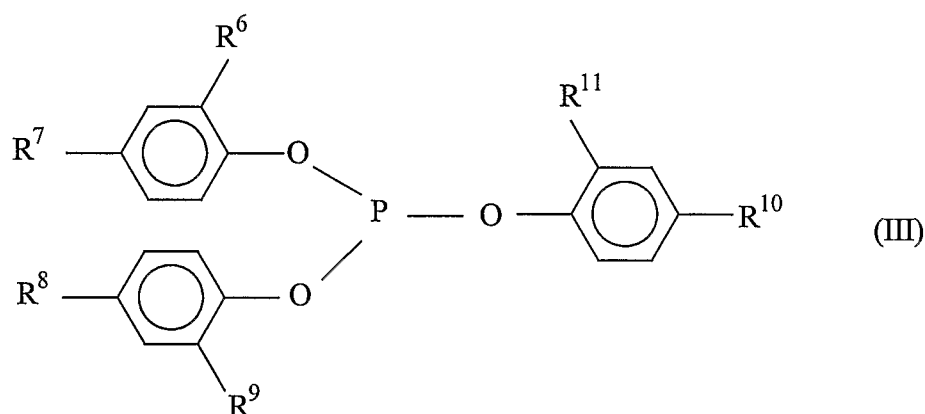
(b) a long-chain organic partial ester having the general formula:



(II)

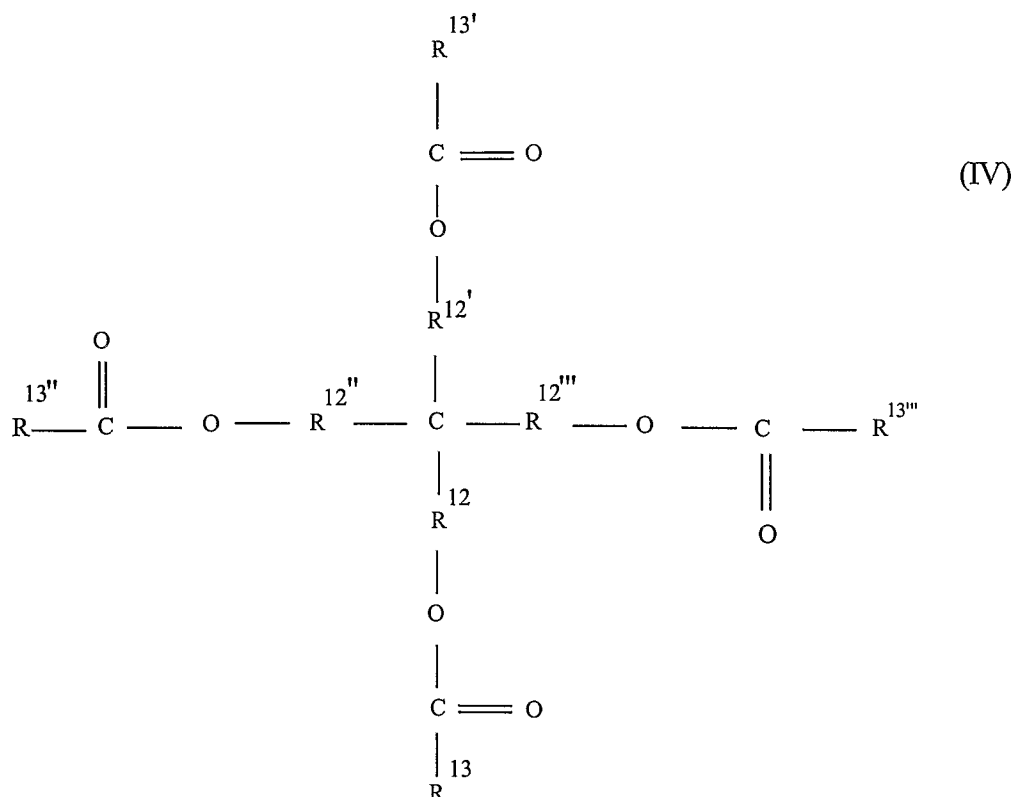
wherein  $R^4$  and  $R^5$  are each  $C_iH_{2i+1}$  alkyl groups and  $i$  is an integer of about  $7 \leq i \leq 15$ ;

(c) an aryl or alkyl phosphite having the general formula:

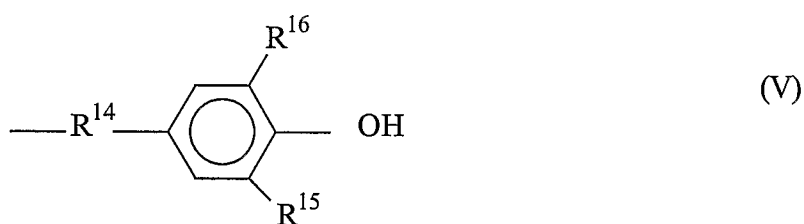


wherein  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ , and  $R^{11}$  are each  $C_jH_{2j+1}$  alkyl groups preferably having tertiary structures, wherein  $j$  is an integer of about  $1 \leq j \leq 20$ ; and

(u) a phenol compound having the general formula:



wherein  $\text{R}^{12}$ ,  $\text{R}^{12'}$ ,  $\text{R}^{12''}$ , and  $\text{R}^{12'''}$  are each  $\text{C}_p\text{H}_{2p+1}$  alkyl groups, and  
 5  $p$  is an integer of about  $1 \leq p \leq 12$ ; wherein  $\text{R}^{13}$ ,  $\text{R}^{13'}$ ,  $\text{R}^{13''}$ , and  $\text{R}^{13'''}$  are  
 each a phenol group represented by the formula:



wherein  $\text{R}^{14}$ ,  $\text{R}^{15}$ , and  $\text{R}^{16}$  are each a  $\text{C}_o\text{H}_{2o+1}$  alkyl group and  $o$  is an  
 10 integer of about  $1 \leq o \leq 20$ , wherein  $\text{R}^{15}$  and  $\text{R}^{16}$  are preferably tertiary  
 structures.

The present invention also provides a method for improving the performance characteristics (i.e, load-carrying capacity and/or surface fatigue life, etc.) of a lubricant. The method includes mixing a lubricant with one of the above-described multifunctional lubricant additive compositions.

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### **BRIEF DESCRIPTION OF THE DRAWING**

The figure shows the relationship between the average traction (friction) coefficient and average failure load stage for various lubricants.

10 The vertical arrows 11, 21, 31, 41 indicate the average scuffing (scoring) failure load stage (load-carrying capacity) of the Hatco HXL-7944 oil, Formulation #1, Exxon-Mobil Jet Oil II, and Formulation #2, respectively. "Load stage" in this context is a numerical value that is proportional to the force applied between the rotating ball and the rotating disc. A higher

15 scuffing (scoring) failure load stage indicates greater load-carrying capacity of the lubricant. The results of a polished surface with standard lubricant are indicated by line 5; the results of the Hatco HXL-7994 oil are indicated by line 10; the results of Formulation #1 of this invention are indicated by line 20; the results of Exxon-Mobil Jet Oil II are indicated by line 30; and the

20 results of Formulation #2 of this invention are indicated by line 40.

