

1 **LUBRICATING OIL ADDITIVE SYSTEM**
2 **PARTICULARLY USEFUL FOR NATURAL GAS**
3 **FUELED ENGINES**
4

5 **BACKGROUND**

6 This invention relates to lubricating oil comprising a combination of a
7 hindered phenol and Group II, III and IV base oil. The lubricating oil of this
8 invention may be used in any manner, however its enhanced properties make
9 it particularly applicable for use in engines fueled by natural gas.

10 Natural gas has a higher specific heat content than liquid hydrocarbon
11 fuels and therefore it burns hotter than liquid hydrocarbon fuels under typical
12 conditions. In addition, since it is already a gas, natural gas does not cool
13 intake air by evaporation as liquid hydrocarbon fuel droplets do. Furthermore,
14 many natural gas fueled engines are run either at or near stoichiometric
15 conditions, at which less excess air is available to dilute and cool combustion
16 gases. As a result, natural gas fueled engines generate higher combustion
17 gas temperatures than engines burning liquid hydrocarbon fuels. Since the
18 rate of formation of NO_x increases exponentially with temperature, natural gas
19 fueled engines may generate NO_x concentrations high enough to cause
20 severe nitration of lubricating oil.

21 In most cases, natural gas fueled engines are used continuously at
22 70 to 100% load, whereas an engine operating in vehicular service may only
23 spend 50% of its time at full load. Lubricating oil drain intervals may vary in
24 vehicular service, but are typically shorter than those for natural gas fueled
25 engines.

26 It is important to ensure the reliability of natural gas fueled engines
27 because natural gas fueled engines may be located in remote areas where
28 service is not readily available. Lubricating oil used in natural gas engines
29 therefore requires high resistance to oxidation and nitration.

30 Good valve wear control is important for keeping engine operating
31 costs down and may be achieved by providing the proper amount and
32 composition of ash. Minimizing combustion chamber deposits and spark plug
33 fouling are also considerations in setting the ash content and composition in
34 these oils. Lubricating oil ash levels are limited, so detergents must be

1 carefully selected to minimize piston deposits and ring sticking. Good wear
2 protection is required to prevent scuffing and corrosion.

3 If lubricating oils for natural gas fueled engines are not formulated to
4 handle typical environments for those engines, the lubricating oil will
5 deteriorate rapidly during use. This deterioration will typically cause the
6 lubricating oil to thicken, which results in engine sludge, piston deposits, oil
7 filter plugging, and in severe cases, accelerated ring and liner wear.

8 The general industry approach to reduce deterioration of lubricating oil
9 and the resultant engine sludge, piston deposits, oil filter plugging and
10 accelerated ring and liner wear is to add antioxidants such as hindered phenols
11 as well as diphenyl amines and sulfurized compounds. Increasing the amount
12 of these antioxidants in lubricating oil is increasingly effective to avoid
13 lubricating oil deterioration. But at some point the solubility limit of the additional
14 antioxidant reaches maximum effectiveness and at times further addition of
15 antioxidant may even detrimentally affect piston deposit control.

16 While it is no surprise that increasing the amount of antioxidant is
17 effective in increasing the life of lubricating oil, this invention provides a
18 method to increase the life of lubricating oil with out necessarily increasing the
19 amount of antioxidant.

20

21 SUMMARY

22 The lubricating oil of this invention may comprise a minor amount of one or
23 more hindered phenols of the general formula:

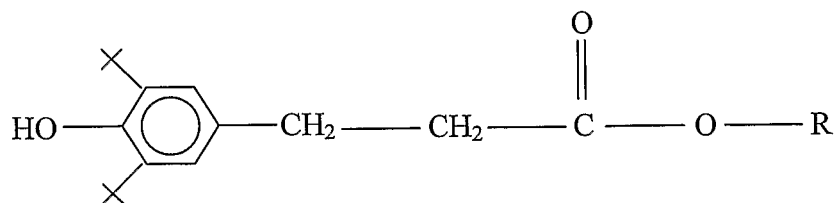
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29 wherein R is a C₇ – C₉ alkyl group

30 and a major amount of at least one of Group II, III and IV base oils. More
31 specifically, the lubricating oil of this invention may comprise about

32 0.20 wt. % to about 3 wt. % of one or more hindered phenols having this

33 general formula. Liquid hindered phenols are preferred. One embodiment of

1 the lubricating oil of this invention may comprise one or more molybdenum
2 oxidation sulfide inhibitors in an amount no more than 0.5 % wt. Unless
3 otherwise specified the term "wt. %" as used herein means wt. % of
4 lubricating oil. One embodiment of this invention comprises a lubricating oil of
5 Claim 1 having a total base number of about 2.15 milligrams Potassium
6 Hydroxide per gram of sample (mg KOH/gr) to about 8.88 mg KOH/gr as
7 determined by ASTM D 2896. One embodiment of this invention comprises a
8 lubricating oil having a total ash content of about 0.10 wt. % to about
9 1.50 wt. % as determined by ASTM D874. Lubricating oil of this invention may
10 have less than 4000 ppm sulfur. One embodiment of this invention comprises
11 combining the hindered phenol of the invention with the base oil in any order
12 and mixing. Another embodiment of this invention comprises a method of
13 lubricating engines comprising contacting one or more engines with the
14 lubricating oil of this invention. Lubricating oil of this invention may comprise a
15 major amount of at least one of Group II, III and IV base oil and a minor
16 amount of 3,5-di-t-butyl 4-hydroxyphenyl propionate (also known as
17 benzenepropanoic acid, 3,5-bis (1,1-dimethyl-ethyl)-4-hydroxy-, C₇-C₉
18 branched alkyl esters; or 3,5-di-tert-butyl-4-hydroxyhydrocinnamic acid, C₇-C₉
19 branched alkyl ester) having the structure of formula (1) above. Lubricating oil
20 of this invention may comprise about 0.20 wt. % to about 3 wt. % 3,5-di-t-
21 butyl 4-hydroxy phenyl propionate, preferably about 0.6 wt % to about
22 2.5 wt. %. The 3,5-di-t-butyl 4-hydroxy phenyl propionate may be liquid. One
23 embodiment of this invention may comprise an additive formulation
24 comprising 3,5-di-t-butyl 4-hydroxy phenyl propionate; one or more
25 dispersants; one or more wear inhibitors; and one or more detergents.
26 Lubricating oil of this invention may comprise about 1 wt. % to about
27 8 wt. % of one or more dispersants, about 1 wt. % to about 8.5 wt. % of one or
28 more detergents, about 0.2 wt. % to about 1.5 wt. % of one or more wear
29 inhibitors, about 0.5 wt. % to about 3 wt. % 3,5-di-t-butyl 4-hydroxy phenyl
30 propionate, and about 40 wt. % to about 97 wt. % of at least one of
31 Group II, III and IV base oil or preferably about 80 wt. % to about 97 wt. % of
32 at least one of Group II, III and IV base oil or more preferably about
33 60 wt. % to about 97 wt. % of at least one of Group II, III and IV base oil.

1 Lubricating oil of this invention may comprise about 1.25 wt. % to about
2 6 wt. % of one or more dispersants; about 2 wt. % to about 6 wt. % of one or
3 more detergents; about 0.3 wt. % to about 0.8 wt. % of one or more wear
4 inhibitors, about 0.6 to about 2.5 wt. % 3,5-di-t-butyl 4-hydroxy phenyl
5 propionate and about 40 wt. % to about 97 wt. % of at least one of
6 Group II, III and IV base oil or preferably about 80 wt. % to about 97 wt. % of
7 at least one of Group II, III and IV base oil or more preferably about
8 60 wt. % to about 97 wt. % of at least one of Group II, III and IV base oil.

9

10 **DETAILED DESCRIPTION OF THE INVENTION**

11 This invention provides lubricating oil that may be used in any engine,
12 but that has exhibited a surprisingly long life when tested in a natural gas fueled
13 engine.

14 The lubricating oil of this invention may comprise one or more of the
15 hindered phenols described herein and Group II, III and IV base oils. A
16 preferred lubricating oil of this invention comprises a major amount of one or
17 more base oils from Groups II through IV and a minor amount of the hindered
18 phenols described herein. The term "major amount" when used herein
19 means more than 40 wt. %. The term "minor amount" when used herein means
20 less than 20 wt. %.

21 One embodiment of this invention comprises an additive formulation
22 comprising one or more of the hindered phenols described herein, one or more
23 dispersants, one or more detergents and one or more wear inhibitors.

24 A preferred lubricating oil of this invention may comprise a major amount
25 of base oils from Group II through Group IV, a minor amount of one or more of
26 the additive formulations comprising the hindered phenols described herein,
27 one or more detergents, one or more dispersants and one or more wear
28 inhibitors.

29 Another embodiment of this invention comprises lubricating oils
30 comprising additive formulations comprising the hindered phenols described
31 herein.

32 Preferred lubricating oil of this invention may comprise the hindered
33 phenols described herein and Group II through IV base oils in a formulation

1 that has about 0.10 wt. % to about 1.50 wt. % ash in the finished lubricating oil
2 and more preferably about 0.3 wt. % ash to about 0.95 wt. % ash in the finished
3 lubricating oil as determined by ASTM D874. When ash contents are discussed
4 herein, the ash contents were determined by ASTM D874.

