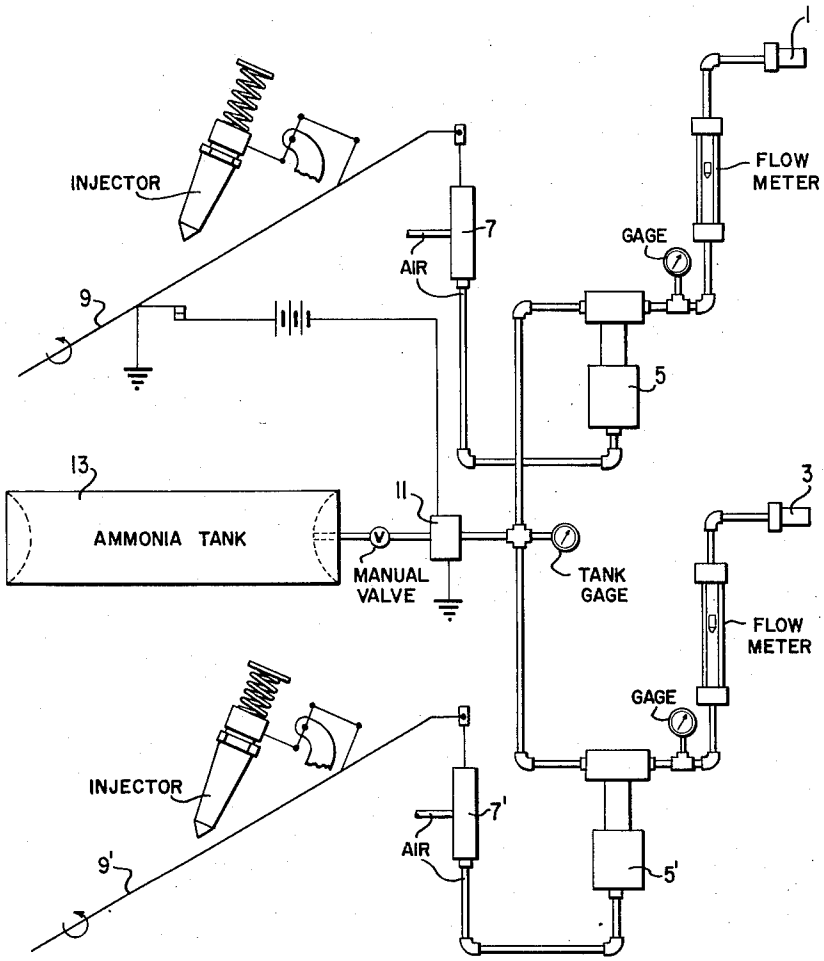
Sept. 29, 1964 A. V. MRSTIK ETAL 3,150,645

METHOD OF OPERATING A COMPRESSION-IGNITION ENGINE

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FIG 1



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FIG 2

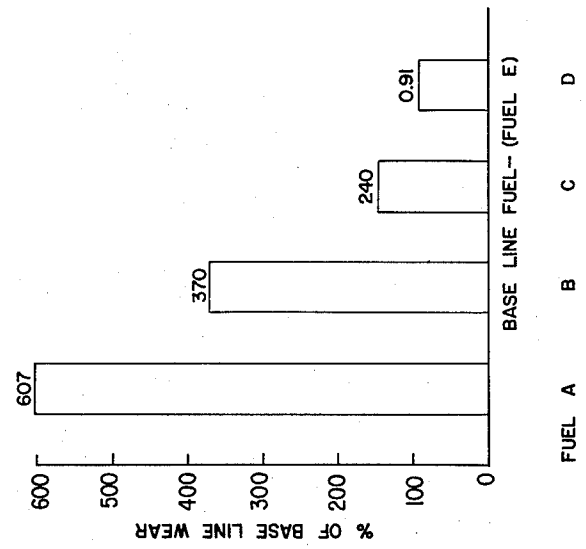
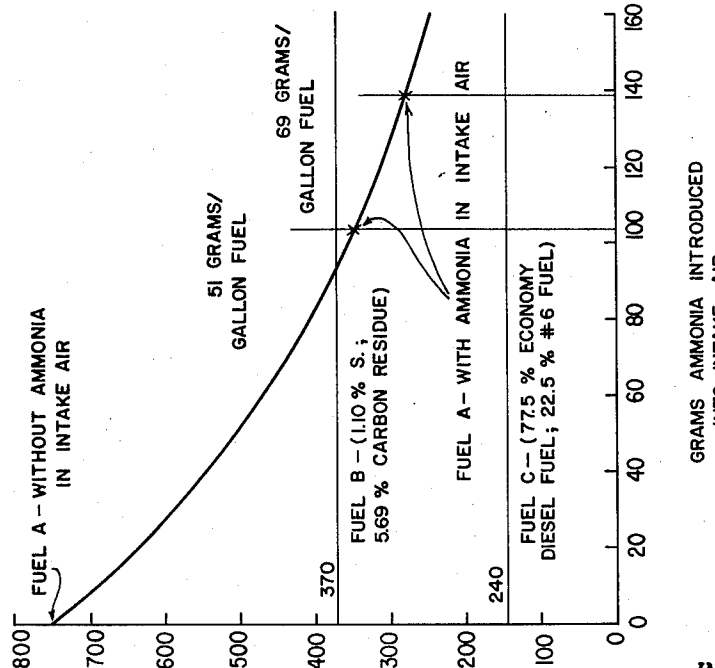


