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LUBRICITY OF WELL-CHARACTERIZED JET AND BROAD-CUT FUELS BY BALL-ON-CYLINDER MACHINE

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SUMMARY

A ball-on-cylinder machine (BOCM) was used to measure the lubricity of fuels. The fuels tested were well-characterized fuels available from other programs at the NASA Lewis Research Center plus some in-house mildly hydroprocessed shale products. The fuels from other programs included Jet-A, ERBS fuel, ERBS blends, and blend stock. The BOCM tests were made before and after clay treatment of some of these fuels with both humidified air and dry nitrogen as the preconditioning and cover gas. As expected, clay treatment always reduced fuel lubricity. Using nitrogen preconditioning and cover gas always resulted in a smaller wear scar diameter than when humidified air was used. Also observed was an indication of lower lubricity with lower boiling range fuels and lower aromatic fuels. Gas chromatographic analysis indicated changes in BOCM-stressed fuels.

INTRODUCTION

The use of heavy crudes and residual oils as a fraction of the feedstock to refineries has been increasing. Thus less jet fuel is produced normally, that is, by atmospheric distillation. Heavy crudes in the refinery feedstock require cracking and hydrotreating beyond that formerly used in order to meet the refinery product slate. Residual oils require delayed coking or fluid coking followed by hydrotreating in order to be used as a refinery feedstock. Consequently Jet A from these feedstocks will have experienced significant hydroprocessing. This product may have a lower freezing point, better stability, and poorer lubricity than straight run virgin Jet-A product. The fact that hydroprocessing may produce a poor lubricity fuel has been reported by a number of workers (refs. 1 to 3). One of the main reasons for this is the removal of naturally occurring polar compounds during hydroprocessing.

In addition to polar compounds, which include sulfur, nitrogen, and oxygenated compounds, other characteristics of fuels that can affect friction and wear in fuel systems are viscosity, volatility, aromatics, and dissolved oxygen (ref. 2). Jet fuels from highly processed heavy crudes or residual oils can have changes in the characteristics that affect lubricity. Also, the physical and chemical property changes in a broadened-specification fuel could have an influence on lubricity. The properties of some broadened-specification fuels used in NASA Lewis Research Center fuels programs are reported in references 4 and 5.

The literature reports various means used for determining fuel lubricity. One frequently used is the ball-on-cylinder machine (BOCM) (ref. 3). The BOCM has been selected by the military and the Coordinating Research Council (CRC) for their lubricity programs (ref. 6).

In the present work the BOCM was used to determine the lubricity of a broad spectrum of well-characterized research fuels that vary in lubricity. These include ERBS fuel, ERBS fuel blends, and hydroprocessed fuels. Most of the fuels were tested before and after clay treatment. After clay treatment the lubricity performance of a fuel should be similar to that of a highly refined fuel (ref. 6). To determine the significance of dissolved oxygen, dry nitrogen was used for preconditioning and as a cover gas for BOCM tests on some fuels. All of the fuels were tested with air as the preconditioning and cover gas.

APPARATUS

The ball-on-cylinder machine was built in-house according to drawings furnished by Woodward Governor Company. The BOCM (shown in fig. 1 without the drive motor) was similar to the original Exxon design and other BOCM's used by CRC members in a roundrobin test series. As has been the case for most other users of a BOCM, only wear measurements were made in the present study.

During operation of the BOCM there was a cover over the rotating cylinder (fig. 1) with an opening at the top for the ball. The 1.27-cm-diameter ball with a Rockwell hardness of C64 to C66 was held in a chuck and was forced vertically downward against the top of the 1.80-cm-diameter rotating cylinder. The cylinder had a Rockwell hardness of C20 to C22. The bottom portion of the cylinder was covered by the fuel in the fuel reservoir as it rotated. The shaft of the cylinder was connected to the variable-speed motor through a 5/1 reduction gearbox. Motor speed was maintained at 240 rpm throughout testing. The axial position of the cylinder on the shaft could be adjusted so that 14 to 16 wear measurements could be made. Tubes penetrated the reservoir and reservoir cover to provide access for the preconditioning and cover gas. A 500-g load at the end of the balance arm provided the required 1000-g load of the ball at the center of the balance arm.

Fuel moisture content has a significant effect on wear results (ref. 3); therefore fuel preconditioning and cover gas humidity is important for consistent results. Figure 2 shows the preconditioning-and-cover-gas system used during BOCM testing. The gas, either air or nitrogen, was separated into two streams. One stream was saturated with water, and the other stream was dried. The two streams were combined to give the desired humidity in the gas. The gas humidity was determined by passing a known volume of gas through a tube of Drierite and measuring the increase in weight.