5 One embodiment of the lubricating oil of this invention may have a
6 Total Base Number (TBN) of about 2.15 milligrams Potassium Hydroxide
7 per gram of sample (mg KOH/gr) to about 8.88 mg KOH/gr. A more preferable
8 embodiment would have a TBN from about 3 mg KOH/gr to about
9 8 mg KOH/gr. Unless otherwise specified, TBNs, as used herein, are
10 determined by using the method ASTM D2896.

11 The lubricating oil of this invention may have a sulfur content of less than
12 4000 ppm or 0.4 wt. %.

13 Another embodiment of this invention comprises methods of making the
14 lubricating oils of this invention or the additive formulations of this invention by
15 combining the components with agitation until all components are mixed. The
16 ingredients may be combined in any order and at a temperature sufficient to
17 blend the components but not high enough to degrade the components. A
18 temperature of about 120 degrees F (approximately 49 degrees C) to about
19 160 degrees F (approximately 71 degrees C) may be used. Heating may occur
20 at any time during the process.

21 Another embodiment of this invention comprises the method of
22 lubricating one or more engines by contacting one or more of the lubricating oils
23 of this invention with one or more engines.

24 Another embodiment of this invention comprises the method of
25 lubricating one or more natural gas engines by contacting one or more of the
26 lubricating oils of this invention with one or more natural gas engines.

27 Another embodiment of this invention comprises the method of
28 lubricating one or more engines by lubricating one or more of the lubricating oils
29 of this invention with one or more engines.

30 Another embodiment of this invention comprises the method of
31 lubricating one or more natural gas engines by lubricating one or more of the
32 lubricating oils of this invention with one or more natural gas engines.

1 The lubricating oil of this invention has shown a surprisingly long life in a
2 natural gas fueled engine when the hindered phenols described herein are
3 used in an additive formulation with Group II, III and IV base oils over that seen
4 when the hindered phenols described herein were used in a similar additive
5 formulation with Group I base oils or when other types of hindered phenols
6 were used in a similar additive formulation with Group I or Group II base oils.
7 The surprising long life exhibited by the lubricating oil of this invention may be
8 the result of a synergistic effect of the Group II, III and IV base oils with the
9 hindered phenols described herein and/or a synergistic effect of the Group II, III
10 and IV base oils and the additive formulation comprising the hindered phenols
11 described herein.

12

13 **I. BASE OIL**

14 Base Oil as used herein is defined as a base stock or blend of base
15 stocks. Base Stock as used herein is defined as a lubricant component that is
16 produced by a single manufacturer to the same specifications (independent of
17 feed source or manufacturers location): that meets the same manufacturer's
18 specification; and that is identified by a unique formula, product identification
19 number, or both. Base stocks may be manufactured using a variety of
20 different processes including but not limited to distillation, solvent refining,
21 hydrogen processing, oligomerization, esterification, and rerefining. Rerefined
22 stock shall be substantially free from materials introduced through
23 manufacturing, contamination, or previous use. The base oil of this invention
24 may be any natural or synthetic lubricating base oil fraction particularly those
25 having a kinematic viscosity at 100 degrees Centigrade (C) and about
26 5 centistokes (cSt) to about 20 cSt, preferably about 7 cSt to about
27 16 cSt, more preferably about 9 cSt to about 15 cSt. Hydrocarbon synthetic
28 oils may include, for example, oils prepared from the polymerization of
29 ethylene, i.e., polyalphaolefin or PAO, or from hydrocarbon synthesis
30 procedures using carbon monoxide and hydrogen gases such as in a
31 Fisher-Tropsch process. A preferred base oil is one that comprises little, if
32 any, heavy fraction; e.g., little, if any, lube oil fraction of viscosity 20 cSt or
33 higher at 100 degrees C.

The base oil may be derived from natural lubricating oils, synthetic lubricating oils or mixtures thereof. Suitable base oil includes base stocks obtained by isomerization of synthetic wax and slack wax, as well as hydrocrackate base stocks produced by hydrocracking (rather than solvent extracting) the aromatic and polar components of the crude. Suitable base oils include those in API categories II, III, IV and V. Saturates levels and viscosity indices for Group I, II and III base oils are listed in Table 1. Group IV base oils are polyalphaolefins (PAO). Group V base oils include all other base oils not included in Group I, II, III, or IV. Suitable base oils for use in this invention include those in API categories II, III and IV as defined in API Publication 1509, 14th Edition, Addendum I, December 1998. A summary of the characteristics of Group II, III and IV base oil is presented in Table I. Though Group II, III and IV base oils are preferred for use in this invention, these preferred Group II, III and IV base oils may be prepared by combining one or more of Group I, II, III, IV and V base stocks or base oils.

TABLE 1
Saturates, Sulfur and
Viscosity Index of Group I, II and III Base Stocks

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

Natural lubricating oils may include animal oils, vegetable oils (e.g., rapeseed oils, castor oils and lard oil), petroleum oils, mineral oils, and oils derived from coal or shale.

Synthetic oils may include hydrocarbon oils and halo-substituted hydrocarbon oils such as polymerized and inter-polymerized olefins, alkylbenzenes, polyphenyls, alkylated diphenyl ethers, alkylated diphenyl

1 sulfides, as well as their derivatives, analogues and homologues thereof, and
2 the like. Synthetic lubricating oils also include alkylene oxide polymers,
3 interpolymers, copolymers and derivatives thereof wherein the terminal
4 hydroxyl groups have been modified by esterification, etherification, etc.
5 Another suitable class of synthetic lubricating oils comprises the esters of
6 dicarboxylic acids with a variety of alcohols. Esters useful as synthetic oils
7 also include those made from C₅ to C₁₂ monocarboxylic acids and polyols and
8 polyol ethers. Tri-alkyl phosphate ester oils such as those exemplified by
9 tri-n-butyl phosphate and tri-iso-butyl phosphate are also suitable for use as
10 base oils.

11 Silicon-based oils (such as the polyakyl-, polyaryl-, polyalkoxy-, or
12 polyaryloxy-siloxane oils and silicate oils) comprise another useful class of
13 synthetic lubricating oils. Other synthetic lubricating oils include liquid esters
14 of phosphorus-containing acids, polymeric tetrahydrofurans, polyalphaolefins,
15 and the like.

16 The base oil may be derived from unrefined, refined, rerefined oils, or
17 mixtures thereof. Unrefined oils are obtained directly from a natural source or
18 synthetic source (e.g., coal, shale, or tar sand bitumen) without further
19 purification or treatment. Examples of unrefined oils include a shale oil
20 obtained directly from a retorting operation, a petroleum oil obtained directly
21 from distillation, or an ester oil obtained directly from an esterification process,
22 each of which may then be used without further treatment. Refined oils are
23 similar to the unrefined oils except that refined oils have been treated in one
24 or more purification steps to improve one or more properties. Suitable
25 purification techniques include distillation, hydrocracking, hydrotreating,
26 dewaxing, solvent extraction, acid or base extraction, filtration, and
27 percolation, all of which are known to those skilled in the art. Rerefined oils
28 are obtained by treating used oils in processes similar to those used to obtain
29 the refined oils. These rerefined oils are also known as reclaimed or
30 reprocessed oils and often are additionally processed by techniques for
31 removal of spent additives and oil breakdown products.

32 Base oil derived from the hydroisomerization of wax may also be used,
33 either alone or in combination with the aforesaid natural and/or synthetic base

oil. Such wax isomerate oil is produced by the hydroisomerization of natural or synthetic waxes or mixtures thereof over a hydroisomerization catalyst.

It is preferred to use a major amount of base oil in the lubricating oil of this invention. A major amount of base oil as defined herein comprises 40 wt. % or more. Preferred amounts of base oil comprise about 40 wt. % to about 97 wt. % of at least one of Group II, III and IV base oil or preferably about 80 wt. % to about 97 wt. % of at least one of Group II, III and IV base oil or more preferably about 60 wt. % to about 97 wt. % of at least one of Group II, III and IV base oil. (When wt. % is used herein, it is referring to wt. % of the lubricating oil unless otherwise specified.) A more preferred embodiment of this invention may comprise an amount of base oil that comprises about 85 wt. % to about 95 wt. % of the lubricating oil.

A preferred lubricating oil of this invention may comprise Group II base oil. Preferred base oils may comprise base oil that is commercially available from Chevron Corporation in San Ramon, California, Pennzoil Quaker State Company in Houston, Texas, Conoco in Houston, Texas, Motiva Enterprises in Houston, Texas, ExxonMobil in Irving, Texas and Petro Canada Lubricants in Mississauga, Ontario Canada. Other base oils useful in this invention may be commercially available throughout the world from other base oil suppliers.

II. ADDITIVE FORMULATION

When incorporated in lubricating oil, the additive formulation of this invention provides enhanced oxidation inhibition, nitration inhibition, total base retention, reduction in acid formation and reduction percent viscosity increase of lubricating oil.

One embodiment of the additive formulation of this invention may comprise one or more dispersants, one or more detergents, one or more wear inhibitors and one or more hindered phenols described herein.