FIG 3



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METHOD OF OPERATING A COMPRESSION-IGNITION ENGINE

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The present invention relates to a method of reducing wear in compression-ignition engines burning residual fuels of high sulfur and carbon residue content.

The diesel fuels acknowledged as possessing characteristics most advantageous for buring in compression-ignition engines, particularly from the standpoint of engine wear, are the straight run distillate type diesel fuels characterized by low sulfur and carbon residue content or fuel blends containing in large part the straight run distillates. On the other hand, the burning of residual fuels or cutback residuel fuels of high sulfur and carbon residue content is known to cause excessive wear of power assembly components such as rings and liners, especially when the engine is operating at part load or idling. For example, the part load ring wear resulting from the burning of residual fuels of high sulfur and carbon residue content has been reported to be as much as 25 times that obtained with economy type distillate fuels. Economy type fuels are widely used diesel fuels and usually represent blends of straight run and catalytically cracked stocks with the latter type frequently predominating. Thus, for obvious economic reasons, a method of buring these residual fuels so as to obtain a reduced rate of engine wear, particularly piston ring wear, becomes highly desirable.

Residual fuels are currently being used to a limited extent in the operation of locomotive diesels but only under high load conditions, i.e. in seventh and eighth throttle positions. Distillate fuel is used for idle and part load operation. This method of using residual fuel in locomotive engines is called "Dual-Fuel" operation. The present invention permits the employment of high sulfur, high carbon residue content residuals across the entire load range of the locomotive diesel without the assist of fuel containing only distillates for part load operation.

It has now been discovered that in a compression-ignition engine wherein a residual fuel of high sulfur and carbon residue content is burned in the cylinders in the presence of combustion air, the piston ring wear of the engine can be substantially reduced by having in the combustion chamber of the engine prior to, i.e. during compression, and at the time of fuel injection, combustion air and a vaporous nitrogen compound selected from the group consisting of ammonia and low molecular weight alkyl amines. This can be accomplished, for example, by injecting the vaporous nitrogen compound into the air intake of the engine whereby the combustion air and nitrogen compound simultaneously enter the cylinders or the nitrogen compound can be added to the cylinders directly, thereby mixing with the combustion air for the burning operation. Thus the mixture of air and vaporous nitrogen compound is in the engine cylinder when the fuel is injected for ignition and burning. By "vaporous" is meant pure gaseous or dispersed condensed particles of the nitrogen compound under the conditions existing in the chamber where the fuel is burned.

Low molecular weight alkyl amines suitable for use in the present invention are, for example, primary, secondary and tertiary alkyl amines wherein the alkyl group contains from say 1 to 4 or perhaps even 6 carbon atoms. The preferred alkyl amines are diethyl amine and trimethylamine. The actual rate of ammonia or alkyl amine introduced will be dependent on the specific type and grade of residual fuel selected, the particular engine utilized, the power output at which the engine is run, etc. but in any event will be sufficient to substantially reduce the piston ring wear. Generally, best results are obtained when ammonia or the alkyl amine is introduced at a rate of about 5 or 10 to 100 or more grams per gallon of fuel, the upper limit being a matter of economics. An effective range for achieving a ring wear reduction of between about 40–60% of the ring wear obtained on a cutback residual fuel of 1.75% sulfur and 6–7% carbon residue content without introduction of the nitrogen compounds, is about 20–70 grams per gallon of fuel. Improvement is obtained with as little as about 5 grams of diethylamine per gallon of fuel. It is important that the engine combustion chamber be provided with the vaporous ammonia or alkyl amine in the manner stated above since injection of the gaseous nitrogen compounds directly into the residual diesel fuel for example is ineffective.