### **DETAILED DESCRIPTION OF THE INVENTION**

The present invention provides a multifunctional lubricant

25 composition for improving the performance characteristics of a lubricant, especially the lubricant's ability to enhance surface fatigue life and/or load-carrying capacity (i.e, scuffing or scoring performance) of mechanical components. The composition includes one or more of the following additive components (or, in some embodiments, each of the following

30 components): (a) an antiwear additive (AW) such as an aryl or alkyl neutral phosphate represented by the general formula (I); (b) a friction modifier (FM) such as an aryl or alkyl neutral phosphate as represented by the general formula (II); an extreme pressure additive (EP) of the mixture of (c)

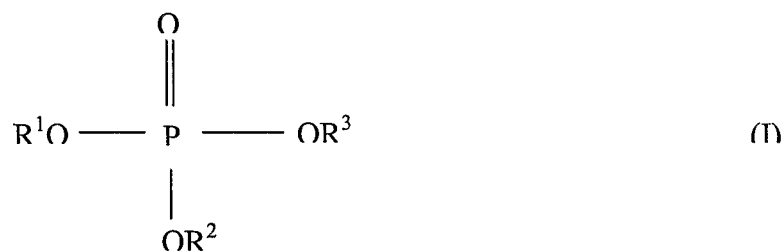
an aryl or alkyl phosphite as represented by the general formula (III) and (d) a phenol compound as represented by general formula (IV). The total amount of additives (a) – (d) is preferably about 10% by mole or less based on the total amount of lubricant.

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The combination of the above-noted additive components results in a lubricant that performs in a synergistic manner, such that deleterious competition among additive components is avoided.

10 The above components of the lubricant composition are further described below. In one non-limiting embodiment, the composition includes the following:

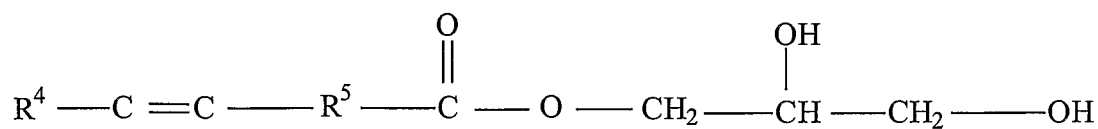
(a) an aryl or alkyl neutral phosphate having the general formula:



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wherein  $\text{R}^1$ ,  $\text{R}^2$ , and  $\text{R}^3$  are each independently  $\text{C}_n\text{H}_{2n+1}$  alkyl groups of an alkyl neutral phosphate or  $(\text{C}_6\text{H}_5\text{C}_m\text{H}_{2m+1})$  aryl groups of an aryl neutral phosphate,  $n$  is an integer of about  $2 \leq n \leq 10$ , preferably about  $4 \leq n \leq 6$ ,  
 20  $m$  is an integer of about  $0 \leq m \leq 8$ , preferably about  $1 \leq m \leq 5$ ;

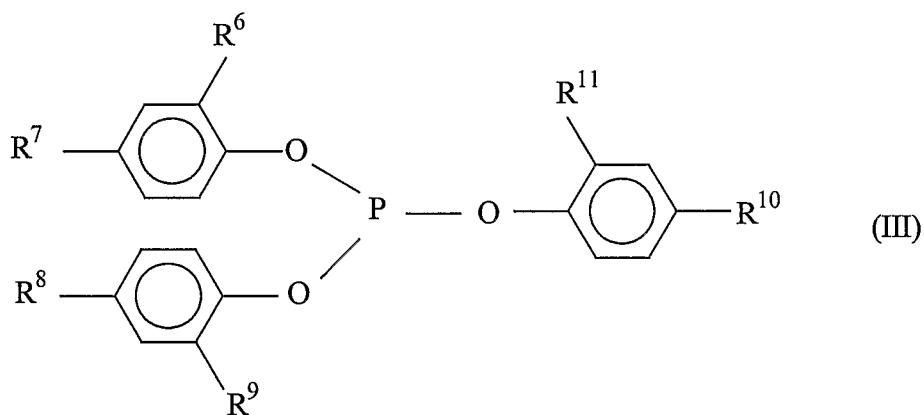
(b) a long-chain partial organic ester having the general formula:



(II)

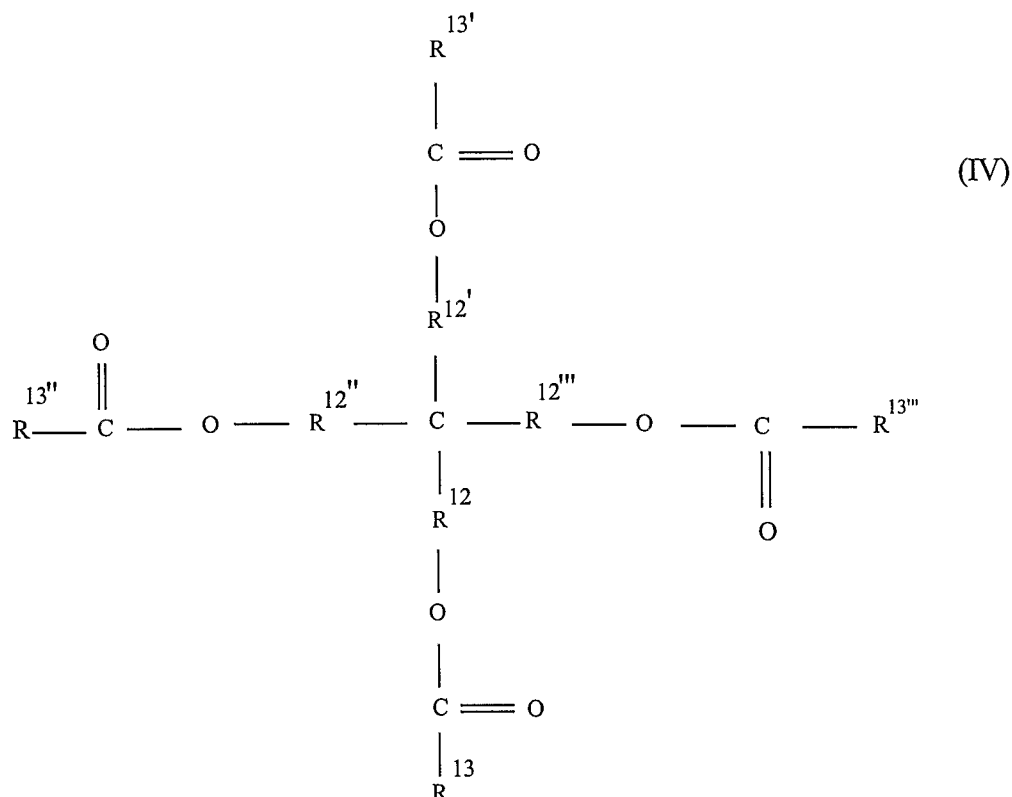
wherein  $R^4$  and  $R^5$  are each independently a normal  $C_iH_{2i+1}$  alkyl groups  
 5 and  $i$  is an integer of about  $7 \leq i \leq 15$ , preferably about  $8 \leq i \leq 10$ ;

(c) an aryl or alkyl phosphite having the general formula:

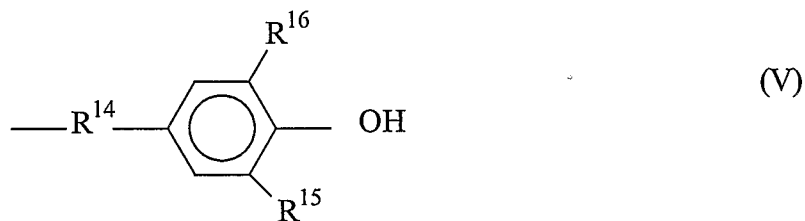


10 wherein  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ , and  $R^{11}$  are each independently  $C_jH_{2j+1}$  alkyl groups, wherein  $j$  is an integer of about  $1 \leq j \leq 20$ , preferably about  $4 \leq j \leq 8$ , preferably the alkyl groups exhibit tertiary structures; and

(a) a phenol compound-having the general formula:



wherein  $R^{12}$ ,  $R^{12'}$ ,  $R^{12''}$ , and  $R^{12'''}$  are each independently a normal  
 5 alkyl group,  $C_pH_{2p+1}$ , and  $p$  is an integer of about  $1 \leq p \leq 12$ , preferably  
 about  $1 \leq p \leq 5$ ; wherein  $R^{13}$ ,  $R^{13'}$ ,  $R^{13''}$ , and  $R^{13'''}$  are each independently a  
 phenol group represented by the general formula:



10 wherein R<sup>14</sup>, R<sup>15</sup>, and R<sup>16</sup> are each independently a normal C<sub>o</sub>H<sub>2o+1</sub> alkyl group and o is an integer of about 1 ≤ o ≤ 20, preferably about 2 ≤ o ≤ 12, wherein R<sup>15</sup> and R<sup>16</sup> preferably are tertiary structures or exhibit such a form.