The lubricating oil of this invention may comprise an additive formulation that provides the lubricating oil with about 1 wt. % to about 8 wt. % of one or more dispersants, about 1 wt. % to about 8.5 wt. % of one or more detergents, about 0.2 wt. % to about 1.5 wt. % of one or more wear inhibitors and about

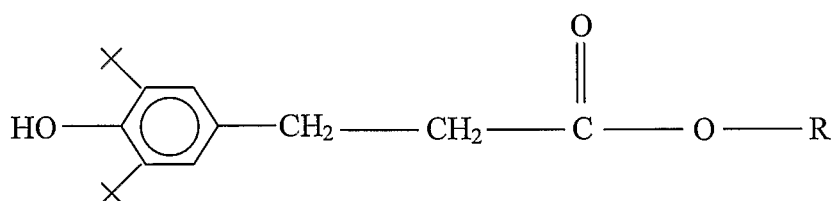
0.2 wt. % to about 3 wt. % of one or more hindered phenols described herein. The additive formulation of this invention may also comprise other additives traditionally used in the lubricating oil industry.

Another embodiment of a lubricating oil of this invention may comprise an additive formulation that provides the lubricating oil with about 1.25 wt. % to about 6 wt. % of one or more dispersants, about 2 wt. % to about 6 wt. % of one or more detergents, about 0.3 wt. % to about 0.8 wt. % of one or more wear inhibitors and about 0.6 wt. % to about 2.5 wt. % of one or more hindered phenols described herein. These components make up one embodiment of the additive formulation of this invention. The additive formulation of this invention may also comprise other additives traditionally used in the lubricating oil industry.

The additive formulation of this invention may comprise diluent oil. It is known in the art to add diluent oil to additive formulations and this is called "trimming" the additive formulation. A preferred embodiment may be trimmed with any diluent oil typically used in the industry. This diluent oil may be a Group I or above oil. A preferred amount of diluent oil may comprise about 4.00 wt. %.

A. Hindered Phenol Antioxidant

One embodiment of this invention comprises one or more hindered phenols having the general formula:



(1)

wherein R is a C₇ – C₉ alkyl group.

The lubricating oil of this invention may comprise the additive formulation of this invention that provides the lubricating oil with about 0.2 wt. % to about 3wt. % of one or more hindered phenols having the general structural formula in (1). Preferred lubricating oils of this invention may comprise an additive formulation that provides the lubricating oil with about 0.6 wt. % to about

1 2.5 wt. % of one or more hindered phenols having the general structural
2 formula (1).

3 Another embodiment of the lubricating oil of this invention may
4 comprise an additive formulation that provides the lubricating oil with
5 3,5-di-t-butyl 4-hydroxy phenol propionate. The hindered phenol, 3,5-di-t-butyl
6 4-hydroxy phenyl propionate may be available commercially from
7 Ciba Specialty Chemicals at 540 White Plains Road, Tarrytown, NY 10591 as
8 IRGANOX L135® or Crompton Corporation at 199 Benson Road,
9 Middlebury, CT 06749 as Naugard®PS-48. IRGANOX L 135® and
10 Naugard®PS-48 are liquid high molecular weight phenolic antioxidants of
11 formula (1) above, wherein R is a mixture of C₇ to C₉ alkyl groups for use in
12 lubricating oils.

13 Liquid hindered phenol is preferred.

14 Lubricating oil of this invention may comprise greater than about
15 0.2 wt. % to more than about 3 wt. % 3,5-di-t-butyl 4-hydroxy phenyl
16 propionate. Preferred lubricating oils of this invention comprise about
17 0.6 wt. % to about 2.5 wt. % 3,5-di-t-butyl 4-hydroxy phenyl propionate.

18 Additional amounts of 3,5-di-t-butyl 4-hydroxy phenyl propionate or
19 additional types of hindered phenols or other antioxidants may reduce the
20 synergistic effect of the 3,5-di-t-butyl 4-hydroxy phenyl propionate and the base
21 oil of Group II, III and IV that may be responsible for the surprising antioxidant
22 properties presented herein in Examples 1 to 6.

23

24 **B. Detergent**

25 Any detergents commonly used in lubricating oils may be used in this
26 invention. These detergents may or may not be overbased detergents or they
27 may be low, neutral, medium, or high overbased detergents. For example,
28 detergents of this invention may comprise sulfonates, salicylates and
29 phenates. Metal sulfonates, salicylates and phenates are preferred. When the
30 term metal is used with respect to sulfonates, salicylates and phenates herein,
31 it refers to calcium, magnesium, lithium, magnesium, potassium and barium.

1 The detergent may be incorporated into the lubricating oil of this
2 invention in an amount of about 1.0 wt. % to about 8.5 wt. %, preferably from
3 about 2 wt. % to about 6 wt. %.

4

5 **C. Dispersant**

6 A preferred embodiment of the lubricating oil of this invention may
7 comprise one or more nitrogen containing ashless dispersants of the type
8 generally represented by succinimides (e.g., polyisobutylene succinic
9 acid/anhydride (PIBSA)-polyamine having a PIBSA molecular weight of about
10 700 to 2500). The dispersants may or may not be borated or non-borated.
11 The dispersant may be incorporated into the lubricating oil of this invention in
12 an amount of about 1 wt. % to about 8 wt. %, more preferably in the amount
13 of about 1.5 wt. % to about 6 wt. %.

14 Preferred dispersants for this invention comprise one or more ashless
15 dispersants having an average molecular weight (mw) of about 1000 to about
16 5000. Dispersants prepared from polyisobutylene (PIB) having a mw of about
17 1000 to about 5000 are such preferred dispersants.

18 A preferred dispersant of this invention may be one or more
19 succinimides. The term "succinimide" is understood in the art to include many
20 of the amide, imide, etc. species that are also formed by the reaction of a
21 succinic anhydride with an amine and is so used herein. The predominant
22 product, however, is succinimide and this term has been generally accepted
23 as meaning the product of a reaction of an alkenyl- or alkyl-substituted
24 succinic acid or anhydride with a polyamine. Alkenyl or alkyl succinimides are
25 disclosed in numerous references and are well known in the art. Certain
26 fundamental types of succinimides and related materials encompassed by the
27 term of art "succinimide" are taught in U.S. Pat. Nos. 2,992,708; 3,018,250;
28 3,018,291; 3,024,237; 3,100,673; 3,172,892; 3,219,666; 3,272,746;
29 3,361,673; 3,381,022; 3,912,764; 4,234,435; 4,612,132; 4,747,965;
30 5,112,507; 5,241,003; 5,266,186; 5,286,799; 5,319,030; 5,334,321;
31 5,356,552; 5,716,912, the disclosures of which are hereby incorporated by
32 reference.

1 This invention may comprise one or more succinimides, which may be
2 either a mono or bis-succinimide. This invention may comprise a lubricating oil
3 involving one or more succinimide dispersants that have or have not been
4 post treated.

5

6 **D. Wear inhibitor**

7 Wear inhibitors such as metal dithiophosphates (e.g., zinc dialkyl
8 dithiophosphate, ZDDP), metal dithiocarbamates, metal xanthates or
9 tricresylphosphates may be included. Wear inhibitors may be present in the
10 amount of about 0.24 wt. % to 1.5 wt. %, more preferably in the amount of
11 about 0.3 wt. % to about 0.80 wt. %, most preferably in the amount of about
12 0.35 wt. % to about 0.75 wt. % of the lubricating oil.

13 A preferred wear inhibitor is zinc dithiophosphate. Other wear inhibitors
14 that may be included are zinc dialkyldithiophosphate and/or zinc
15 diaryldithiophosphate (ZnDTP). The wear inhibitor may be incorporated into
16 the lubricating oil of this invention in an amount of about 0.2 wt. % to
17 1.5 wt. %, more preferably in the amount of about 0.3 wt. % to about
18 0.8 wt. % of the lubricating oil. These values may include a small amount of
19 hydrocarbon oil that was used in preparing zinc dithiophosphate. Preferred
20 ranges of phosphorus in the finished lubricating oil are about 0.01 wt. % to
21 about 0.11 wt. %, more preferably about 0.02 wt. % to about 0.07 wt. %.

22 The alkyl group in the zinc dialkyldithiophosphate may be, for example,
23 a straight or branched primary, secondary or tertiary alkyl group of about
24 2 to about 18 carbon atoms. Examples of the alkyl groups include ethyl,
25 propyl, iso-propyl, butyl, pentyl, hexyl, heptyl, octyl, decyl, dodecyl, and
26 octadecyl.

27 The alkylaryl group of the zinc dialkylaryldithiophosphate is, for
28 example, a phenyl group having an alkyl group of about 2 to about 18 carbon
29 atoms, such as butylphenyl group, nonylphenyl group, and dodecylphenyl
30 group.

1
2 **III. OTHER ADDITIVE COMPONENTS**

3 The following additive components are examples of some of the
4 components that may be favorably employed in this invention. These
5 examples of additives are provided to illustrate this invention, but they are not
6 intended to limit it:
7

8 **A. Antioxidants**

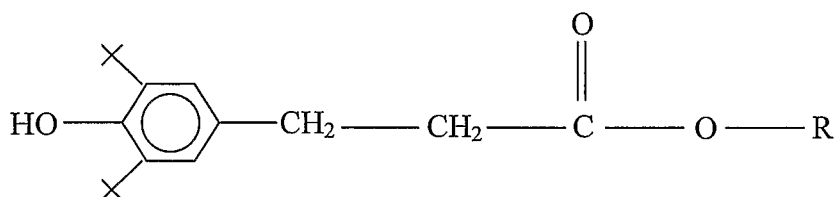
9 Additional antioxidants are not required to provide the enhanced
10 oxidation, nitration and reduced viscosity increase properties of this invention,
11 but embodiments of this invention may include the use of additional
12 antioxidants. For example, one embodiment of this invention may comprise
13 one or more hindered phenols of the general formula (1) and one or more
14 molybdenum oxidation inhibitors such as that described in U.S.
15 Patent 4,263,152 in an amount no more than about 0.3 wt. % or in an amount
16 more than 0.5 wt. %. In some embodiments of this invention, no molybdenum
17 oxidation inhibitor was added.