The residual fuels of the type referred to in this invention can be derived from various crudes, for example, naphthenic, paraffinic and Mid-Continent crudes. The residual component of such fuels are commonly obtained as still bottoms from vacuum flashing topped crudes and as bottoms from thermal and catalytic cracking operations. Usually, these residual stocks are cut back to appropriate viscosity levels by means of distillate cutter stocks to produce three grades of fuel commonly referred to as ASTM #4, #5 and #6 residual fuels. ASTM #4 grade fuels have a kinematic viscosity range at 100° F. of between 5.8 to 26.4 centistokes. The kinematic viscosity of ASTM #5 grade residual fuels will range from 32.1 centistokes at 100° F. to 81.0 centistokes at 122° F. ASTM #6 residual fuels will have a kinematic range at 122° F. of 92.0 to 638. The API gravities of such fuels will usually range from about 10 to 30.

The type of residual fuels with which this invention is largely concerned is the ASTM 4 grade, i.e. residual stocks cut back with 50% or more of a distillate cutter stock composed either of straight run distillate, catalytically cracked distillate, or combinations of straight run and catalytically cracked distillates. Economy diesel fuels may well represent a type of distillate fuel used for cutting back residual stocks to produce a residual diesel fuel possessing the required handling characteristics for use in locomotive diesel engines. Residuel stocks may be cut back with appropriate distillates to give the finished product other desirable properties in addition to handling characteristics. These properties are cetane number, viscosity, sulfur and carbon residue level, volatility as well as metals content. Residual fuels as implied in this invention are blends of any type which contain residual stocks amounting to about 5% or more in volume, often

about 25–80%. In one specific aspect this invention relates to the burning of residual type fuels containing about 40–60% of distillate cutter stock composed of straight run and/or catalytically cracked components.

Further, the fuels employed in this invention are residual type fuels having a sulfur content in excess of about 1.25 weight percent and a carbon residue level in excess of about 3.5 weight percent. Ring and liner wear when burning residual fuels of below about 1.25% sulfur and below about 3.5 carbon residue level is helped but is not materially improved by the addition of ammonia or vaporous nitrogen compounds. As will be demonstrated below, the method of the present invention is not especially applicable or effective in the burning of distillate fuels having a sulfur level of below about 1.5 weight percent and, in fact, may increase piston-ring wear to a minor degree instead of reducing it.

Any technique can be used to supply the ammonia to the diesel engine and relatively inexpensive items of additional equipment would be required. For example, a cylinder of ammonia, a pressure reducing valve, a flow meter and a simple orifice in the air intake manifold of the engine will suffice for carrying out the injection of the ammonia. An example of a workable system for the introduction of ammonia or other gaseous nitrogen compounds into the intake air of a diesel locomotive engine is shown in FIGURE 1.

This system is a dual system for the right and left bank of cylinders of a V block engine where separate air blowers are used for each bank. The fixed orifice nozzles 1 and 3 are installed in the air intake of each blower. A variable pressure regulator 5 and 5′ is employed for each bank of cylinders to meter the proper amount of ammonia or other vaporous nitrogen compounds in accordance with engine load, i.e. fuel output. In the operation of a 2400 H.P. locomotive on residual fuel the amount of gas introduced into the engine air intake will vary from around 0.5 pound per hour at idle to as high as sixteen pounds per hour at full load operation. Each fixed orifice therefore must be capable of accurately delivering ammonia, diethylamine, or trimethylamine over a range of about 0.25 lb. to 8 lbs. per hour by means of the variable pressure regulating valves 5 and 5′. A standard 400# tank of ammonia would be adequate for 25 hours of operation at full load for a 2400 horsepower locomotive.

The schematic drawing of the gas system shows the variable pressure regulating valve to be controlled by an air operated pilot valve 7 connected by mechanical linkage to each injector lay shaft 9, 9′. This could also be done electrically, hydraulically, or fully mechanically.

A solenoid valve 11 is shown between the ammonia tank 13 and pressure regulating valves 5, 5′. This valve is actuated through electrical contacts 13 on one of the injector layshafts 9. When diesel fuel is not being used these contacts are open and the solenoid valve 11 is closed, thus preventing escape of the gaseous nitrogen compounds into the atmosphere. This valve 11 is thus open only when the layshaft 9, 9′ is rotated to open the rack of the fuel injectors thus admitting fuel into the combustion chambers.