In embodiments, the aryl or alkyl neutral phosphate of component (a) is present in a concentration of about 0.1% to 5% by mole, preferably about 0.2% to 2% by mole, based on the total amount of lubricant. A non-limiting example of an aryl neutral phosphate is tricresyl phosphate.

In embodiments, the long-chain partial ester of component (b) is present in a concentration from about 0.2% to 6% by mole, preferably about 0.6% to 2% by mole, based on the total amount of lubricant. A non-limiting example of a long chain partial ester is glycerol monooleate.

In embodiments, the aryl or alkyl phosphite of component (c) is present in a concentration of about 0.05% to 4.5 % by mole, preferably about 0.18% to 1.8% by mole, based on the total amount of lubricant. A non-limiting example of an aryl phosphite is tris-(2,4- di-tertiary-butyl-phenyl) phosphite.

In embodiments, the phenol compound of component (d) is present in a concentration of about 0.005% to 1% by mole, preferably about 0.02% to 0.3% by mole, based on the total amount of the lubricant. A non-limiting example of a phenol compound is tetrakis-(methylene-3,5-ditert-butyl-4-hydroxy hydrocinnamate) methane.

In embodiments, the total concentration of all four additives (a) - (d) combined is about 10% or less by mole based on the total amount of lubricant.

Lubricants that the present invention can improve include, but are not limited to, gear oil, bearing oil, sliding surface lubrication oil, chain lubricating oil, and engine oil. In a preferred embodiment, various types of lubricants, greases, especially synthetic polyol ester (POE) based lubricants, can be used as the lubricating materials. A skilled artisan will recognize that the embodiments of this invention are not limited to the

above oils or the polyol ester type, but also apply to other compositions and oils including but not limited to greases, mineral oil based lubricants (hydrocarbon-based), polyalkylene glycol (PAG), aromatic naphthalene (AN), alkyl benzenes (AB), and polyalphaolefin (PAO) types.

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The present invention is useful as an additive composition for natural and synthetic aviation (aerospace) and automotive lubricants. Moreover, a combination of the multifunctional additive composition with the above-described lubricants improves transmission power throughput, system power density, surface fatigue life, and load-carrying capacity.

Specific uses also include turbine engine and transmission oils designed to meet government civil (FAA) and military (DoD) specification and requirements. Additional uses of these multifunctional additive compositions include the demonstrated ability to improve scuffing (scoring) performance of metals and alloys that are commonly used for power transmission components, including but not limited to gears, bearing, splines shafts, and springs. As such, these improvements decrease the incidence of component and system failure and rejection during customer acceptance test protocols (ATPs). These additive compositions also improve resistance to surface degradation, including surface fatigue, and reduce the rate of component and system degradation due to wear and other phenomena.

In another embodiment, the present invention provides a method of improving the performance characteristics of a lubricant. The method comprises the step of:

mixing a lubricant with a multifunctional lubricant additive composition that includes at least one of components (a) - (d) of the above-described lubricant additive composition thereby producing a fully formulated improved lubricant. For this embodiment, the molar concentration of additive components (a) - (d) may be varied to achieve a

## Formulation #2

In this embodiment, a multifunctional additive package was added to Exxon-Mobil Jet Oil II (a standard version of MIL-PRF-23699, a 5 cSt gas turbine oil) to create Formulation #2. Formulation #2 contained the following additives:

|              | Additive                                                                       | Mole % | Supplier        |
|--------------|--------------------------------------------------------------------------------|--------|-----------------|
| Compound (b) | Glycerol Monooleate                                                            | 1.0    | Crompton        |
| Compound (c) | Tris-(2,4-di-tertiary-butyl-phenyl) Phosphite                                  | 0.45   | Strem Chemicals |
| Compound (d) | Pentaerythritol Tetrakis-(methylene-3,5-di-tert-butyl-4-hydroxyhydrocinnamate) | 0.05   | Sigma-Aldrich   |

Exxon-Mobil Jet Oil II contains tricresyl phosphate, which is one example of compound (a). Therefore, it was not necessary to add any additional compound (a) to Formulation #2. Exxon-Mobil Jet Oil II typically has excellent lubricant performance compared to other brands and versions of MIL-PRF-23699 oil. This multifunctional additive package increased the load carrying capacity (i.e., scuffing or scoring performance) of the Exxon-Mobil Jet Oil II by a factor of about 1.43 times. Additionally, the components that were tested with Formulation #2 had a surface fatigue life of at least about about 2.9 times greater than that of the components that were tested with the Exxon-Mobil Jet Oil II alone (unmodified by any additive package of this invention).

## Experimental Results

### I. Load-Carrying Capacity (Scuffing/Scoring Performance)

The experimental results for the two Formulations of this invention and the two base oils noted above were obtained using a generally accepted modified variation of the Wedeven Associates, Inc. WAM Load Capacity Test Method ("WAM Test"). The WAM Test is designed to

evaluate the load-carrying capacity of lubricants and load bearing surfaces by evaluating the wear, tear, and scuffing (scoring) thereof over a large temperature range.

- 5           Table A below shows a summary of the modified WAM Test conditions that were utilized to test various lubricants of this invention.

**TABLE A.**

---

|                                     |                                 |
|-------------------------------------|---------------------------------|
| Ball: AISI 9310; Ra: 10-12 $\mu$ in | Rolling Velocity: 158 in/sec    |
| Disc: AISI 9310; Ra: 6 $\mu$ in     | Sliding Velocity: 345 in/sec    |
| Ball Velocity: 234 in/sec           | Entraining Velocity: 158 in/sec |
| Disc Velocity: 234 in/sec           | Velocity Vector Angle (Z): 95°  |
| Disc Hardness: 62.5 - 63.5 HRC      | Temperature: Ambient (~22°C)    |
| Ball Hardness: 62.5 - 63.5 HRC      |                                 |

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For a detailed description of the WAM Test, see WAM High Speed Load Capacity Test Method, SAE Aerospace AIR4978, Revision B, 2002, and U.S. Patent No. 5,679,883 to Wedeven, both of which are hereby incorporated in full by reference.

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High load-carrying oils frequently result in test suspension at load stage 30 without a scuffing (scoring) event. To differentiate candidate formulations that reach test suspension, tests can be run with a modified test protocol. The modified protocol operates at a lower entraining velocity  
 20   than the standard test protocol, which reduces the EHD film thickness and increases the test severity by causing greater asperity interaction, essentially operating at a reduced film thickness to surface roughness ( $h/\sigma$ ) ratio. Table A, above, summarizes the test parameters that comprise the more severe, modified WAM test protocol that were applied to evaluate the  
 25   two base (reference) oils and the two Formulations of this invention.

~~The modified test protocol~~ The modified test protocol was developed for high load-carrying oils used for aviation (aerospace) gearboxes. These oils include the DOD-PRF-85734 oils for the U.S. Navy and the Def Stan 91-100 oils for the U.K. Ministry of Defense. With the modified test protocol, the highest load-carrying oils currently used in military aircraft experience scuffing (scoring) failures at load stages that range from approximately 19 to 28.