18 The description of the molybdenum oxidation inhibitor in
19 U.S. Patent 4,263,152 is incorporated herein by reference. A method for
20 preparing the molybdenum oxidation inhibitor described in
21 U.S. Patent 4,263,152 that may be used in one embodiment of this invention
22 is to prepare a solution of the acidic molybdenum precursor and a polar
23 promoter with a basic nitrogen-containing compound with or without diluent.
24 Diluent may be used, if necessary, to provide a suitable viscosity for easy
25 stirring. Typical diluents are lubricating oil and liquid compounds containing
26 only carbon and hydrogen. If desired, ammonium hydroxide may also be
27 added to the reaction mixture to provide a solution of ammonium molybdate.
28 This reaction may be carried out at a temperature from the melting point of the
29 mixture to reflux temperature. It is ordinarily carried out at atmospheric
30 pressure although higher or lower pressures may be used if desired. This
31 reaction mixture may be treated with a sulfur source at a suitable pressure
32 and temperature for the sulfur source to react with the acidic molybdenum and
33 basic nitrogen compounds. Preferred sulfur sources are sulfur, hydrogen

1 sulfide, phosphorus pentasulfide, $R_2 S_x$ where R is hydrocarbyl, preferably
2 C_{1-10} alkyl, and x is at least 3, mercaptans wherein R is C_{1-10} alkyl, inorganic
3 sulfides and polysulfides, thioacetamide, and thiourea. Most preferred sulfur
4 sources are sulfur, hydrogen sulfide, phosphorus pentasulfide, and inorganic
5 sulfides and polysulfides. Water may be removed from the reaction mixture
6 prior to completion of reaction with the sulfur source.

7 Embodiments of this invention may comprise, in addition to the
8 hindered phenols described herein, such antioxidants including but not limited
9 to phenol type (phenolic) oxidation inhibitors, such as
10 4,4'-methylene-bis(2,6-di-tert-butylphenol), 4,4'-bis(2,6-di-tert-butylphenol),
11 4,4'-bis(2-methyl-6-tert-butylphenol),
12 2,2'-ethylene-bis(4-methyl-6-tert-butylphenol),
13 4,4'-butylidene-bis(3-methyl-6-tert-butylphenol),
14 4,4'-isopropylidene-bis(2,6-di-tert-butylphenol),
15 2,2'-methylene-bis(4-methyl-6-nonylphenol),
16 2,2'-isobutylidene-bis(4,6-dimethylphenol),
17 2,2'-methylene-bis(4-methyl-6-cyclohexylphenol),
18 2,6-di-tert-butyl-4-methylphenol, 2,6-di-tert-butyl-4-ethylphenol,
19 2,4-dimethyl-6-tert-butylphenol, 2,6-di-tert-butyl-4-dimethylamino-p-cresol,
20 2,6-di-tert-butyl-4-(N,N'-dimethylaminomethylphenol),
21 4,4'-thiobis(2-methyl-6-tert-butylphenol),
22 2,2'-thiobis(4-methyl-6-tert-butylphenol),
23 bis(3-methyl-4-hydroxy-5-tert-butylbenzyl)-sulfide, and
24 bis(3,5-di-tert-butyl-4-hydroxybenzyl). Diphenylamine-type oxidation inhibitors
25 include, but are not limited to, alkylated diphenylamine,
26 phenyl- α -naphthylamine, and alkylated- α -naphthylamine. Other
27 types of oxidation inhibitors include metal dithiocarbamate (e.g., zinc
28 dithiocarbamate), and methylenebis (dibutyldithiocarbamate).

One embodiment of this invention comprises one or more hindered phenols having the general formula:



(2)

wherein R is a C₇ – C₉ alkyl group

and no other antioxidant additive. This embodiment of this invention comprises 3,5-di-*t*-butyl 4-hydroxy phenyl propionate 3,5-di-*t*-butyl 4-hydroxyphenyl propionate (also known as benzenepropanoic acid, 3,5-bis (1,1-dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters; or 3,5-di-*tert*-butyl-4-hydroxyhydrocinnamic acid, C₇-C₉ branched alkyl ester) commercially available from Ciba Specialty Chemicals at 540 White Plains Road, Terrytown, NY 10591 as IRGANOX L135® or Crompton Corporation at 199 Benson Road, Middlebury, CT 06749 as Naugard®PS-48 and no other antioxidant.

B. Wear Inhibitors

In addition to the wear inhibitors mentioned in the additive formulation section, other traditional wear inhibitors may be used. As their name implies, these agents reduce wear of moving metallic parts. Examples of such agents include, but are not limited to, phosphates, phosphites, carbamates, esters, sulfur containing compounds, and molybdenum complexes.

C. Rust Inhibitors (Anti-Rust Agents)

Applicable rust inhibitors include:

1. Nonionic polyoxyethylene surface active agents:

polyoxyethylene lauryl ether, polyoxyethylene higher alcohol ether, polyoxyethylene nonyl phenyl ether, polyoxyethylene octyl phenyl ether, polyoxyethylene octyl stearyl ether, polyoxyethylene oleyl ether, polyoxyethylene sorbitol monostearate, polyoxyethylene sorbitol mono-oleate, and polyethylene glycol mono-oleate; and

2. Other compounds: stearic acid and other fatty acids, dicarboxylic acids, metal soaps, fatty acid amine salts, metal salts of heavy sulfonic acid, partial carboxylic acid ester of polyhydric alcohol, and phosphoric ester.

D. Demulsifiers

Demulsifiers that may be used include addition products of alkylphenol and ethylene oxide, polyoxyethylene alkyl ether, and polyoxyethylene sorbitan ester.

E. Extreme Pressure Agents (EP Agents)

EP Agents that may be used include Zinc dialkyldithiophosphate (primary alkyl, secondary alkyl, and aryl type), sulfurized oils, diphenyl sulfide, methyl trichlorostearate, chlorinated naphthalene, fluoroalkylpolysiloxane, and lead naphthenate.

F. Friction Modifiers

Fatty alcohol, fatty acid, amine, borated ester, and other esters.

G. Multifunctional Additives

Sulfurized oxymolybdenum dithiocarbamate, sulfurized oxymolybdenum organo phosphorodithioate, oxymolybdenum monoglyceride, oxymolybdenum diethylate amide, amine-molybdenum complex compound, and sulfur-containing molybdenum complex compound may be used.

H. Viscosity Index Improvers

Polymethacrylate type polymers, ethylene-propylene copolymers, styrene-isoprene copolymers, hydrated styrene-isoprene copolymers, polyisobutylene, and dispersant type viscosity index improvers may be used.

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I. Pour Point Depressants

Polymethyl methacrylate may be used.

J. Foam Inhibitors

Alkyl methacrylate polymers and dimethyl silicone polymers may be used.

IV. LUBRICATING OIL FOR NATURAL GAS FUELED ENGINES

There is a difference in the lubricating oil requirements for natural gas fueled engines and engines that are fueled by liquid hydrocarbon fuels. The combustion of liquid hydrocarbon fuels such as diesel fuel often results in a small amount of incomplete combustion (e.g., exhaust particulates). In a liquid hydrocarbon fueled engine, these incombustibles provide a small but critical degree of lubrication to the exhaust valve/seat interface, thereby ensuring the durability of both cylinder heads and valves. The combustion of natural gas fuel is often very complete, with virtually no incombustible materials. Therefore, the durability of the cylinder head and valve is controlled by the ash content and other properties of the lubricating oil and its consumption rate. There are no incombustible materials to aid in lubrication to the exhaust valve/seat interface in a natural gas fueled engine. Natural gas fueled engines burn fuel that is introduced to the combustion chamber in the gaseous phase. This has a significant affect on the intake and exhaust valves because there is no fuel-derived lubricant for the valves like liquid droplets or soot. Consequently, gas engines are solely dependent on the lubricant ash to provide lubricant between the hot valve face and its mating seat. Too little ash or the wrong type can accelerate valve and seat wear, while too much ash may lead to valve guttering and subsequent valve torching. Too much ash can also lead to detonation from combustion chamber deposits. Consequently, gas engine builders frequently specify a narrow ash range that they have learned provides the optimum performance. Since most gas is low in sulfur, excess ash is generally not needed to address alkalinity requirements, and

1 ash levels are largely optimized around the needs of the valves. There may
2 be exceptions to this in cases where sour gas or landfill gas is used.

3 Natural gas fueled engine lubricating oils are classified according to
4 their ash content. The lubricant ash acts as a solid lubricant to protect the
5 valve/seat interface in place of naturally occurring exhaust particles in a
6 hydrocarbon fueled engine. The oil industry has accepted guidelines that
7 classify natural gas fueled engine lubricating oil according to their ash level.
8 The classifications of natural gas fueled engine lubricating oil according to
9 their ash levels are presented in Table 2.