For an in-line engine the dual ammonia injection system would not be required. In a perfectly synchronized V-block engine the dual system possibly could be dispensed with. A common air intake containing a single fixed orifice for each bank of cylinders would be required in this arrangement.

The following examples are included to further illustrate the present invention.

EXAMPLE I

Fuels designated A, B, C, D and E were tested for piston ring wear in a GM 2–71 diesel engine. The identity and physical properties of the test fuels are shown in Table I.

Table I

Fuel	A	B	C	D	E
Gravity, °API	20.7	15.4	29.8	37.3	33.0
Specific Gravity	.9297	.9632	.8772	.8383	.8602
Wt./Gallon, lbs	7.742	8.021	7.305	6.980	7.163
Gross Heating Value, B.t.u./lb	18,770	18,450	19,165	19,710	19,470
Gross Heating Value, B.t.u./gal	145,300	148,000	140,000	136,600	139,500
Flash, PM	178	182		156	206
Saybolt Vis. at 100° F. SUS	74.9	92.3		34.0	41.5
Saybolt Vis. at 150° F. SUS			34.7		
Saybolt Vis. at 210° F. SUS	37.0	39.1			
Cloud, ° F				−8	+18
Pour, ° F	−10	−40		−25	+15
Color, ASTM				2.0	0.5
Carbon Residue, percent (Ramsbottom)	6.72	5.69	2.77	0.14	0.095
Sulfur, percent	1.83	1.10	1.15	0.73	1.09
ASTM, Ash percent	0.009	0.023			84.9
Pentane Insols	3.862	8.503	1.962	1B	1A
Benzene Insols	0.559	0.956			
Insol. Resins	3.303	7.547			
SO_4 Ash of Benzene Insols	0.030	0.011			
Cetane No	36.2	23.0	44.1	47.7	51.2
200 cc. Dist.:					
IBP	(1)	[1] 308	346	356	468
50	615	565	505	478	570
EP				608	670

[1] Vacuum distillations.

Fuel A.—A cut-back residual fuel of 1.83% sulfur composed of 53.0% economy type distillate diesel fuel and 47% No. 6 residual fuel. The economy type distillate fuel is composed of 80% straight-run distillate fuel and 20% fluid light cycle oil.

Fuel B.—A cut-back residual fuel of 1.1% sulfur.

Fuel C.—A cut-back residual fuel of 1.15% sulfur having a composition of 22.5% No. 6 residual fuel and 77.5% economy type distillate diesel fuel.

Fuel D.—Economy type distillate diesel fuel of 0.73% sulfur content.

Fuel E.—1.0% sulfur straight-run distillate. This fuel was used for engine calibration purposes and for relative evaluation of all test fuels.

The GM 2–71 diesel engine was equipped with radioactive compression rings installed in the second grooves of the pistons. The fuel system was modified slightly to permit operation on either cut-back residual fuel or on distillate fuel. The lubricating oil system of the engine is provided with a shielded monitoring well which contains a scintillation counter. The ring wear rate was determined by passing the lubricating oil through the monitoring well and therein detecting the concentration of activated iron transported to the oil due to wear of the piston rings. Prior to the running of each test fuel the engine was standardized to a constant ring wear rate with 1.0% sulfur distillate fuel. The test fuels were run either on the basis of a single 5-hour run or on a 3-hour back-to-back basis, that is, running one test fuel for 3 hours followed immediately by another test fuel for 3 hours. The back-to-back basis was used when it was found that a constant wear rate could be reached in 3 hours or less. The engine was run at a load of 30 horsepower and a speed of 1200 r.p.m. The relative wear data (i.e. percent of base line wear) obtained with the basic test fuels as compared to that obtained with the 1% sulfur fuel (Fuel E) is shown in FIGURE 2. The percent of base line wear data for fuels A and B represent an average of several tests. In the case of fuels C and D the percent of base line wear is based on single tests.

Examination of the data in FIGURE 2 shows that the ring wear on Fuel A (a 47/53% blend of #6 residual fuel and economy fuel, respectively, having a sulfur level of 1.83%) is over 6 times that obtained on the economy type distillate diesel fuel alone. The sulfur content of this latter fuel is 0.73%.