Using this modified test protocol, it was found that the multifunctional additive package utilized in Formulation #1 increased the load carrying capacity (i.e., scuffing/scoring performance) of the Hatco HXL-7994 oil by a factor of about 1.93 times. As can be seen in the attached figure and Table 1, the Hatco HXL-7994 oil had an average scuffing (scoring) failure load stage of about 5.7 (arrow 11), and Formulation #1 had an average scuffing (scoring) failure load stage of about 11 (arrow 21), which indicates that Formulation #1 has a load carrying capacity about 1.93 times greater than that of the Hatco HXL-7994 oil.

Using this modified test protocol, it was also found that the multifunctional additive package utilized in Formulation #2 increased the load carrying capacity (i.e., scuffing/scoring performance) of the Exxon-Mobil Jet Oil II by a factor of about 1.43 times. As can be seen in the attached figure and Table 2, the Exxon-Mobil Jet Oil II had an average scuffing (scoring) failure load stage of about 19.2 (arrow 31), and Formulation #2 had an average scuffing (scoring) failure load stage of about 27.5 (arrow 41), which indicates that Formulation #2 has a load carrying capacity about 1.43 times greater than that of the Exxon-Mobil Jet Oil II.

TABLE 1.

| Lubricant      | Ball       | Disc/t.d. | Micro-scuff (score) Stage | Macro-scuff (score) Stage | Average Scuffing (Scoring) Failure Stage | Increased Load-Carrying Capacity |
|----------------|------------|-----------|---------------------------|---------------------------|------------------------------------------|----------------------------------|
| Hatco HXL-7944 | UTLCC6-9a  | 9-10a/3.2 | 4                         | 16                        |                                          |                                  |
| Hatco HXL-7944 | UTLCC6-9b  | 9-10a/3.1 | 6                         | 20                        |                                          |                                  |
| Hatco HXL-7944 | UTLCC5-9b  | 9-10a/3.0 | 7,16                      | 17                        | 5.7                                      | 1                                |
| Formulation #1 | UTLCC9-9a  | 9-10b/3.4 | 12                        | 20                        |                                          |                                  |
| Formulation #1 | UTLCC9-9b  | 9-10b/3.5 | 11                        | 20                        |                                          |                                  |
| Formulation #1 | UTLCC11-9a | 9-10b/3.6 | 10                        | 18                        | 11                                       | 1.93                             |

TABLE 2.

5

| Lubricant              | Ball       | Disc/t.d. | Micro-scuff (score) Stage | Macro-scuff (score) Stage | Average Scuffing (Scoring) Failure Stage | Increased Load-Carrying Capacity |
|------------------------|------------|-----------|---------------------------|---------------------------|------------------------------------------|----------------------------------|
| Exxon-Mobil Jet Oil II | SBAD12-9a  | 9-10a/3.7 |                           | 25                        |                                          |                                  |
| Exxon-Mobil Jet Oil II | SBAD12-9b  | 9-10a/3.6 |                           | 15                        |                                          |                                  |
| Exxon-Mobil Jet Oil II | UTLCC3-9a  | 9-10a/3.5 |                           | 24                        |                                          |                                  |
| Exxon-Mobil Jet Oil II | UTLCC3-9b  | 9-10a/3.4 |                           | 25                        |                                          |                                  |
| Exxon-Mobil Jet Oil II | UTLCC5-9a  | 9-10a/3.3 | 7                         | 15                        | 19.2                                     | 1                                |
| Formulation #2         | UTLCC12-9a | 9-10b/3.3 |                           | 27                        |                                          |                                  |
| Formulation #2         | UTLCC12-9b | 9-10b/3.2 |                           | 28                        | 27.5                                     | 1.43                             |

## II. Surface Fatigue Life Measurement by Spur Gear Testing

Spur gear blanks, having a pitch diameter of 4 inches (100 mm), were fabricated from the Carpenter Technology alloy, Pyrowear alloy 53, in vacuum-induction-melted, vacuum-arc-remelted (VIM/VAR) condition. Following rough machining, gear blanks were given a standard heat treatment and carburization cycle and were finish ground to produce gears that conform to minimum standards of AGMA class 12. The arithmetic average surface roughness (Ra) of the spur gear involute surfaces that resulted from the final grinding operation was nominally 16  $\mu\text{in}$ . Following final grinding, some gears were afforded an isotropic superfinishing (ISF) operation to refine the surface finish on the involute surfaces to a nominal arithmetic average value of 2  $\mu\text{in}$ .

Spur gear tests were performed on a "four-square" test machine, in which two pairs of identical, mated gears are exposed to the same conditions of contact stress, rotational speed, oil-film thickness, and oil temperature. The employed test protocol called for experimental conditions to remain imposed on the spur gears until incipient failure was detected by *in situ* accelerometers, in which the accelerometer signal amplitude exceeded a predetermined threshold. Visual examination was used to confirm surface failure of the spur gear involute surface. Specific conditions that were applied for the conducted spur-gear tests included a rotational speed of 3500 min<sup>-1</sup>, an inlet oil temperature of approximately 115°F (46°C), and an oil film thickness of approximately 6 μin (152 nm). Discrete contact stresses of 235 Ksi (1.62 GPa) or 280 Ksi (1.93 GPa) were applied and maintained until surface failure was detected and confirmed. The ball and disc were composed of AISI 9310 and had a surface hardness of Rc 63 (63 HRC).

Results from the spur-gear tests are summarized in Table 3 below. As indicated in Table 3, the average life to surface fatigue failure of as-ground gears lubricated with Formulation #2 at a contact stress of 235 Ksi (1.62 GPa) is a factor of 2.9 times greater than that for as-ground gears lubricated with Exxon-Mobil Jet Oil II. Similarly, the surface fatigue life of isotropically superfinished (ISF) spur gears lubricated with Formulation #2 at a contact stress of 280 Ksi (1.93 GPa) is a factor of more than 3.3 times greater than that for ISF-processed gears lubricated with Exxon-Mobil Jet Oil II.

**TABLE 3.**

| <b>Surface Condition</b> | <b>Surface Roughness (<math>\mu</math>in)</b> | <b>Lubricant</b>       | <b>Contact Stress (Ksi)</b> | <b>Power Increase Factor</b> | <b>Surface Life, <math>N_f</math> (<math>\times 10^6</math>)</b> | <b>Life Increase Factor</b> |
|--------------------------|-----------------------------------------------|------------------------|-----------------------------|------------------------------|------------------------------------------------------------------|-----------------------------|
| As-Ground                | 16                                            | Exxon-Mobil Jet Oil II | 235                         | 1.00                         | 16.6                                                             | 1.0                         |
|                          |                                               | Formulation #2         | 235                         | 1.00                         | <b>48.3</b>                                                      | <b>2.9</b>                  |
| ISF-Processed            | 2                                             | Exxon-Mobil Jet Oil II | 263                         | 1.25                         | >61.9                                                            | >3.7                        |
|                          |                                               |                        | 280                         | 1.42                         | 37.6                                                             | 2.3                         |
|                          |                                               | Formulation #2         | 280                         | 1.42                         | <b>&gt;55.1</b>                                                  | <b>&gt;3.3</b>              |

5            Advantageously, as shown and described herein, the multifunctional additive packages of this invention enhanced the scuffing (scoring) performance of the base oil to which they were added and increase the surface-fatigue life of the mechanical component to which they were applied .

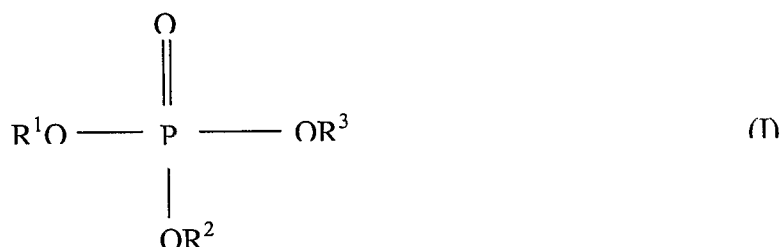
10            While the embodiments described above are directed to lubricants of the polyol ester (POE) type, a skilled artisan would recognize that the compositions apply equally to other lubricant stock compositions, as previously noted above.