A clay column was used for reducing fuel lubricity by removing the polar compounds. The clay column was made of glass 5.08 cm i.d. and 152 cm high. It was filled three-quarters full of Attapulgus clay 30/60 mesh, LVM (calcined) grade. The total volume of clay in the column was 1850 cm^3. Valves at each end of the column were used for flow control.

During a test the only instrumentation used was rotometers for measuring the wet and dry gas flow and a portable oscilloscope for measuring the cylinder rpm. A controller matched to the variable-speed motor controlled cylinder rotation to ±2 rpm. After completion of the BOCM test the wear scar was measured by using a 100X microscope with a measuring reticle.

PROCEDURE

Ball-on-Cylinder-Machine Tests

At least two wear scar diameter tests were made on most fuels for each test condition. The two conditions were 10-percent-humidity air as the purge and cover gas or dry nitrogen as the purge and cover gas. If there was only a limited quantity of fuel for characterization and testing, only one test, with 10-percent-humidity air, was performed.

Before each fuel was tested, the ball vice assembly, ball, cylinder, and fuel reservoir were cleaned in an ultrasonic cleaner. The cleaning fluid was Micro cleaner in water. The parts were removed from the ultrasonic cleaner, dried, and rinsed with iso-octane. The iso-octane-rinsed parts were then dried and assembled in the BOCM tester. From the time the parts were removed from the ultrasonic cleaner, they were only handled with clean tongs and lint-free laboratory tissue.

If a test was a repeat with the same fuel with either cover gas, the stressed fuel was removed and the ball replaced with a clean ball. This was followed by rinsing the fuel reservoir, cylinder, and ball assembly thoroughly with iso-octane. The system was then dried with lint-free laboratory tissue and dry nitrogen.

While the BOCM was being cleaned, the cylinder was positioned for a new wear scar track. Positioning of the cylinder was done by using a micrometer. Fourteen wear tracks were made on a cylinder before resurfacing was required. Wear tracks were located 1.27 mm from each other or from the cylinder edge.

After the BOCM was readied for testing, 50 cm^3 of fuel was placed in the fuel reservoir. Purge gas (either 10-percent-humidity air or dry nitrogen) was bubbled through the fuel at the rate of 11.8 cm^3/sec for 15 min by adjusting the system valves (fig. 2). For the air purge the humidity was determined by measuring the water content of a sample of gas. After the 15-min purge valves were adjusted to use the same gas as a cover gas for the BOCM test. The gas flow rate was kept at 11.8 cm^3/sec. After the gas had been diverted over the fuel, the motor was started and adjusted to a speed of 240 rpm. The 500-g mass was placed at the end of the lever arm (fig. 1), and the lever arm was lowered until the ball rested on the rotating cylinder. After 30 min the lever arm was raised, removing the contact between ball and cylinder, and the motor was stopped. The ball and vice were removed from the lever arm. After the ball was rinsed with iso-octane, the major and minor diameters of the elliptical wear scar were measured by using a 100X microscope with a measuring reticle. Measurements could be read to about 0.0125 mm. The average of the major and minor diameters was the wear scar diameter. All BOCM tests for the present work were run at 25.5 °C.

The BOCM testing just described is very similar to that used by Woodward Governor Company (private communication). The main difference between this procedure and that used in reference 6 is that test time in the reference 6 work was 32 min.

Clay Treatment of Fuel

To have sufficient fuel for characterization and lubricity testing after clay treatment, approximately 4 liters of fuel before clay treatment was required. In some cases, the test quantities of fuel were inadequate for clay treatment.

A fuel was clay treated by pouring it into a reservoir at the top of the clay column described in the section APPARATUS. As soon as fuel started flowing from the bottom of the column, the exit valve was adjusted for a flow rate of 50 to 55 cm^3/min. Flow rate was determined by measuring the flow into a graduated cylinder over a 2-min period. The first liter of fuel that flowed through the column was collected in a waste fuel container and discarded. The rest of the fuel was collected and stored in a bottle that had been cleaned, rinsed with iso-octane, and oven dried. A fuel that was clay treated one day was always tested in the BOCM the next day.