The ring wear obtained with Fuel B (a 1.1% sulfur cutback residual fuel) is substantially less than that ob-

tained on Fuel A despite the fact that except for sulfur content, the quality of the fuel is either comparable and, in certain respects, e.g. cetane number, inferior to that of Fuel A. These data tend to indicate that since sulfur level is the observed major difference between Fuels A and B that this property, i.e. sulfur level or a functional effect associated with sulfur is largely responsible for the bulk of the ring wear obtained when burning Fuel A.

It will also be noted that when #6 residual fuel is cut back with 77.5% of economy type distillate diesel fuel (Fuel C), the resulting ring wear rate is appreciably lower than that obtained on Fuel B despite the fact that in this case the sulfur levels of the two fuels are nearly identical (1.1% vs. 1.15%). These observed variations in ring wear indicate that the lower rate of ring wear obtained on Fuel C must be due to other favorable characteristics. One of the principal differences between Fuels B and C is the lower carbon residue level of Fuel C (5.69% vs. 2.77%). There are other differences of course, e.g. cetane number, but it has been established that cetane number is not controlling.

Fuel E is also closely similar to Fuels B and C with respect to sulfur content (1.09%: 1.10%: 1.15%) yet there are wide differences in their carbon residue levels (0.095%: 5.69%: 2.77%). The difference in the carbon residue levels of these fuels is believed to be reflected in the relative rates of ring wear obtained on the three fuels. Fuel B with a carbon residue level of 5.69% gave a rate of ring wear 3.7 times that of Fuel E which had a carbon residue level of 0.095%. Fuel C with a carbon residue level of 2.77% gave a rate of ring wear 2.5 times that of Fuel E. These data are shown in Table I.

Thus the analysis of the data of FIGURE 2, coupled with the characteristics of the fuels shown in Table I, indicates that sulfur or a side effect attributable to sulfur is chiefly responsible for the high wear encountered with cut-back residual fuels. A second major cause of wear with such fuels appears to be high carbon residue.

EXAMPLE II

Back-to-back runs were made in the GM 2–71 engine as in Example I using Fuel A with and without the concurrent introduction of substantially anhydrous ammonia into the air intake of the engine at a rate of 69 grams/gallon of cutback residual fuel (Fuel A). A wear rate reduction of 15.3% was noted when using ammonia in combination with Fuel A. Since past experience has shown that when a low wear fuel follows a high wear fuel in a back-to-back run, a true evaluation of the low wear fuel may be clouded by a carry-over effect of the high wear fuel. A second back-to-back run was therefore made wherein Fuel A plus air intake introduction of ammonia preceded the run on Fuel A without ammonia. A 63.5% reduction in wear was noted with the ammonia. A similar back-to-back test was run in which the quantity of ammonia introduced was reduced to 51 grams/gallon of fuel, and a 49% reduction in wear was realized over that resulting with Fuel A, neat.

FIGURE 3 is a plot of percent of base line wear vs. grams of ammonia introduced into the intake air when operating on Fuel A. For purposes of reference, percent of base line wear data for Fuel B, and Fuel C are also given in this chart. It is apparent that the wear obtained with Fuel A using 69 grams of ammonia per gallon of fuel, in the intake air stream per gallon of diesel fuel nearly approaches that obtained on Fuel C whose residual fuel component is the same as that of Fuel A cutback with 77.5% of economy diesel fuel. That is, the addition of ammonia to the intake air had the same result as reducing sulfur content of Fuel A from 1.83% to 1.15% and carbon residue level from 6.72% to 2.77%.

EXAMPLE III

Fuel A of Table I was burned in the GM 2–71 test engine as in Example I with and without the injection of ammonia at a rate of 59 grams/gallon of diesel fuel. The piston ring wear results are shown in Table II.

Table II

Test Fuels	Ring Wear, Mg./Hr.	Test Fuel Wear/Base line fuel wear	Percent Wear Reduction relative to Fuel A
Fuel E	0.15		
Fuel A	2.83	18.8	
Fuel A + NH_3 in intake air	1.66	11.1	41.3

EXAMPLE IV

Fuel E of Table I, a 1% sulfur straight run distillate was tested in the GM 2–71 engine as in Example I without and with the injection of ammonia into the air intake at rates of 50 g./gal., 102 g./gal., and 138 g./gal. The results are shown in Table III.

