The LSPI frequency is reported as the number of LSPI-impacted combustion cycles per million combustion cycles and is calculated as follows:

LSPI Frequency = [(Total Number of LSPI Impacted Combustion Cycles in Six Truncated Segments)/(Total Number of Combustion Cycles in Six Truncated Segments)] × 1,000,000

An additive associated with a test lubricant that reduces the LSPI frequency, when compared to the corresponding baseline lubricant, is considered an additive that mitigates LSPI frequency. The test results are set forth in Table 1.

Baseline Formulation

The base line formulation contained a Group 2 base oil, a mixture of primary and secondary dialkyl zinc dithiophosphates in an amount to provide 741-814 ppm phosphorus to the lubricating oil composition, a mixture of polyisobutenyl succinimide dispersants (borated and ethylene carbonate post-treated), a molybdenum succinimide complex in an amount to provide 177-187 ppm molybdenum to the lubricating oil composition, an alkylated diphenylamine antioxidant, a borated friction modifier, a foam inhibitor, a pour point depressant, and an olefin copolymer viscosity index improver. The baseline formulation contains about 5 ppm silicon from a foam inhibitor.

The lubricating oil compositions were blended into a 5W-30 viscosity grade oil.

Silane compound A

The silane compound A was a commercially available silane compound which was Bis[3-(triethoxysilyl)propyl]disulfide with the chemical formula $C_{18}H_{42}O_6S_2Si_2$.

Example 1

CLAIMS

What is claimed is:

1. A method for preventing or reducing low speed pre-ignition in a direct injected, boosted, spark ignited internal combustion engine, said method comprising the step of lubricating the crankcase of the engine with a lubricating oil composition comprising from ~~about~~ 100 to ~~about~~ 3000 ppm of silicon from at least one silane-containing compound, based on the total weight of the lubricating oil composition, wherein the silane-containing compound includes at least one sulfur atom in the molecule.~~.~~

2. The method of claim 1, wherein the engine is operated under a load with a break mean effective pressure (BMEP) of from ~~about~~ 12 to ~~about~~ 30 bars.

3. The method of claim 1, wherein the engine is operated at speeds between 500 and 3,000 rpm.

4. The method of claim 1, wherein the silane-containing compound has the following generic formula (I):

$$[(R^1)_{3-a}(R^2O)_aSi]_rA \qquad (I),$$

wherein R^1 is selected from the group consisting of saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; R^2 is selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; a is an integer from 1 to 3, and A is a group of valence r, r being an integer greater than or equal to 1, selected from the group consisting of saturated and unsaturated, linear, branched, or cyclic hydrocarbyl groups, ~~an oxygen atom,~~ or a linear,

branched, or cyclic siloxane or polysiloxane group, each of which comprises substituents having sulfur heteroatoms~~, except for an oxygen atom, optionally comprises substituents having oxygen, nitrogen, sulfur, or halogen heteroatoms~~.

5. The method of claim 1, wherein the lubricating oil further comprises a detergent selected from calcium detergents, magnesium detergents, sodium detergents, lithium detergents, and potassium detergents, optionally wherein the detergent is a carboxylate, salicylate, phenate, or sulfonate detergent.

~~6. The method of claim 5, wherein the detergent is a carboxylate, salicylate, phenate, or sulfonate detergent.~~

~~7~~6. The method of claim 1, wherein the lubricating oil further comprises a molybdenum containing compound.

~~8~~7. The method of claim 1, wherein the lubricant composition further comprises at least one other additive selected from an ashless dispersant, an ashless antioxidant, a phosphorus-containing anti-wear additive, a friction modifier, and a polymeric viscosity modifier.

~~9~~8. The method of claim 1, wherein the engine is fueled with a liquid hydrocarbon fuel, a liquid nonhydrocarbon fuel, or mixtures thereof; or wherein the engine is fueled by natural gas, liquefied petroleum gas (LPG), compressed natural gas (CNG), or mixtures thereof.