15            It should therefore be understood that the foregoing description is only illustrative of the present invention. A skilled artisan, without departing from the present invention, can devise various alternatives and modifications. Accordingly, the present invention is intended to embrace all  
20 such alternatives, modifications and variations that fall within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A multifunctional lubricant composition comprising at least one  
 5 additive selected from the group consisting of:  
 an aryl or alkyl neutral phosphate, a long-chain ester, an aryl or alkyl  
 phosphite, a phenol compound, or any combinations thereof;

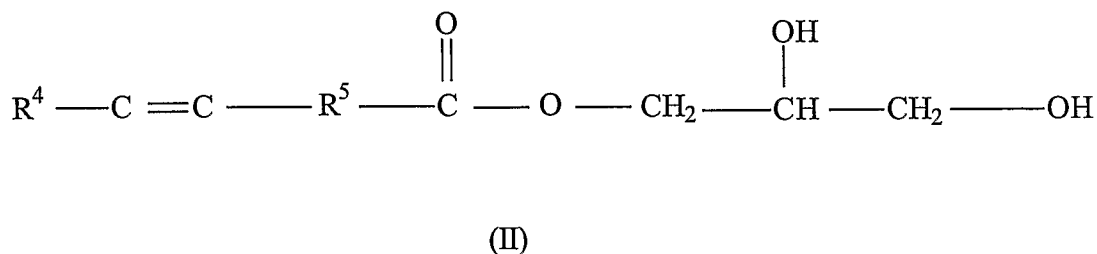
wherein the aryl or alkyl neutral phosphate has the formula:



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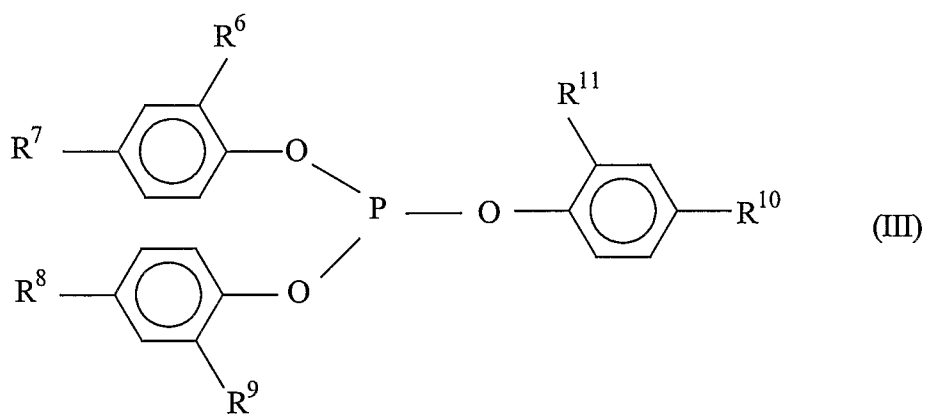
- wherein  $\text{R}^1$ ,  $\text{R}^2$ , and  $\text{R}^3$  are each independently  $\text{C}_n\text{H}_{2n+1}$  alkyl groups  
 of an alkyl neutral phosphate or  $(\text{C}_6\text{H}_5\text{C}_m\text{H}_{2m+1})$  aryl groups of an aryl  
 neutral phosphate, wherein  $n$  is an integer of about  $2 \leq n \leq 10$ , and wherein  
 15  $m$  is an integer of about  $0 \leq m \leq 8$ ;

wherein the long-chain ester has the general formula:



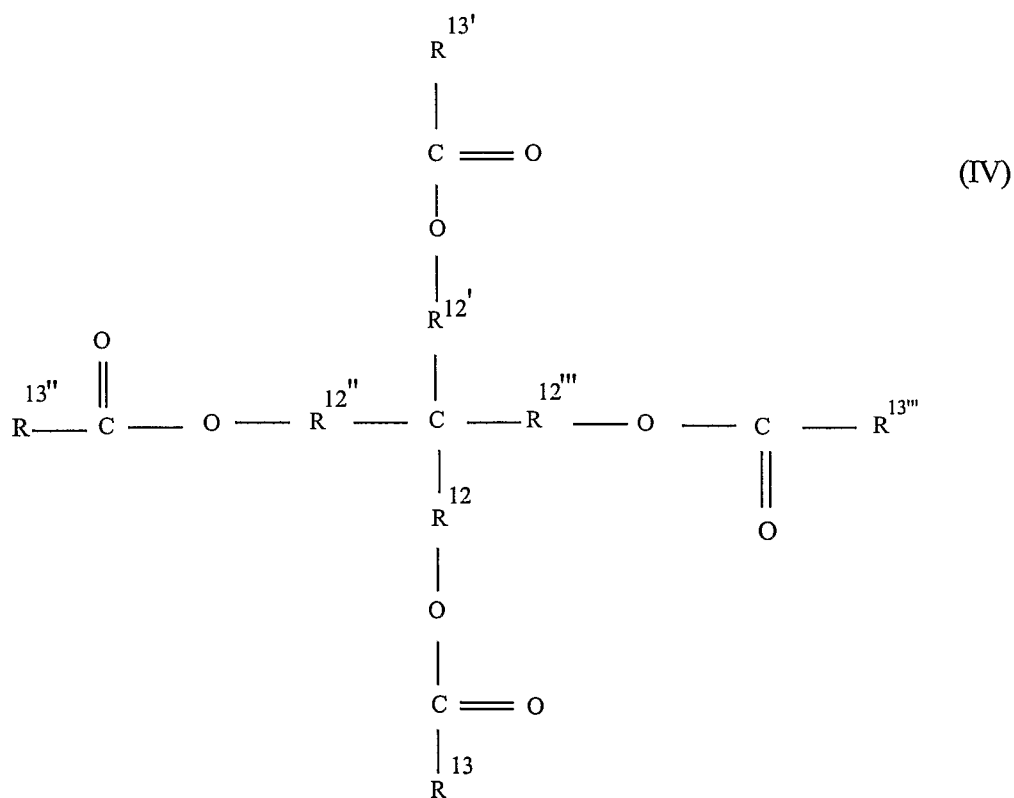
- 20 wherein  $\text{R}^4$  and  $\text{R}^5$  are each independently a normal  $\text{C}_i\text{H}_{2i+1}$  alkyl  
 groups, wherein  $i$  is an integer of about  $7 \leq i \leq 15$ ;

wherein the aryl or alkyl phosphite, has the following formula:

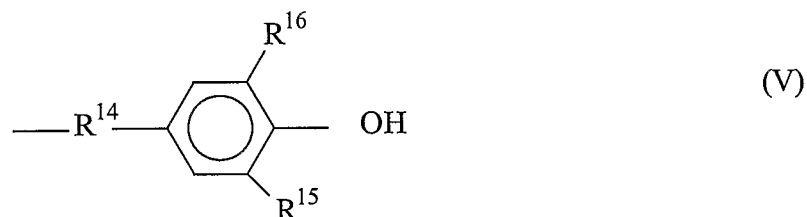


wherein  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ , and  $R^{11}$  are each independently a  
 5  $C_jH_{2j+1}$  alkyl groups, and  $j$  is an integer of about  $1 \leq j \leq 20$ ; and

wherein the phenol compound has the general formula:



wherein  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ , and  $R^{15}$  are each  $C_pH_{2p+1}$  alkyl groups, wherein  $p$  is an integer of about  $1 \leq p \leq 12$ ; wherein  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ , and  $R^{19}$  are each independently a phenol group represented by the formula:



5 wherein  $R^{14}$ ,  $R^{15}$ , and  $R^{16}$  are each independently a normal  $C_oH_{2o+1}$  alkyl group, and wherein  $o$  is an integer of about  $1 \leq o \leq 20$ .