TEST FUELS AND FUEL CHARACTERIZATION

The fuels used in the present work were those available from other programs at Lewis and from some in-house hydrotreating. These fuels were either in the Jet A boiling range (121 to 300 °C) or the broad-cut boiling range (121 to 327 °C). The fuels included Jet-A; Jet-A (twice filtered); experimental referee broadened-specification (ERBS) fuel (12.8 percent H); ERBS blend (12.3 percent H); ERBS blend (11.8 percent H); blend stock; Paraho JP-5; coker distillate Jet-A; Geokinetics (Jet-A cut); Geokinetics (broad cut); Occidental (Jet-A cut); Occidental (broad cut); TOSCO (Jet-A Cut); TOSCO (broad cut); Paraho (Jet-A cut); and Paraho (broad cut). All of the Geokinetics, Occidental, TOSCO, and Paraho fuels were mildly hydrotreated.

The Jet-A was obtained commercially and was used as a standard for the present work. The twice-filtered Jet-A is an upgraded fuel used in thermal stability studies. The ERBS fuel, ERBS blends, and blend stock have been extensively used in Lewis fuels program and are well characterized (refs. 4 and 5). The Paraho JP-5 is a specification-grade JP-5 derived from shale oil and was obtained from the Navy. The remainder of the fuels were hydroprocessed in-house. The coker distillate was processed sufficiently severely to remove the sulfur and nitrogen. The shale products (Geokinetics, Occidental, TOSCO, and Paraho) are the distilled products from mildly hydrotreated whole-shale syncrude where all the sulfur and only some nitrogen were removed. These shale oil products were prepared in-house by using a 1-liter hydroprocessing unit and a 1-gal batch distillation column.

Either ASTM tests or acceptable substitutes were used for characterizing the fuels. The fuel characterization results are shown in table I. Since most properties would not change during clay treatment, only those properties that may have changed were measured on clay-treated fuels.

In addition to normal characterization, the Jet-A ERBS fuels and ERBS blends were analyzed with a capillary gas chromatograph before and after BOCM testing to determine if any composition changes occurred. The gas chromatograph was equipped with a hydrogen flame ionization detector (FID). The capillary column used was a 60-m fused-silicon column with a 0.25-mm internal diameter coated with liquid-phase methyl silicone. The carrier gas was helium

at a flow rate of 1 milliliter/min measured at the outlet of the column. Fuels analyzed in the gas chromatograph were diluted tenfold (1:10) with methylene chloride. One microliter of diluted fuel was injected into the gas chromatograph, where the sample volume was split in the ratio of 1:100. The fraction of fuel entering the column was separated into individual fuel components by programming the oven temperature to increase at the rate of 2 deg/min from 50 to 280 °C.

RESULTS AND DISCUSSION

Wear scars were typical of those obtained by others. An example is shown in figure 3 for ERBS blend (11.8 percent H) with air as the cover gas. Results of all wear scar measurements are shown in table II. The results are the average of two tests except for the fuels from the in-house hydroprocessed shale oil (Geokinetics, Occidental, TOSCO, and Paraho), which are the results of one test. For 84 percent of the duplicate runs the reported results are within the measuring accuracy. There was a variation in the results of four replicate tests for some of the larger wear scars, but this variation was less than 5 percent of the reported results.

Initially wear scar measurements were made on fuels that were sometimes stored overnight in rectangular 1-gal metal cans. It was observed that after overnight storage the wear scar diameter increased significantly. Apparently the metal in the cans was removing the naturally occurring lubricants, a phenomenon similar to what occurs when corrosion inhibitors added to a fuel are removed. Henceforward fuels were stored in glass containers only.

The wear scars are larger for the air-purged cases. This agreed with reported results where water and dissolved oxygen increase wear (refs. 1 and 3). In all cases clay filtering decreased fuel lubricity and resulted in a much larger wear scar diameter. The twice-filtered Jet-A was treated to improve thermal stability by twice passing it through a small clay filter used for WISM tests. After this twice-filtered Jet-A was passed through the large clay column, the BOCM test gave the second largest wear scar diameter. Only coker distillate fuel produced a larger scar; however, the coker distillate fuel has a significantly lower boiling range than Jet-A fuels.

Comparisons can be made between wear scar diameter and the properties of some fuels given in table I. This was done for hydrogen content and aromatics content of Jet-A, ERBS fuel, ERBS blends, and blend stock in figures 4 and 5, respectively. Curves were drawn through points for untreated fuels only as an aid in viewing the results. The effects of preconditioning gas and clay treatment discussed earlier can clearly be seen. The contribution to lubricity made by polar compounds is shown by the difference between untreated and clay-treated fuels. The variation with hydrogen content is undoubtedly the result of varying aromatics: lubricity increased as aromatics increased. The larger wear scar diameter for blend stock than for 11.8-percent-hydrogen ERBS blend (49.6 aromatics) was probably caused by the higher volatility of the blend stock.