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TABLE 2
Classifications of Lubricating Oils for
Natural Gas Fueled Engines According To Ash Levels

<u>Ash Designation</u>	<u>Sulfated Ash Level</u> (wt. %. Determined by ASTM D874)
Ashless	$0 < \text{Ash} < 0.15$
Low Ash	$0.15 < \text{Ash} < 0.6$
Medium Ash	$0.6 < \text{Ash} < 1.0$
High Ash	$\text{Ash} > 1.0$

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15 The ash level of lubricating oil is often determined by its formulation
16 components. Metal-containing detergents (e.g., barium, calcium) and
17 metallic-containing wear inhibitors contribute to the ash level of lubricating
18 oils. For correct engine operation, gas engine manufacturers define lubricating
19 oil ash requirements as part of the lubricating oil specifications. For example,
20 manufacturers of 2-cycle engines often require natural gas engine lubricating
21 oil to be Ashless to minimize the extent of harmful deposits that form on the
22 piston and combustion chamber area. Manufacturers of 4-cycle engines often
23 require natural gas engine lubricating oils to be Low, Medium or High Ash
24 levels, refer to Table 2, to provide the correct balance of engine cleanliness
25 and durability of the cylinder head and valves. Running the engine with
26 lubricating oil with too low an ash level will likely result in shortened life for the
27 valves or cylinder head. Running the engine with lubricating oil having too
28 high an ash level will likely cause excessive deposits in the combustion
29 chamber and upper piston area.

The degree of nitration of the lubricating oil may vary significantly depending on the engine design and operating conditions. Lean burn engines produce less NO_x than their stoichiometric counterparts, so they tend to nitrate the oils less. Some operators may richen the air/fuel mixture on natural gas fueled engines to increase power output and consequently increase oil nitration levels. Lubricating oils with good nitration resistance are required in most natural gas engine installations because the lubricating oil may be used to lubricate a number of engines including stoichiometric and lean-burn models.

This invention will be further illustrated by the following examples that set forth particularly preferred embodiments. While the examples are provided to illustrate this invention, they are not intended to limit it.

EXAMPLES

The Examples describe experiments performed using Samples A through I. Multiple experiments were performed in each example using a variety of detergents such as but not limited to sulfonate, phenate and salicylate detergents; succinimide dispersants; and zinc dithiophosphate wear inhibitors. The examples are explained using the terms detergent, dispersant and wear inhibitor because no significant difference was found when these components were varied.

Sample A was prepared by combining about 0.91 wt. % 3,5-di-t-butyl 4-hydroxy phenyl propionate, about 3.3 wt. % dispersant, about 3.4 wt. % detergent, about 0.38 wt. % wear inhibitor, 5 ppm foam inhibitor and Group II base oil. Sample A was prepared by combining the components at 140 degrees Fahrenheit (approximately 60 degrees Celsius) with agitation until all components were mixed.

Sample B was prepared by combining about 0.91 wt. % 3,5-di-t-butyl 4-hydroxy phenyl propionate, about 3.3 wt. % dispersant, about 3.4 wt. % detergent, about 0.38 wt. % wear inhibitor, 5 ppm foam inhibitor and Group I base oil. Sample B was prepared by combining the components at

1 140 degrees F (approximately 60 degrees C) with agitation until all
2 components were mixed.

3 Sample C was prepared by combining about 1.25 wt. % 3,5-di-t-butyl
4 4-hydroxy phenyl propionate, about 3 wt. % dispersant, about
5 3.4 wt. % detergent, about 0.38 wt. % wear inhibitor, 5 ppm foam inhibitor and
6 Group II base oil. Sample C was prepared by combining the components at
7 140 degrees F (approximately 60 degrees C) with agitation until all
8 components were mixed.

9 Sample D was prepared by combining about 1.25 wt. % 3,5-di-t-butyl
10 4-hydroxy phenyl propionate, about 3 wt. % dispersant, about
11 3.4 wt. % detergent, about 0.38 wt. % wear inhibitor, 5 ppm foam inhibitor and
12 Group I base oil. Sample D was prepared by combining the components at
13 140 degrees F (approximately 60 degrees C) with agitation until all
14 components were mixed.

15 Sample E was a finished oil product, Mobil Pegasus 805, which is
16 commercially available from ExxonMobil Corporation in Fairfax, Virginia.

17 Sample F was prepared by using OLOA 1255, commercially available
18 from Chevron Oronite Company in Houston, Texas. The OLOA 1255 was
19 mixed with Group I base oil under typical blending conditions of about
20 140 degrees F with agitation until all components are thoroughly mixed. As
21 explained in U.S. Pat. No. 5,726,133 lubricating oil made by combining OLOA
22 1255 is one of the most widely sold gas engine oil additive formulations and
23 represents, therefore, a "benchmark standard" against which other
24 formulations useful as engine oils may be measured.

25 Sample G was prepared by using OLOA 1255, commercially available
26 from Chevron Oronite Company in Houston, Texas. The OLOA 1255 was
27 mixed with Group II base oil under typical blending conditions of about
28 140 degrees F (approximately 60 degrees C) with agitation until all
29 components were thoroughly mixed.

30 Sample H was a commercially available lubricating oil designated as
31 Chevron Oronite lab code RI0994.

32 Sample I was SS15633 commercially available from
33 Chevron Oronite LLC.

Sample J was prepared by combining the components of Sample A except that instead of a Group II base oil, Sample J comprises a Group III base oil.

Sample K was prepared by combining the components of Sample A except that instead of a Group II base oil, Sample K comprises a Group IV base oil.

EXAMPLE 1

Oxidation – Resistance Bench Test

The Oxidation–Resistance Bench Test shows the capacity of lubricating oil to resist oxidation. This is one method that is used to analyze the performance of an oil to inhibit the incorporation of oxygen into oil. The results of this test are the number of hours it takes for samples to oxidize and absorb one liter of oxygen. The longer the time it takes for a sample to oxidize, the more resistant the sample is to oxidation.

All measurements are reported on a relative measurement basis so that large results or values represent greater levels of oxidation resistance. Lower numbers represent shorter oil life. Sample F was the reference oil and all results are reported as a ratio, which is the sample time divided by Sample F time. For example, if oil has a test result of 1.03, this sample would have a 3 % increased performance over the reference sample. Sample F was the reference sample for the results reported in Table 3.

The Oxidation-Resistance bench tests were performed on Samples A through I. Results are presented in Table 3. The results demonstrate that Sample A and C show enhanced oxidation resistance when compared to samples B and D through I.

Surprisingly, when oil hour measurements were taken, the performance of the Sample A and Sample C exceeded that of comparative Samples B, D, E, F, G, and I. The only Sample that exhibited similar oxidation performance was Sample H. Although it is unknown what exact type and the exact amount of antioxidant(s) that are in Sample H, it was estimated to have approximately 2 wt. % antioxidant when analyzed by thin layer chromatography, whereas, Sample A and Sample C have 0.91 wt. % and 1.25 wt. % of antioxidant

respectively. Therefore, Sample A has approximately 54 % less antioxidant than Sample H and Sample C has about 37 % less antioxidant than Sample H. The higher oxidation resistance exhibited by Sample A and Sample C may be due to a synergy of 3,5-di-t-butyl 4-hydroxy phenyl propionate and Group II base oil or a synergy of the additive formulation comprising 3,5-di-t-butyl 4-hydroxy phenyl propionate and Group II base oil.

$$\% \text{ Difference} = (\text{Sample (x)} - \text{Sample (F)}) / \text{Sample (F)} \times 100\%$$

TABLE 3

Oxidation-Resistance Bench Test Results

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G	Sample H	Sample I
Ratio*	1.98	1.27	2.14	1.27	0.97	1.00	1.59	2.04	1.67
% Difference compared to Sample F**	98	27	114	27	-3	0	59	104	67

*Ratio – These numbers are relative ratios compared to Sample F's performance in this test. Numbers larger than 1.00 perform better than Sample F and less than 1.00 perform worse than the reference. The higher the ratio number, the higher the performance of the sample.

**% Difference – These numbers are the percentage difference between Sample F and the comparative Sample. A negative number indicates worse performance than Sample F.