~~10. The method of claim 1, wherein the engine is fueled by natural gas, liquefied petroleum gas (LPG), compressed natural gas (CNG), or mixtures thereof.~~

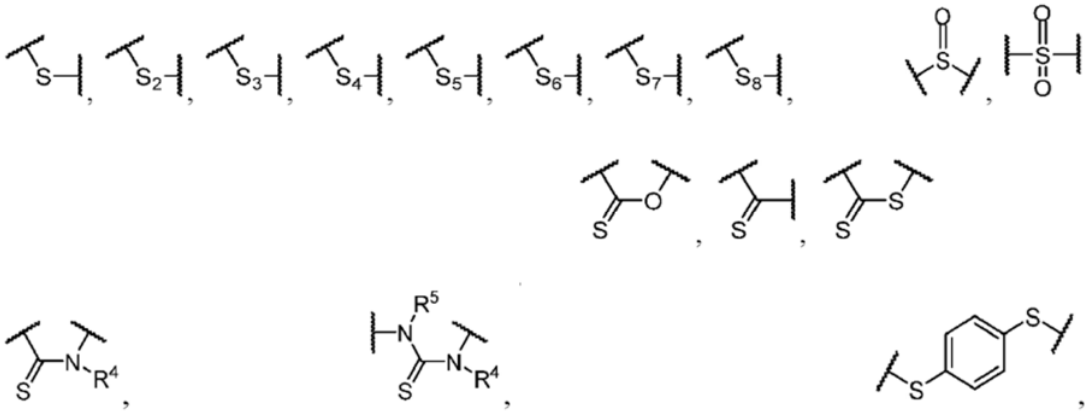
~~11~~9. Use of at least one silane-containing compound in a lubricating engine oil composition for preventing or reducing low speed pre-ignition in a direct injected, boosted, spark ignited internal combustion engine, wherein the silane-containing compound includes at least one sulfur atom in the molecule.

~~12~~10. Use of claim ~~11~~9, wherein the at least one silane-containing compound is present in from ~~about~~ 100 to ~~about~~ 3000 ppm of silicon from the at least one silane-containing compound, based on the total weight of the lubricating oil composition.

11. The method of any one of claims 1 to 8, or the use of claim 9 or 10, wherein the silane-containing compound has the following generic formular (II):

$$(R^1{}_{3-a})(R^2O)_a—Si—B—Si—(OR^2)_a(R^1{}_{3-a}) \quad (II)$$

wherein R^1 is selected from the group consisting of saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; R^2 is selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; a is an integer from 1 to 3, and B is a divalent group selected from the group consisting of a saturated and unsaturated, linear, branched, or cyclic hydrocarbyl group, a linear, branched, or cyclic siloxane or polysiloxane group, each of which comprises substituents having sulfur heteroatoms, $C_bH_{2b}—X'—C_cH_{2c}$, $(CR^4R^5)_p—X'—(CR^6R^7)_q$, b, c, p, and q are integers independently selected from 1 to 18, s is an integer greater than 2, t is an integer greater than 1, a is an integer from 1 to 3 and X′ is selected from the group consisting of:



and mixtures thereof, wherein R^4, R^5, R^6, and R^7 are independently the same or different and selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl, and saturated and unsaturated chain-substituted hydrocarbyl.

12. The method of any one of claims 1 to 8, or the use of claim 9 or 10, wherein the amount of silicon from the at least one silane compound is from 250 to 1500 ppm.

13. A lubricating engine oil composition for use in a down-sized boosted engine comprising a lubricating oil base stock as a major component; and at least one silane-containing compound, as a minor component; wherein the downsized engine ranges from 0.5 liters to 3.6 liters, wherein the silane-containing compound includes at least one sulfur atom in the molecule, and optionally wherein the lubricating oil further comprises a detergent selected from calcium detergents, magnesium detergents, sodium detergents, lithium detergents, and potassium detergents.

14. The lubricating oil composition of claim 13, wherein the silane-containing compound has the following generic formula (I):