Table III

Fuel:	Wear mg./hr.
1% S. Distillate Fuel (Fuel E)	0.286
Fuel E+50 gr. NH_3 in intake air (25 gr./gal. of fuel)	0.340
Fuel E+12 gr. NH_3 in intake air (51gr./gal. of fuel)	0.354
Fuel E+138 gr. NH_3 in intake air (69 gr./gal. of fuel)	0.420

The data of Table III shows that the addition of ammonia to the engine intake air when burning a 1% sulfur distillate fuel tends to increase ring wear rather than decrease it as is the case when burning the high sulfur content residual fuels of the present invention.

EXAMPLE V

Fuel A of Table I was burned in the GM 2–71 test engine as in Example I with and without the injection of diethylamine (B.P. 132° F.) into the engine air intake. The test results are shown in Table IV.

Table IV

Test Fuels	Ring Wear, mg./hr.	Ratio of test fuel wear to Base line fuel wear	Percent Wear reduction relative to Fuel A, neat
Fuel E	0.16		
Fuel A	2.98	18.6	
Fuel A+diethylamine in intake air (5 gr./gal. Fuel A)	1.84	11.5	38.3
Fuel A+diethylamine in intake air (23 gr./gal. Fuel A)	1.62	10.1	45.7

As shown in Table IV a wear reduction of 38.3% and 45.7% is obtained on Fuel A by the concurrent introduction of diethylamine in the engine intake air at a rate of 5 gr./gallon of Fuel A in the first instance and 23 gr./gallon of Fuel A in the second instance.

Fuel A was also similarly burned but with and without the injection of trimethylamine (B.P. 28° F.) into the engine air intake. The test results are shown in Table V.

Table V

Test Fuels	Ring Wear, mg./hr.	Ratio of test fuel wear to Base line fuel wear	Percent Wear reduction relative to Fuel A, neat
Fuel E	0.12		
Fuel A	2.36	19.7	
Fuel A+trimethylamine in intake air (58 gr./gal. Fuel A)	1.06	8.8	55.0

As shown in Table V a wear reduction of 55.0% is obtained on Fuel A by the concurrent introduction of

58 g. of trimethylamine per gallon of fuel, in the engine intake air when burning Fuel A. The data of Tables IV and V demonstrate that diethylamine and trimethylamine are even more effective than ammonia when introduced into the engine intake air while using high sulfur, high carbon residue level cutback residual fuel.

EXAMPLE VI

The unusual effect of introducing gaseous nitrogen compounds into the engine intake air to combat the deleterious wear characteristics of high sulfur, high carbon residue level residual fuels is demonstrated by the data shown in Table VI. In this table data are presented to show that the addition of diethylamine to the residual fuel has a greatly reduced effectiveness compared with introduction of the material through the engine intake air. Further, the quantity of diethylamine introduced in the latter manner to achieve a given reduction in ring wear is much less than if the same material is incorporated in the fuel.

Table VI

Test Fuels	Ring Wear, mg./hr.	Ratio of test fuel wear to Base line fuel wear	Percent Wear reduction relative to Fuel A, neat
Fuel E	0.46		
Fuel A	2.62	5.7	
Fuel A+200 gr./gal. diethylamine	2.24	4.9	14.5

We claim:

1. In a method of operating a compression-ignition engine wherein is burned in the presence of combustion air a diesel hydrocarbon fuel having a sulfur content of at least about 1.25 weight percent and a carbon residue number of at least about 3.5, said diesel fuel

containing at least about 5% of residual hydrocarbon fuel oil the step of providing in the engine combustion chambers at the time of fuel injection a mixture of combustion air and a vaporous nitrogen compound selected from the group consisting of ammonia and low molecular weight alkyl amines in an amount sufficient to reduce piston ring wear.

2. The method of claim 1 wherein the amount of the vaporous nitrogen compound added is about 5 to 100 grams/gallon of fuel and sufficient to reduce piston ring wear.

3. The method of claim 1 wherein the vaporous nitrogen compound selected is ammonia.

4. The method of claim 3 wherein the amount of ammonia injected is about 20 to 70 grams/gallon of fuel.

5. The method of claim 1 wherein the alkyl amine is diethylamine.

6. The method of claim 1 wherein the alkylamine is trimethylamine.

7. The method of claim 1 wherein the diesel fuel consists essentially of distillate hydrocarbon fuel oil and about 25 to 80% of residual hydrocarbon fuel oil.

8. The method of claim 7 wherein the diesel fuel contains about 40 to 60% of distillate fuel oil.

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