EXAMPLE 2

The Oxidation-Nitration And Viscosity Increase Resistance Test

The Oxidation-Nitration and Viscosity Increase Resistance bench test demonstrates the capacity of lubricating oil to resist oxidation, nitration and viscosity increase. This test is an additional tool to help determine the performance of oils as they relate to the actual service of lubricating engines that use natural gas as a fuel source. The level of oxidation and nitration of oil, may also be compared by monitoring the viscosity increase of the oil. The lower the values for oxidation, nitration and viscosity increase at the end the test, the more superior the product's performance. The Oxidation-Nitration and Viscosity Increase Resistance bench test was designed to simulate Caterpillar 3500 series engine conditions as related to actual field performance of the Caterpillar 3516 model. Oxidation-Nitration and Viscosity Increase Resistance tests were performed on Samples A, B, C, D, and F through I. The samples

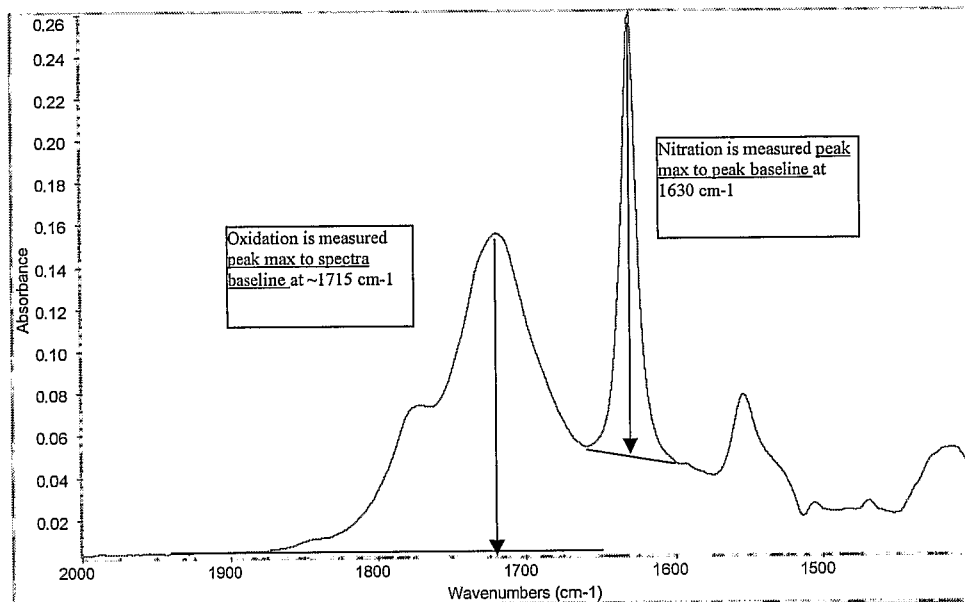
1 were placed in a heated glassware bath and subjected to calibrated levels of
2 nitrous oxide gas over a specific period of time. The tests were run on each
3 sample in duplicate and the results are an average of the two runs. The
4 samples were evaluated using differential infra red spectroscopy before placing
5 them in the heated glassware bath to determine a base line for each sample.
6 The samples were re-evaluated at the end of testing period. The differential
7 between the base line data, absorbance units at 5.8 and 6.1 microns, and the
8 data taken at the end of test cycle provides an indication of the
9 oxidation-nitration resistance of the samples.

10 Differential infra red spectroscopy measures the amount of light that is
11 absorbed by an oil sample and provides a unit of measure called an
12 absorbance unit. DIR (Differential Infrared) spectra was determined by
13 subtracting the fresh oil spectra from the used oil spectra to observe changes
14 that have occurred due to oxidation, nitration, fuel dilution, soot accumulation,
15 and or contamination. Typically a 0.1 millimeter (mm) cell is used, however
16 an ATR crystal setup may be used after determining its associated path
17 length. If the instrument does not have software that determines path length,
18 the path length may be back calculated by measuring oxidation with a
19 calibrated 0.1 mm cell. The variation between ATR and vertical cell
20 measurements is minimal if restricted to the narrow area of oxidation and
21 nitration (~ 1725 to 1630 cm^{-1}).

22 DIR Oxidation was measured from peak maximum at $\sim 1715 \pm 5\text{ cm}^{-1}$ to
23 the spectra baseline (in units of absorbance).

24 DIR Nitration was measured from peak maximum at $\sim 1630 \pm 1\text{ cm}^{-1}$ to
25 peak baseline (in units of absorbance).

GRAPH I Infrared Spectra



Oxidation (&/or Nitration) Number Reported (abs/cm) = peak absorbance divided by path length in cm^{-1} (report in whole numbers)

During the Oxidation-Resistance Bench Test, the viscosity increases of the samples were measured at 100°C by ASTM D 445. The viscosity increase is a percentage that compares the initial "fresh" kinematic viscosity with the end of test "used" oil kinematic viscosity. The formula to calculate for % viscosity difference is:

$$\% \text{ Viscosity difference} = (\text{Sample (x)}_{\text{initial}} - \text{Sample (x)}_{\text{final}}) / \text{Sample (x)}_{\text{initial}} \times 100 \%$$

Oxidation levels of 5.8 microns and Nitration levels of 6.1 microns were used as peak height comparisons.

Measurements are reported on a relative measurement basis so that large results or values represent greater levels of oxidation-nitration and viscosity increase resistance. Lower numbers represent shorter oil life.

Sample F was used as a reference oil and the results in the Tables 4, 5 and 6 were reported as a ratio in the first row of each table. This ratio was calculated by dividing measurements for Sample F by the measurements taken

using the sample being compared to sample F. The second row of each table displays the percent difference between the reference Sample F and the samples being compared to Sample F. The larger the percentage difference between Sample F and the other samples, the better performing the sample in respect to oxidation resistance. Sample F was the reference sample for the results reported in Table 4-6. The formula to calculate percentage difference of the ratios compared to Sample F for Tables 4-6 is:

$$\% \text{ difference} = (\text{Sample (x)} - \text{Sample (F)}) / \text{Sample (F)} \times 100 \%$$

TABLE 4
Oxidation Resistance Test Results

	Sample A	Sample B	Sample C	Sample D	Sample F	Sample G	Sample H	Sample I
Ratio*	5.16	0.81	6.38	0.63	1.00	4.10	2.63	3.56
% Difference compared to Sample F**	416	-19	538	-37	0	310	163	216

*Ratio – These numbers are relative ratios compared to Sample F's performance in this test. Numbers larger than 1.00 perform better than Sample F and less than 1.00 perform worse than the reference. The higher the ratio number, the higher the performance of the sample.

**% Difference – These numbers are the percentage difference between Sample F and the comparative Sample. A negative number indicates worse performance than Sample F.

The results presented in Table 4 indicate that Sample A and C exhibited a 416 % and 538 % improvement, respectively, in oxidative resistance over the reference Sample F.

TABLE 5
Nitration Resistance Test Results

	Sample A	Sample B	Sample C	Sample D	Sample F	Sample G	Sample H	Sample I
Ratio*	3.85	1.06	87.00	1.75	1.00	4.22	29.00	1.83
% Difference compared to Sample F**	285	6	8600	75	0	322	2800	73

*Ratio – These numbers are relative ratios compared to Sample F's performance in this test. Numbers larger than 1.00 perform better than Sample F and less than 1.00 perform worse than the reference. The higher the ratio number, the higher the performance of the sample.

***% Difference – These numbers are the percentage difference between Sample F and the comparative Sample. A negative number indicates worse performance than Sample F.

The results in Table 5 indicate the improved performance of Samples A and C over the reference sample. The improvement ranged from 285 % to 8600 % over the reference sample in nitration resistance.

TABLE 6
Viscosity Increase Resistance Test Results

	Sample A	Sample B	Sample C	Sample D	Sample F	Sample G	Sample H	Sample I
Ratio*	3.14	0.66	23.98	0.75	1.00	6.03	17.64	4.40
% Difference compared to Sample F**	214	-37	2298	-25	0	503	1664	340

*Ratio – These numbers are relative ratios compared to Sample F's performance in this test. Numbers larger than 1.00 perform better than Sample F and less than 1.00 perform worse than the reference. The higher the ratio number, the higher the performance of the sample.

**% Difference – These numbers are the percentage difference between Sample F and the comparative Sample. A negative number indicates worse performance than Sample F.

The results in Table 6 indicate the improved performance of Samples A and C over the reference sample. The improvement ranged from 214 % to 2298 % over the reference sample in viscosity increase resistance.

Samples A and C perform superior to the reference sample with respect to oxidation, nitration and viscosity increase. Sample C performed better than all the samples tested with respect to oxidation, nitration and viscosity increase. These tests that quantify a lubricating oil's resistance to oxidation and nitration and the resultant viscosity increase are used to determine whether samples are good candidates for extending the life of lubricating oil particularly those lubricating oils for use in natural gas fueled engines. Absorbing oxygen and nitrogen and the resultant viscosity increase associated with absorbing oxygen and nitrogen are undesirable for lubricating oil particularly lubricating oils for use in natural gas fueled engines.

EXAMPLE 3

Sample A, D, F, and G were tested separately by using each one as a lubricant in a Caterpillar 3516 natural gas fueled engine. Because the Caterpillar 3500 series natural gas fueled engines are one of the most

1 commonly used and one of the most severe engines with respect to oil life, they
 2 were used as a tool to determine the life of lubricating oil. These tests were run
 3 in the same model of Caterpillar 3516 engine at the same location to minimize
 4 the amount of variables that are introduced in the testing environment. Oil life
 5 as used herein is the length of time it takes for a lubricating oil to reach
 6 Caterpillar's condemning limits for natural gas fueled engine lubricating oil. At
 7 the time of testing the Caterpillar limits are presented in Table 7.