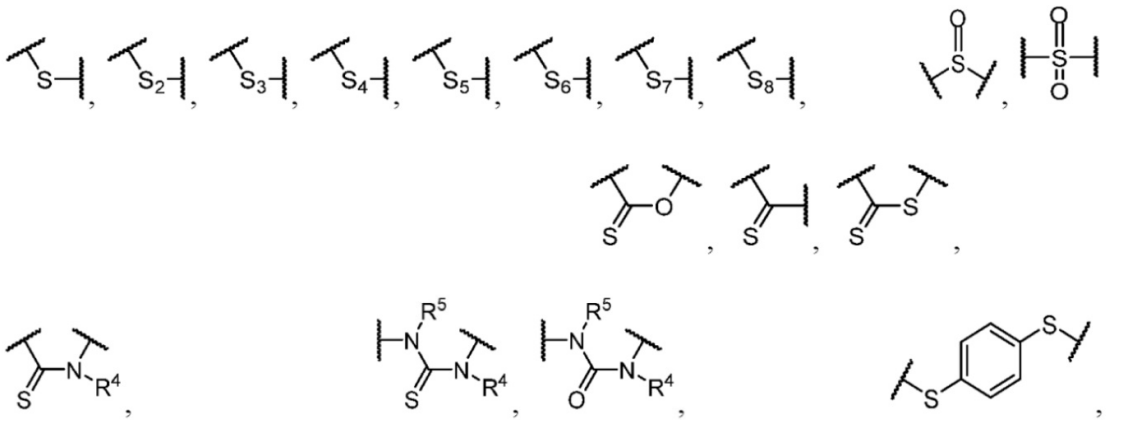
$$[(R^1)_{3-a}(R^2O)_aSi]_rA \qquad (I),$$

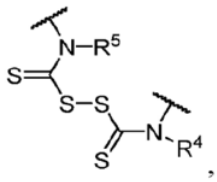
wherein R^1 is selected from the group consisting of saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; R^2 is selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; a is an integer from 1 to 3, and A is a group of valence r, r being an integer greater than or equal to 1, selected from the group consisting of saturated and unsaturated, linear, branched, or cyclic hydrocarbyl groups, ~~an oxygen atom,~~ or a linear, branched, or cyclic siloxane or polysiloxane group, each of which~~,~~ comprises substituents having sulfur heteroatoms~~except for an oxygen atom, optionally comprises substituents having oxygen, nitrogen, sulfur, or halogen heteroatoms~~.

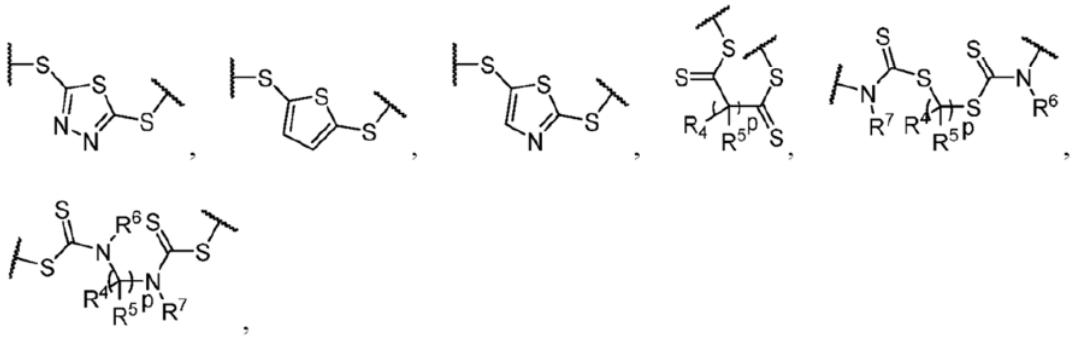
15. The lubricating oil composition of claim 13, wherein the silane-containing compound has the following generic formula (II)

$$(R^1{}_{3-a})(R^2O)_a\text{—}Si\text{—}B\text{—}Si\text{—}(OR^2)_a(R^1{}_{3-a}) \qquad (II)$$

wherein R^1 is selected from the group consisting of saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; R^2 is selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl and chain-substituted saturated and unsaturated hydrocarbyl; a is an integer from 1 to 3, and B is a divalent group selected from the group consisting of a saturated and unsaturated, linear, branched, or cyclic hydrocarbyl group, a linear, branched, or cyclic siloxane or polysiloxane group, each of which comprises substituents having sulfur heteroatoms, C_bH_{2b}—X′—C_cH_{2c}, $(CR^4R^5)_p$—X′—$(CR^6R^7)_q$, b, c, p, and q are integers independently selected from 1 to 18, s is an integer greater than 2, t is an integer greater than 1, a is an integer from 1 to 3 and X′ is selected from the group consisting of:







and mixtures thereof, wherein R^4, R^5, R^6, and R^7 are independently the same or different and are selected from the group consisting of hydrogen, saturated and unsaturated hydrocarbyl, and saturated and unsaturated chain-substituted hydrocarbyl.