

of Si, Mo, and B, and optionally provide 0.21 mass% or more of Si, Mo and B to the LOC), based upon the mass of the lubricating oil composition.

Abnormal combustion event ACE inhibitor compound(s) include metal alkylthiophosphate, metal arylthiophosphate and metal alky-arylthiophosphate (such as metal diaryldithiophosphate, such as metal dialkyldithiophosphate, such as zinc diaryldithiophosphate, zinc dialkyldithiophosphate, and the like.

ACE inhibitor phosphorus containing compound(s) are defined to be one or more phosphorus containing compound(s) that provide at least 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.24, 0.3, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) mass % or more phosphorus, to a lubricating oil composition, based upon the mass of the lubricating oil composition. ACE inhibitor phosphorus containing compounds can be compounds having more than one function, such as ZDDP which functions to provide anti-wear and antioxidant effects in addition to providing phosphorus for ACE inhibition.

The lubricating oil composition may comprise 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.24, 0.3, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) or more mass% of phosphorus, boron, molybdenum and silicon, based upon the mass of the lubricating oil composition.

Alternately the lubricating composition may comprise from 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, or 4.0) to 10 (such as 9, 8, 7, 6, or 5) mass % phosphorus, boron, molybdenum and silicon, based upon the mass of the lubricating oil composition.

Alternately, the lubricating composition comprises 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) or more mass% of phosphorus (preferably the phosphorus is derived from metal alkylthiophosphate (such as ZDDP) based upon the mass of the lubricating oil composition.

Alternately the lubricating composition may comprise from 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, or 4.0) to 10 (such as 9, 8, 7, 6, or 5) mass % phosphorus, based upon the mass of the lubricating oil composition.

Alternately, the lubricating composition comprises 0.09 (such as 0.10, 0.12, 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) or more mass% of phosphorus and comprises less than 1500 ppm, such as less than 1000 ppm, such as less than 500 (such as less than 300) mass % Ca and Na.

Alternately, the lubricating composition comprises 0.09 (0.10, 0.12, 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) or more mass% of phosphorus derived from zinc dialkyldithiophosphate and comprises less than 1500 ppm, such as less than 1000 ppm, such as less than 500 (such as less than 300) mass % Ca and Na.

Alternately, the lubricating composition comprises 0.12 (such as 0.15, 0.17, 0.2, 0.4, 0.5, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0) or more mass% or more of phosphorus, boron, molybdenum, and silicon and comprises less than 1500 ppm, such as less than 1000 ppm, such as less than 500 (such as less than 300) mass % Ca.

Experimental

All molecular weights are number average molecular weights (Mn) reported in g/mol unless otherwise noted.

5 *Testing Procedures*

Total Base Number is determined according to ASTM D2896 and reported in units of mg KOH/g.

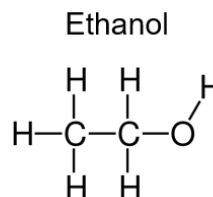
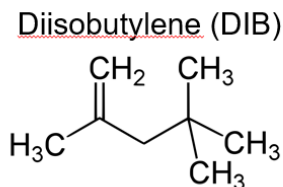
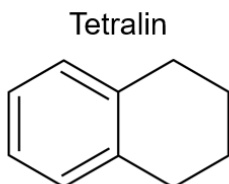
Viscosity index is measured according to ASTM D2270.

KV₁₀₀ is Kinematic viscosity measured at 100 °C according to ASTM D 445-19a.

Sequence IX Testing

- 10 The Sequence IX Test, ASTM D8291-19, is a standard test method for evaluation of performance of automotive engine oils in the mitigation of low-speed, preignition in the Sequence IX gasoline turbocharged direct-injection, spark-ignition engine. 93 octane gasoline reference fuel (Haltermann HF-00003 EEE Lube Certification Gasoline, Haltermann Solutions, Houston, Texas) and 88 octane gasoline reference fuel (Haltermann HF-02021 EPA Tier 3 EEE Emission Certification Fuel, Regular Octane,
- 15 Haltermann Solutions, Houston, Texas) were used in the Sequence IX test, along with Reference oils 220 and 224 obtained from the Test Monitoring Center (Freeport, Pennsylvania, USA, www.astmtmc.org).

Materials



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Table 1

Lubricating Oil Blend 1 (Components)	Concentrate Wt %	Wt% in oil (9.31% treat rate)
PIBSA-PAM 2300 g/mol Mn	32.23	3.001
Si anti-foamant.	0.03	0.003
Magnesium sulfonate detergent TBN 400 mg KOH/g.	20.57	1.915
Diarylamine antioxidant	3.22	0.300

Lubricating Oil Blend 1 (Components)	Concentrate Wt %	Wt% in oil (9.31% treat rate)
Phenol antioxidant	3.22	0.300
PIBSA 950 Mn	2.15	0.200
LOFI blend of diluent and dialkyl fumarate vinyl acetate copolymer. Kv100 approx 175 cSt	0.54	0.050
ZDDP	31.59	2.941
fatty acid ester friction modifier	3.76	0.350
octadecenyl succinic anhydride	2.69	0.250
PPD blend of diluent and dialkyl fumarate vinyl acetate copolymer. Kv100 approx 85 cSt		0.300
Viscosity Modifier (hydrogenated styrene-diene copolymer/diluent)		5.000
Diluent Oil		0.663
Group III base oil KV ₁₀₀ 4 cSt		63.850
Group III base oil KV ₁₀₀ 8 cst		21.540
Total	100	100

Examples

Example 1

5 Lubricant Oil Blend 1, Oils 220 and Oil 224 were evaluated for abnormal combustion events (such as low-speed pre-ignition) performance according to Sequence IX Testing as described above. The pass/fail parameter based on the average number of LSPI events (in four total iterations) was 0 events in 98 octane fuel and less than 2 LSPI events in 88 octane fuel. The results are reported in Table 2.

Table 2

	Oil 224	Oil 220	Lubricating Oil Blend 1 "NK" in Fig 1.
B (ppm)	0	241	0
m% Ca	0.143	0.1125	0
m% Mg	0.084	0	0.174
Mo (ppm)	55	96	0
m% P	0.075	0.080	0.20
m% S	0.308	0.2083	0.4726
m% Zn	0.082	0.0878	0.220
SAE Viscosity Grade	5W-30	5W-30	5W-20
Seq. IX Avg Events w/ 93 Octane fuel	Aprox 4	Approx 1	0 Test completed