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TABLE 7
Caterpillar Limits at Time of Testing

Test	Caterpillar Limit
Oxidation	25 abs/cm ⁻¹ by differential infra red spectroscopy
Nitration	25 abs/cm ⁻¹ by differential infra red spectroscopy
Viscosity Increase	3 cSt increase over fresh oil
Total Base Number (TBN)	50 % of fresh oil TBN by ASTM D 2896
Total Acid Number (TAN)	2.0 number increase over the fresh oil or 3.0 maximum TAN by ASTM D 664

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12 Both samples were run in the Caterpillar 3516 until the condemning
 13 limits were exceeded. The oxidation and nitration of the samples were analyzed
 14 using differential IR as described in Example 2. Viscosity Increase of the
 15 samples was also monitored. The Viscosity Increase analysis is described in
 16 Example 2. Sample A exhibited better performance with respect to oxidation,
 17 nitration and viscosity increase than Samples D, F, and G. Total Base Number
 18 (TBN) and Total Acid Number (TAN) analyses were also performed. TBN refers
 19 to the amount of base equivalent to milligrams of KOH in one gram of sample.
 20 Thus, higher TBN numbers reflect more alkaline products, and therefore a
 21 greater alkalinity reserve. The TBN of a sample may be determined by
 22 ASTM Test No. D2896. TAN refers to the amount of acid equivalent to
 23 milligrams of Potassium Hydroxide (KOH) in 1 gram of sample. TAN can be
 24 determined by the procedure described in ASTM D664.

25 Sample A outperformed the reference Sample F in all the monitored
 26 tests from 176 % for TAN level to an estimated percentage of 374 % for oil life
 27 based on the condemning limit for percent viscosity increase.

Sample A also outperformed Sample G which is the same additive as Sample F, but in a Group II base oil.

The key parameters that are the first to reach the Caterpillars condemning limit are TBN and TAN. In a comparison of the next highest products tested in Table 8, Sample A outperformed Sample G by 33 % for TBN retention and 65 % in the oils ability to inhibit acid production (TAN).

Sample D is similar to Sample F in its composition, but it contains a different quantity and type of antioxidant, formulated in a Group I base oil. The performance of Sample D is worse than Sample F, when evaluated in a Caterpillar field test.

The calculation formula for Relative Percent Improvement for Table 8 is:

$$\text{Relative Percent Improvement} = (\text{Sample (x)} - \text{Sample (F)}) / \text{Sample (F)} \times 100 \%$$

TABLE 8

**Oxidation, Nitration, Viscosity Increase,
TBN and TAN Results for Caterpillar Test of Samples A, D, F, and G**

	Sample A	Sample D	Sample F	Sample G
Hours to Reach Caterpillar Limit for Oxidation	1894	475	479	1082
Relative Percent Improvement Comparison to Sample F for Oxidation	295	- 1	0	126
Hours to Reach Caterpillar Limit for Nitration	1256	496	450	765
Relative Percent Improvement Comparison to Sample F for Nitration	179	10	0	70
Hours to Reach Caterpillar Limit for Viscosity Increase	3632*	600	767	2099
Relative Percent Improvement Comparison to Sample F for Viscosity Increase	374	- 22	0	174
Hours to Reach Caterpillar Limit for TBN	1155	408	408	866
Relative Percent Improvement Comparison to Sample F for TBN	183	0	0	112
Hours to Reach Caterpillar Limit for TAN	1176	392	426	714
Relative Percent Improvement Comparison to Sample F for TAN	176	- 8	0	68

*Note - The viscosity increase hours for Sample A is an estimate based on trend analysis of the Used Oil Analysis (UOA).

EXAMPLE 4

(a) Comparison of Samples A and G

Samples A and G were tested separately by using each one as a lubricant in the same Caterpillar 3516 natural gas fueled engine for about

1 year. The oxidation and nitration of the samples were analyzed using differential IR as described in Example 2. Viscosity Increase of the samples was monitored by using the Viscosity Increase test described in Example 2. Total Base Number (TBN) and Total Acid Number (TAN) analyses were also performed. As described in Example 3.

The performance of Sample A was surprising and unexpected compared to Sample G. Both samples were formulated in Group II base oil and in the critical parameters of TBN and TAN performance, Sample A had an increased oil life of 75 % and 38 %, respectively, when compared to Sample G.

The calculation formula for Relative Percent Improvement for Table 9 is:

$$\text{Relative Percent Improvement} = (\text{Sample (x)} - \text{Sample (G)}) / \text{Sample (G)} \times 100 \%$$

TABLE 9

	Sample A	Sample G
Hours to Reach Caterpillar Limit for Oxidation	1984	1506
Relative Percent Improvement Comparison to Sample G for Oxidation	32	0
Hours to Reach Caterpillar Limit for Nitration	2965*	2632*
Relative Percent Improvement Comparison to Sample G for Nitration	13	0
Hours to Reach Caterpillar Limit for Viscosity Increase**	3381*	3080*
Relative Percent Improvement Comparison to Sample G for Viscosity Increase	10	0
Hours to Reach Caterpillar Limit for TBN	1733	990
Relative Percent Change Improvement Comparison to Sample G for TBN	75	0
Hours to Reach Caterpillar Limit for TAN	1538	1111
Relative Percent Improvement Comparison to Sample G for TAN	38	0

*Note - The nitration level and viscosity increase hours for Sample A are an estimate based on trend analysis of the Used Oil Analysis (UOA).

(b) Comparison of Samples B and F

Samples B and F were tested separately by using each one as a lubricant in the same Caterpillar 3516 natural gas fueled engine for about 1 year. The oxidation and nitration of the samples were analyzed using differential IR as described in Example 2. Viscosity Increase of the samples was monitored by using the Viscosity Increase test described in Example 2.

Total Base Number (TBN) and Total Acid Number (TAN) analyses were also performed using the testing described in Example 4.

The performance of Sample B was slightly better when compared to Sample F. Both samples were formulated in Group I base oil and in the critical parameters of TBN and TAN performance, Sample B had an increased oil life of only 20 % and 16 %, respectively, when compared to Sample F.

The calculation formula for Relative Percent Improvement for Table 10 is:

$$\text{Relative Percent Improvement} = (\text{Sample (B)} - \text{Sample (F)}) / \text{Sample (F)} \times 100 \%$$

TABLE 10

	Sample B	Sample F
Hours to Reach Caterpillar Limit for Oxidation	958	825
Relative Percent Improvement Comparison to Sample F for Oxidation	16	0
Hours to Reach Caterpillar Limit for Nitration	1116	1002
Relative Percent Improvement Comparison to Sample F for Nitration	11	0
Hours to Reach Caterpillar Limit for Viscosity Increase	1364*	1304*
Relative Percent Improvement Comparison to Sample F for Viscosity Increase	5	0
Hours to Reach Caterpillar Limit for TBN	693	578
Relative Percent Improvement Comparison to Sample F for TBN	20	0
Hours to Reach Caterpillar Limit for TAN	800	690
Relative Percent Improvement Comparison to Sample F for TAN	16	0

*Note - The viscosity increase hours for Sample B and Sample F are an estimate based on trend analysis of the Used Oil Analysis (UOA).

(c) Comparison of Examples 4(a) and 4(b)

The performance of Sample A shows a significant improvement over Sample G. Sample A and G both include Group II base oils. The performance increase in the parameters that reach the Caterpillar's condemning limit first, TBN and TAN levels show Sample A with a 75 % and 38 % improvement, respectively, compared to Sample G.

Sample B performed slightly better than Sample F. Comparing the same parameters of Sample B and Sample F to Samples A and G, TBN and TAN levels, show a 20 % and 16 % improvement, respectively. Sample A exhibits a surprising and unexpected improvement when used with Group II base oils.

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EXAMPLE 5

Samples C and E were tested separately by using each one as a lubricant in the same model Caterpillar 3516 natural gas fueled engine at the same location. Sample C was tested by using it as a lubricant for a Caterpillar 3516 for over 6 months. Sample E was tested by using it as a lubricant for a Caterpillar 3516 for about 1 year. The oxidation and nitration of the samples were analyzed using differential IR as described in Example 2. Viscosity Increase of the samples was monitored by using the Viscosity Increase test described in Example 2. Total Base Number (TBN) and Total Acid Number (TAN) analyses were also performed, as described in Example 3.

Sample C exhibited surprisingly better performance with respect to the reduction in oxidation, nitration, viscosity increase, TBN and TAN than Sample E. The level of performance improved from a minimum of 87 % increase for oxidation to 101 % and 108 % for the key areas of TBN and TAN, respectively.

The level of nitration and viscosity increase of the oil for Sample C rose at a low rate. When this rate is used to estimate the number of hours it takes for oil to be condemned, it would be in excess of 15,000 hours. This would be an unfair comparison because Sample C would have been well below the minimum limits for TBN after 1152 hours of operation. Even though Sample C was drained well beyond this condemning limit. To give a realistic perspective of the Nitration and Viscosity Increase performance, two additional lines were added to the chart, which shows the level of nitration in absorbance units and viscosity increase for Sample C at the same hours when Sample E reached the limit. The nitration level for Sample C was 1.83 when Sample E reached the Caterpillar limit of 25. The viscosity increase for Sample C was 0.24 cSt over the fresh oil at the same hours of engine service when Sample E reached the Caterpillar limit of 3 cSt.