2. The composition according to claim 1, wherein  $n$  is an integer of about  $4 \leq n \leq 6$  and  $m$  is an integer of about  $1 \leq m \leq 5$ .

10

3. The composition according to claim 1, wherein  $i$  is an integer of about  $8 \leq i \leq 10$ .

4. The composition according to claim 1, wherein  $j$  is an integer of about  $4 \leq j \leq 8$ .

15

5. The composition according to claim 1, wherein  $p$  is an integer of about  $1 \leq p \leq 5$ , and  $o$  is an integer of about  $2 \leq o \leq 10$ .

20 6. The composition according to claim 1, wherein  $R^{15}$  and  $R^{16}$  are tertiary structures.

7. The composition according to claim 1, wherein the aryl or alkyl neutral phosphate is tricresyl phosphate.

25

8. The composition according to claim 1, wherein the aryl or alkyl neutral phosphate is present in an amount from about 0.1% to 5% by mole based on the total amount of lubricant.

5           9. The composition according to claim 1, wherein the aryl or alkyl neutral phosphate is present in an amount from about 0.2% to 2% by mole based on the total amount of lubricant.

10           10. The composition according to claim 1, wherein the long-chain ester is glycerol monooleate.

15           11. The composition according to claim 1, wherein the long-chain ester is present in an amount from about 0.2% to 6% by mole based on the total amount of lubricant.

            12. The composition according to claim 1, wherein the long-chain ester is present in an amount from about 0.6% to 2% by mole based on the total amount of lubricant.

20           13. The composition according to claim 1, wherein the aryl or alkyl phosphite is tris-(2,4- di-tertiary-butyl-phenyl) phosphite.

            14. The composition according to claim 1, wherein the alkyl or aryl phosphite is present in an amount from about 0.05% to 4.5% by mole based on the total amount of lubricant.

25           15. The composition according to claim 1, wherein the alkyl or aryl phosphite is present in an amount of about 0.18% to 1.8% by mole based on the total about of lubricant.

30           16. The composition according to claim 1, wherein the phenol compound is present in an amount of about 0.005% to 1% by mole based on the total amount of lubricant.

17. The composition according to claim 1, wherein the phenol compound is present in an amount of about 0.02% to 0.3% by mole based on the total about of lubricant.

5

18. The composition according to claim 1, wherein the phenol compound is Tetrakis-(methyline-3,5-ditert-butyl-4-hydroxy hydrocinnamate) methane.

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19. The composition according to claim 1, wherein the total concentration of the additives is about 10% or less by mole based on the total amount of lubricant.

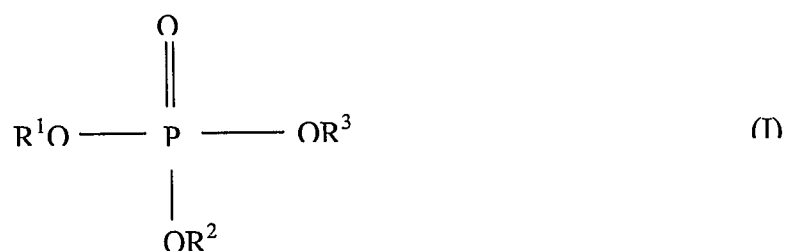
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20. The composition according to claim 1, wherein the lubricant is selected from gear oil, bearing oil, sliding surface lubricating oil, chain lubricating oil, engine oil, and synthetic polyol ester, or any combinations thereof.

20

21. A method of improving the performance characteristics of a lubricant, comprising the step of mixing a lubricant with a multifunctional lubricant additive composition comprising additives selected from the group consisting of:

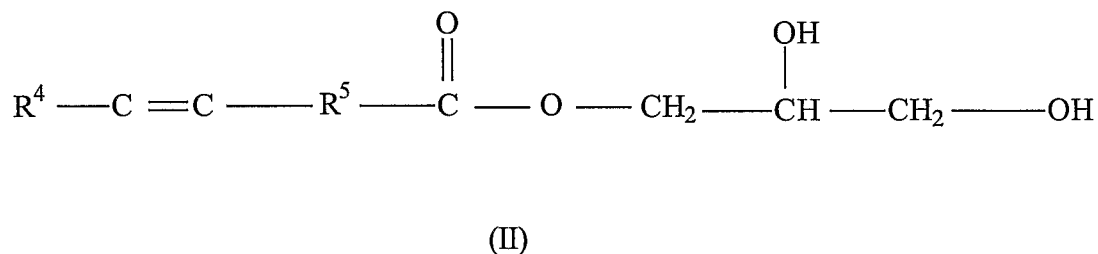
an aryl or alkyl neutral phosphate, a long-chain ester, an aryl or alkyl phosphite, a phenol compound, or any combinations thereof, wherein the aryl of alkyl neutral phosphate has the formula:



wherein  $R^1$ ,  $R^2$ , and  $R^3$  are each independently  $C_nH_{2n+1}$  alkyl groups of an alkyl neutral phosphate or  $(C_6H_5C_mH_{2m+1})$  aryl groups of an aryl neutral phosphate, wherein  $n$  is an integer of about  $2 \leq n \leq 10$ , and wherein  $m$  is an integer of about  $0 \leq m \leq 8$ ;

5

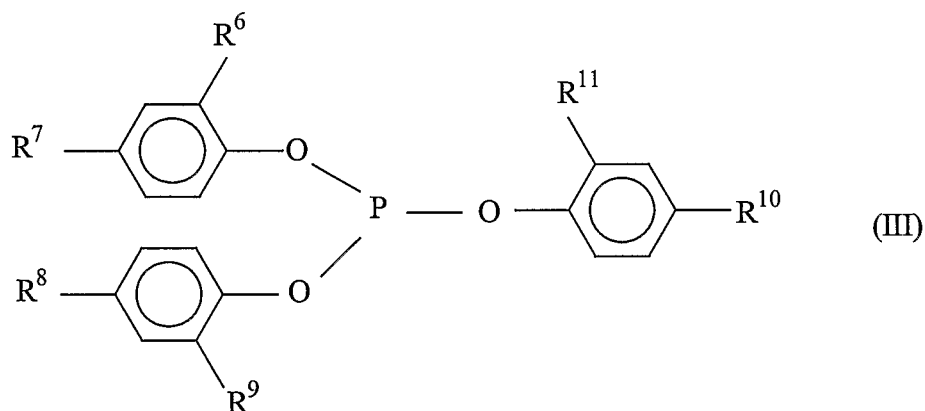
wherein the long-chain ester has the general formula:



wherein  $R^4$  and  $R^5$  are each independently a normal  $C_iH_{2i+1}$  alkyl group, wherein  $i$  is an integer of about  $7 \leq i \leq 15$ ;