1 The calculation formula for Relative Percent Improvement for Table 11
2 is:

3
4
$$\text{Relative Percent Improvement} = (\text{Sample (C)} - \text{Sample (E)}) / \text{Sample (E)} \times 100 \%$$

5

6 **TABLE 11**

	Sample C	Sample E
Hours to Reach Caterpillar Limit for Oxidation	1812	969
Relative Percent Improved Comparison to Sample E for Oxidation	87	0
Hours to Reach Caterpillar Limit for Nitration	27,778*	2033*
Relative Percent Improved Comparison to Sample E for Nitration	1267	0
Nitration DIR values at equal engine hours when Sample E reached Caterpillar Limit	1.83	25.00
Hours to Reach Caterpillar Limit for Viscosity Increase	15,000*	1200
Relative Percent Improved Comparison to Sample E for Viscosity Increase	1150	0
Viscosity Increase values at equal engine hours when Sample E reached Caterpillar Limit	0.24	3.00
Hours to Reach Caterpillar Limit for TBN	1152	573
Relative Percent Improved Comparison to Sample E for TBN	101	0
Hours to Reach Caterpillar Limit for TAN	1667	800
Relative Percent Improved Comparison to Sample E for TAN	108	0

7 *Note - The nitration level and viscosity increase hours for Sample C were estimated based on trend analysis of the
8 Used Oil Analysis (UOA). Also, the viscosity increase hours for Sample E were estimated based on trend analysis of the
9 Used Oil Analysis (UOA)

10

11 **EXAMPLE 6**

12 Sample B was compared to Samples A, J and K for resistance to
13 oxidation using the test procedure described in Example 1. The results of this
14 test are presented in Table 12. These results indicate that Samples A, J and K
15 work surprisingly better than Sample B. The only difference in Sample B and
16 Samples A, J, and K is that Sample B includes Group I base oil, whereas
17 Samples A, J and K include Group II, III, and IV base oils, respectively. These
18 results show that this additive works surprisingly better when combined with
19 Groups II, III, and IV base oil than the same additive when used in Group I
20 base oil.

21

The calculation formula for Oxidation Resistance of an Additive When Combined with Groups I, II, III and IV Base Oil represented by the following:

$$\% \text{ difference} = (\text{Sample (x)} - \text{Sample (A)}) / \text{Sample (A)} \times 100\%$$

The results of the calculations are in Table 12.

TABLE 12

Oxidation Resistance of an Additive When Combined With Groups I, II, III and IV Base Oil

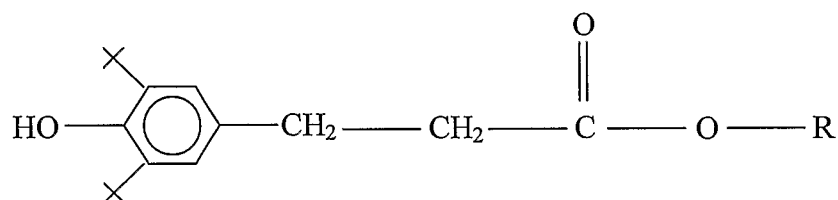
Group of Base Oil	Group I Sample B	Group II Sample A	Group III Sample J	Group IV Sample K
Ratio*	0.64	1.00	1.20	1.14
% Difference**	- 36	0	20	14

*Ratio – These numbers are relative ratios compared to Sample A's performance in this test. Numbers larger than 1.00 perform better than Sample A and less than 1.00 perform worse than the reference. A higher the ratio number represents higher performance of the sample.

**% Difference – These numbers are the percentage difference between Sample A and the comparative Sample. A negative number indicates worse performance than Sample A.

WHAT IS CLAIMED IS:

1. Lubricating oil comprising 0.6 wt% to about 2.5 wt% of one or more hindered phenols of the general formula:



wherein R is a C₇-C₉ alkyl group and a major amount of at least one of Group II and III base oils.

2. Lubricating oil of Claim 1 wherein the hindered phenol is liquid.
3. An additive formulation comprising the hindered phenol of Claim 1 and one or more dispersants, one or more detergents and one or more wear inhibitors.
4. Lubricating oil of Claim 1 having a total base number of about 2.15 to about 8.88 as determined by ASTM D 2896.
5. Lubricating oil of Claim 1 having a total ash content of about 0.1 wt. % to about 1.5 wt. % as determined by ASTM D874.
6. Lubricating oil of Claim 1 having less than 4000 ppm sulfur.
7. A method of making the lubricating oil of Claim 1 by combining the hindered phenol of Claim 1 with the base oil of Claim 1 in any order and mixing.
8. A method of lubricating engines comprising lubricating one or more engines with lubricating oil comprising the hindered phenol of Claim 1.

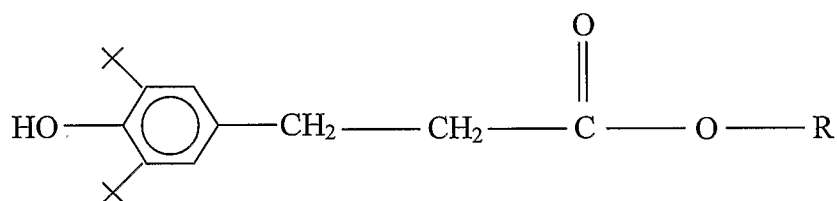
- 1 9. Lubricating oil comprising a major amount of at least one of Group II and
2 III base oil and a minor amount of benzenepropanoic acid, 3,5-bis (1,1-
3 dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters.
4
- 5 10. Lubricating oil of Claim 9 having less than 4000 ppm sulfur.
6
- 7 11. Lubricating oil of Claim 9, wherein about 0.6 wt. % to about 2.5 wt. % of
8 the lubricating oil comprises benzenepropanoic acid, 3,5-bis (1,1-
9 dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters.
10
- 11 12. Lubricating oil of Claim 9, wherein the benzenepropanoic acid, 3,5-bis
12 (1,1-dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters is liquid.
13
- 14 13. Lubricating oil of Claim 9 having a total base number of about 2.15 to
15 about 8.88 as determined by ASTM D 2896.
16
- 17 14. Lubricating oil of Claim 9 having a total ash content of about 0.1 wt. % to
18 about 1.5 wt. % as determined by ASTM D874.
19
- 20 15. A method of lubricating engines comprising contacting the engine with
21 the lubricating oil of Claim 9.
22
- 23 16. A method for making the lubricating oil of Claim 9 comprising combining
24 the benzenepropanoic acid, 3,5-bis (1,1-dimethyl-ethyl)-4-hydroxy-, C₇-
25 C₉ branched alkyl esters with at least one of Group II and III base oil in
26 any order and mixing.
27
- 28 17. An additive formulation comprising benzenepropanoic acid, 3,5-bis (1,1-
29 dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters; one or more
30 dispersants; one or more wear inhibitors; and at least one of sulfonate,
31 salicylate and phenate detergents.
32

- 1 18. Lubricating oil comprising a minor amount of the additive formulation of
2 Claim 17 and a major amount of at least one of Group II and III base
3 oil.
4
- 5 19. Lubricating oil of Claim 18 comprising about 4 wt. % to about 16.50 wt. %
6 of the additive formulation and about 40 wt. % to about 97 wt. % of the
7 base oil.
8
- 9 20. A method for lubricating a natural gas fueled engine comprising
10 lubricating the natural gas fueled engine with the lubricating oil of
11 Claim 18.
12
- 13 21. A method for making the additive formulation of Claim 17, comprising
14 combining one or more detergents; one or more dispersants; one or
15 more wear inhibitors; and benzenepropanoic acid, 3,5-bis (1,1-
16 dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters in any order
17 and agitating until mixed.
18
- 19 22. Lubricating oil comprising:
20
21 about 1 wt. % to about 8 wt. % of one or more dispersants;
22
23 about 1 wt. % to about 8.5 wt. % of one or more detergents;
24
25 about 0.2 wt. % to about 1.5 wt. % of one or more wear inhibitors ;
26
27 about 0.6 wt. % to about 2.5 wt. % benzenepropanoic acid, 3,5-bis
28 (1,1-dimethyl-ethyl)-4-hydroxy-, C₇-C₉ branched alkyl esters; and
29
30 about 6 wt. % to about 97 wt. % of at least one of Group II and III base
31 oil.
32

23. A method for lubricating a natural gas fueled engine comprising lubricating the natural gas fueled engine with the lubricating oil of Claim 22.

24. A method of reducing oxidation in an internal combustion engine which comprises operating an engine with a composition comprising

0.6 wt% to 2.5 wt% of one or more hindered phenols of the general formula:



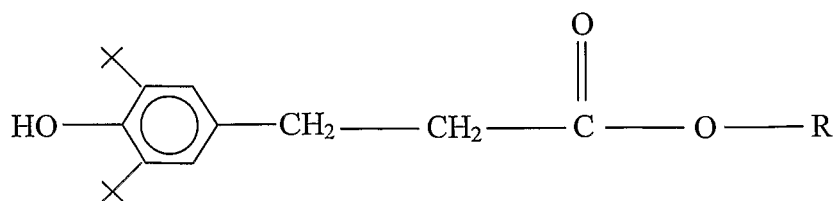
wherein R is a C₇-C₉ alkyl group

and a major amount of at least one of Group II and III base oils.

25. A method of reducing oxidation in an internal combustion engine according to claim 24 wherein said internal combustion engine is a natural gas engine.

26. The use of an antioxidant system comprising

0.6 wt% to 2.5 wt% of one or more hindered phenols of the general formula:



wherein R is a C₇-C₉ alkyl group

and a major amount of at least one of Group II and III base oils, to reduce oxidation in an internal combustion engine.

- 1 27. The use of an antioxidant system according to claim 26 wherein said
- 2 internal combustion engine is a natural gas engine.