10

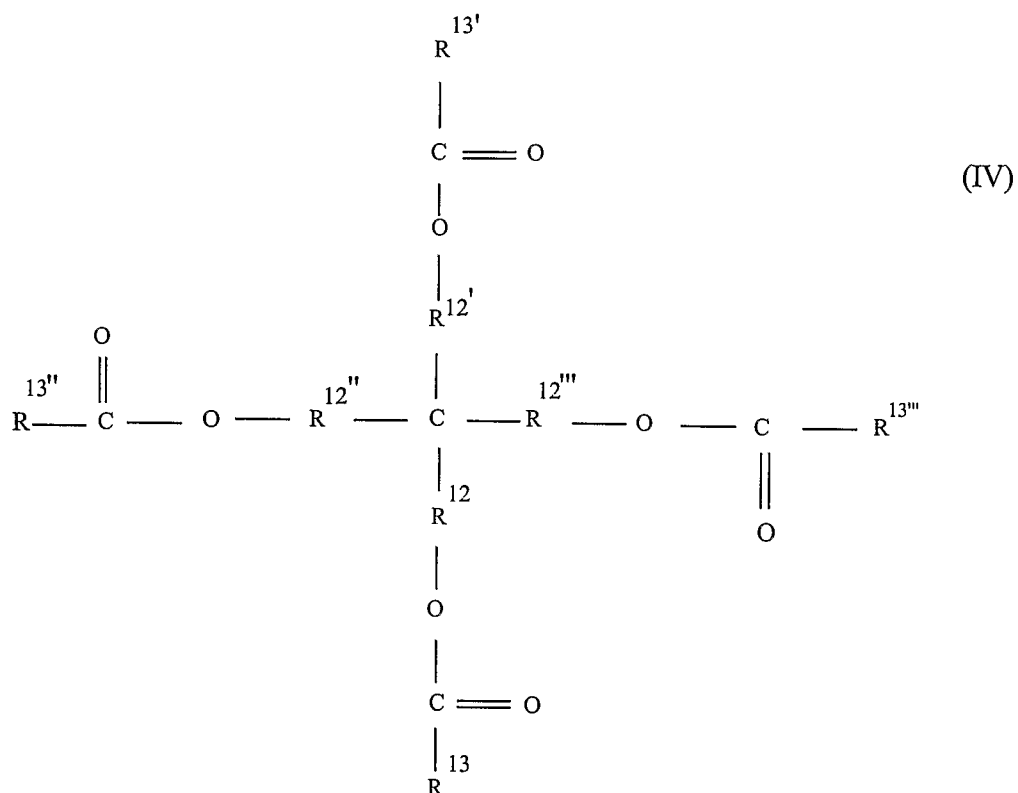
wherein the aryl or alkyl phosphite, has the following formula:



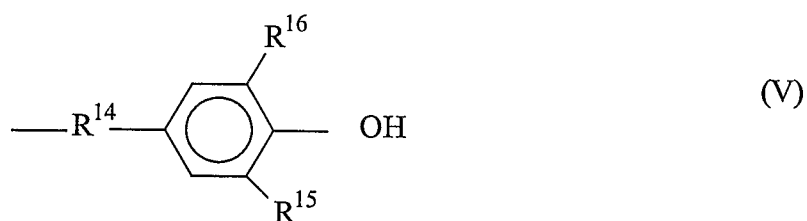
wherein  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ , and  $R^{11}$  are each independently  $C_jH_{2j+1}$  alkyl groups, and  $j$  is an integer of about  $1 \leq j \leq 20$ ; and

15

wherein the phenol compound has the general formula:



- wherein  $\text{R}^{12}$ ,  $\text{R}^{12'}$ ,  $\text{R}^{12''}$ , and  $\text{R}^{12'''}$  are each independently a normal  $\text{C}_p\text{H}_{2p+1}$  alkyl group, wherein  $p$  is an integer of about  $1 \leq p \leq 12$ ; wherein  $\text{R}^{13}$ ,  $\text{R}^{13'}$ ,  $\text{R}^{13''}$ , and  $\text{R}^{13'''}$  are each a phenol group represented by the formula:



- wherein  $\text{R}^{14}$ ,  $\text{R}^{15}$ , and  $\text{R}^{16}$  are each a  $\text{C}_o\text{H}_{2o+1}$  alkyl group, and wherein  $o$  is an integer of about  $1 \leq o \leq 20$ .

22. The method of claim 21, wherein  $n$  is an integer of about  $4 \leq n \leq 6$  and  $m$  is an integer of about  $1 \leq m \leq 5$ .

23. The method of claim 21, wherein i is an integer of about  $8 \leq i \leq 10$ .
- 5        24. The method of claim 21, wherein j is an integer of about  $4 \leq j \leq 8$ .
25. The method of claim 21, wherein p is an integer of about  $1 \leq p \leq 5$ , and o is an integer of about  $2 \leq o \leq 10$ .
- 10        26. The method of claim 21, wherein  $R^{15}$  and  $R^{16}$  are tertiary structures.
27. The method of claim 21, wherein the aryl or alkyl neutral  
15        phosphate is tricresyl phosphate.
28. The method of claim 21, wherein the aryl or alkyl neutral phosphate is present in an amount from about 0.1% to 5% by mole based on the total amount of lubricant.
- 20        29. The method of claim 21, wherein the aryl or alkyl neutral phosphate is present in an amount from about 0.2% to 2% by mole based on the total amount of lubricant.
- 25        30. The method of claim 21, wherein the long-chain ester is glycerol monooleate.
31. The method of claim 21, wherein the long-chain ester is present in an amount from about 0.2% to 6% by mole based on the total amount of  
30        lubricant.

32. The method of claim 21, wherein the long-chain ester is present in an amount from about 0.6% to 2% by mole based on the total amount of lubricant.

5           33. The method of claim 21, wherein the aryl or alkyl phosphite is tris-(2,4- di-tertiary-butyl-phenyl) phosphite.

          34. The method of claim 21, wherein the alkyl or aryl phosphite is present in an amount from about 0.05% to 4.5% by mole based on the total  
10   amount of lubricant.

          35. The method of claim 21, wherein the alkyl or aryl phosphite is present in an amount of about 0.18% to 1.8% by mole based on the total  
15   amount of lubricant.

          36. The method of claim 21, wherein the phenol compound is present in an amount of about 0.005% to 1% by mole based on the total  
20   amount of lubricant.

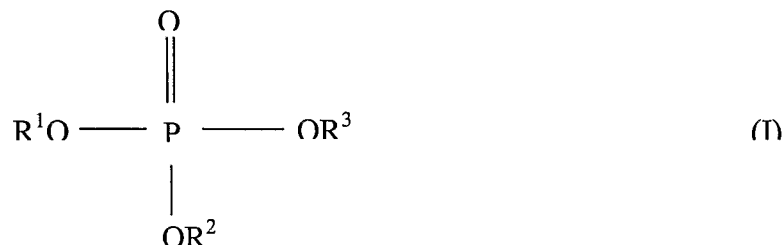
          37. The method of claim 21, wherein the phenol compound is present in an amount of about 0.02% to 0.3% by mole based on the total  
25   amount of lubricant.

          38. The method of claim 21, wherein the phenol compound is tetrakis-(methyline-3,5-ditert-butyl-4-hydroxy hydrocinnamate) methane.  
30   

          39. The method of claim 21, wherein the total concentration of the additives is about 10% or less by mole based on the total amount of  
35   lubricant.

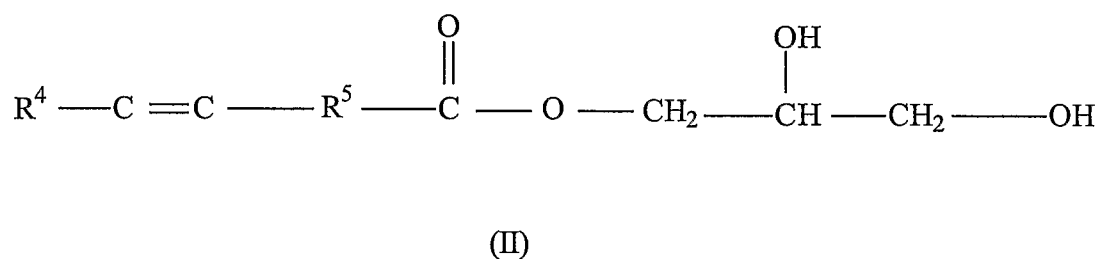
          40. The method of claim 21, wherein the lubricant is selected from gear oil, bearing oil, sliding surface lubricating oil, chain lubricating oil, engine oil, and synthetic polyol ester.

41. A multifunctional lubricant comprising:  
 a base lubricant; and  
 at least one additive selected from the group consisting of: an aryl or  
 5 alkyl neutral phosphate, a long-chain ester, an aryl or alkyl phosphite, a  
 phenol compound, or any combinations thereof;  
 wherein the aryl of alkyl neutral phosphate has the formula:

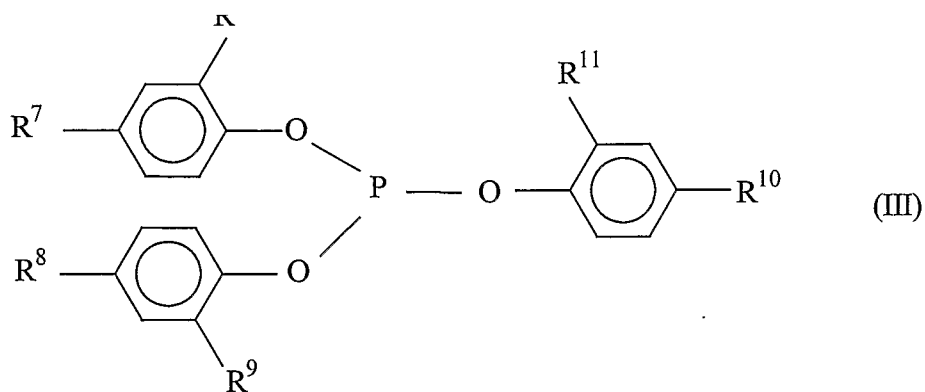


- 10 wherein  $\text{R}^1$ ,  $\text{R}^2$ , and  $\text{R}^3$  are each independently  $\text{C}_n\text{H}_{2n+1}$  alkyl groups  
 of an alkyl neutral phosphate or  $(\text{C}_6\text{H}_5\text{C}_m\text{H}_{2m+1})$  aryl groups of an aryl  
 neutral phosphate, wherein  $n$  is an integer of about  $2 \leq n \leq 10$ , and wherein  
 $m$  is an integer of about  $0 \leq m \leq 8$ ;

- 15 wherein the long-chain ester has the general formula:

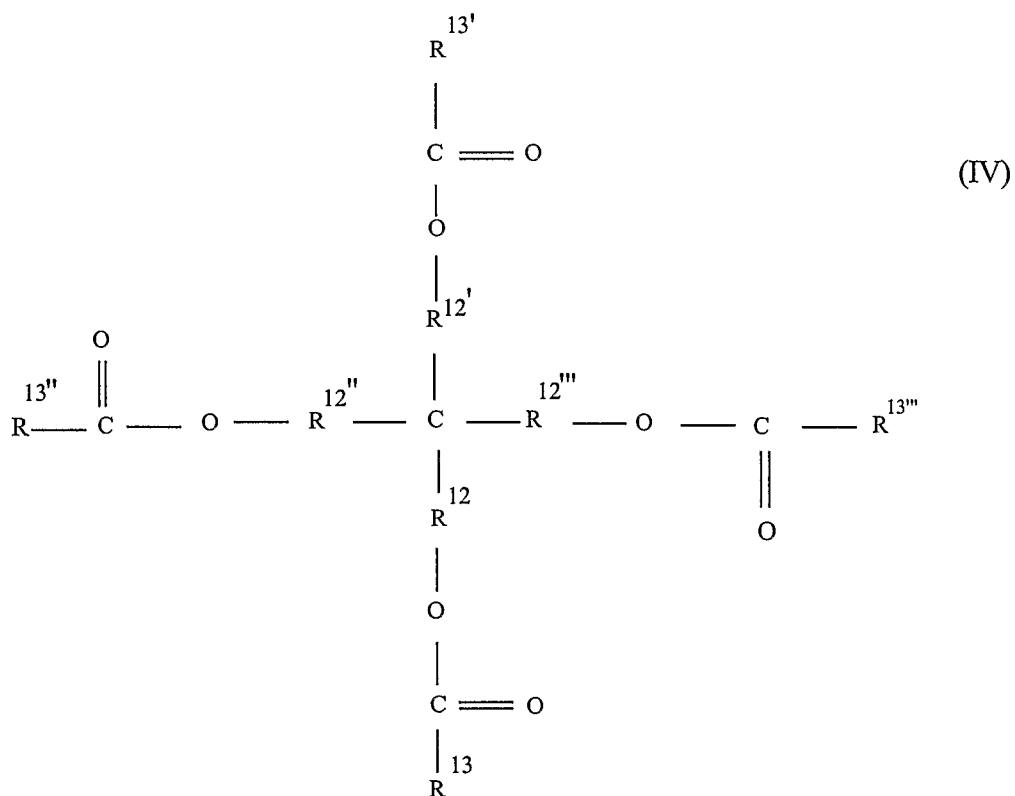


- wherein  $\text{R}^4$  and  $\text{R}^5$  are each independently a normal  $\text{C}_i\text{H}_{2i+1}$  alkyl  
 group, wherein  $i$  is an integer of about  $7 \leq i \leq 15$ ;  
 20 wherein the aryl or alkyl phosphite, has the following formula:



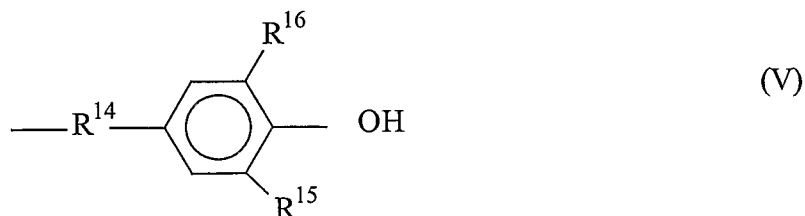
wherein  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ , and  $R^{11}$  are each independently a  $C_jH_{2j+1}$  alkyl group, and  $j$  is an integer of about  $1 \leq j \leq 20$ ; and

5 wherein the phenol compound has the general formula:



wherein  $R^{12}$ ,  $R^{12'}$ ,  $R^{12''}$ , and  $R^{12'''}$  are each  $C_pH_{2p+1}$  alkyl groups, wherein  $p$  is an integer of about  $1 \leq p \leq 12$ ; wherein  $R^{13}$ ,  $R^{13'}$ ,  $R^{13''}$ , and  $R^{13'''}$  are each independently a phenol group represented by the formula:

10



wherein  $R^{14}$ ,  $R^{15}$ , and  $R^{16}$  are each independently a normal  $C_oH_{2o+1}$  alkyl group, and wherein  $o$  is an integer of about  $1 \leq o \leq 20$ .

5           42. The multifunctional lubricant composition of claim 1, wherein when the multifunctional lubricant composition is added to a base lubricant to form an improved lubricant, the improved lubricant has a scuffing performance of at least about 1.43 times greater than the scuffing performance of the base lubricant.

10

          43. The multifunctional lubricant composition of claim 1, wherein when the multifunctional lubricant composition is added to a base lubricant to form an improved lubricant, the improved lubricant has a surface fatigue life performance of at least about 2.9 times greater than the surface fatigue life performance of the base lubricant.

15

          44. The multifunctional lubricant composition of claim 1, wherein the ratio of the amount by mole based on the total amount of lubricant of phenol compound of additive (d) to that of the aryl or alkyl phosphite of additive (c) is about 1:10.

20

          45. The multifunctional lubricant composition of claim 1, wherein the ratio of the amount by mole based on the total amount of lubricant of the an aryl or alkyl neutral phosphate, that of a long-chain ester, and that of an aryl or alkyl phosphate is about 0.5:1.0:0.45.

25