The in-house hydroprocessed fuels from shale oil (Geokinetics, Occidental, TOSCO, and Paraho) generally gave small wear scar diameters (high lubricity). These fuels had essentially no sulfur, but their nitrogen content was high.

Consequently the nitrogen or oxygen compounds undoubtedly gave the fuel its lubricity.

Gas chromatographic results are shown in figure 6. The numbers by the peaks in figure 6(a) are the retention times. Table III identifies compounds associated with these retention times. Each peak represents a separated hydrocarbon compound, and the relative height of the peak indicates the relative amount or concentration of the compound. All changes after stressing a fuel with BOCM testing are identified in figures 6(b) and (c). These changes were significant. The magnitude of the changes in relative peak size before and after the stressing was estimated to be approximately 400 parts per million. The identities of the peaks where changes were observed remain largely unknown. However, the compounds are suspected to be polar compounds such as nitrogen-, sulfur-, and oxygen-containing compounds.

A more in-depth study of the gas chromatographic analysis is required to better understand what occurred during BOCM testing. One approach would be to wash fuel from the cylinder after testing with a small amount of methylene chloride and analyze these samples in a gas chromatograph. Also, surface analysis of the wear scar track on the cylinder or the wear scar on the ball could identify possible surface reactions that may have occurred.

SUMMARY OF RESULTS

In ball-on-cylinder-machine tests of a broad spectrum of well-characterized research fuels, the following results were obtained:

1. Clay filtering always reduced the lubricity of a fuel as determined by the wear scar diameter. Even the higher purity fuels that had an initial low lubricity were significantly reduced in lubricity after clay treatment.

2. Tests using dry nitrogen as the preconditioning and cover gas always gave a smaller wear scar diameter than when humidified air was used.

3. The research fuels derived from a mild hydrotreating of whole shale oil, where almost all of the sulfur was removed and about half of the nitrogen, gave lubricity results equal to those of petroleum-derived fuels.

4. Gas chromatographic results show that certain components changed during BOCM testing as indicated by significant changes in the chromatogram.

5. A plot of wear scar diameter versus percent aromatics and percent hydrogen for Jet-A, ERBS fuel, ERBS blends, and blend stock indicated lower lubricity with decreasing aromatics.

6. The largest wear scars were observed for the lower-boiling-range fuels.

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TABLE I. - FUEL CHARACTERIZATION RESULTS

Fuel property	Jet-A		Jet-A (twice filtered)		ERBS fuel (12.8 percent H)		ERBS blend (12.3 percent H)		ERBS blend (11.8 percent H)		Blend stock	
	Untreated	Clay treated	Untreated	Clay treated	Untreated	Clay treated	Untreated	Clay treated	Untreated	Clay treated	Untreated	Clay treated
Composition:												
Hydrogen, wt %	13.80	13.87	13.90	----	12.96	13.00	12.37	12.33	11.86	11.91	10.32	10.36
Aromatics, vol %	17.2	------	16.0	----	28.9	------	39.6	------	49.6	------	83.3	------
Sulfur, total, wt %	0.063	0.060	0.061	----	0.042	0.002	0.051	0.039	0.058	0.040	0.088	0.077
Nitrogen, total, wt %	0.0004	0.0003	0.0001	----	0.0046	0.0002	0.0048	0.0022	0.0060	0.0032	0.0065	0.0040
Naphthalenes, wt %	2.89	------	2.86	----	13.97	------	15.72	------	17.06	------	22.89	------
Volatility:												
Distillation temperature, °C (°F)												
Initial boiling point	148(298)	------	148(298)	----	178(352)	------	154(310)	------	145(293)	------	133(272)	------
10 percent	187(369)	------	186(366)	----	201(393)	------	183(361)	------	168(335)	------	148(299)	------
50 percent	216(420)	------	213(416)	----	226(439)	------	227(441)	------	226(438)	------	218(424)	------
90 percent	244(472)	------	248(478)	----	286(546)	------	288(550)	------	289(552)	------	299(570)	------
Final boiling point	257(496)	------	260(500)	----	324(615)	------	327(620)	------	326(618)	------	333(632)	------
Residue, percent	2.0	------	0.3	----	1.0	------	1.0	------	1.0	------	1.0	------
Loss, percent	0.5	------	3.7	----	0.5	------	0.5	------	1.0	------	1.0	------
Flashpoint, °C (°F)	52(125)	------	52(125)	----	60(140)	------	53(127)	------	48(118)	------	36(96)	------
Gravity, API (15 °C)	41.6	------	43.1	----	36.6	------	34.3	------	32.3	------	26.4	------
Gravity, specific (15/15 °C)	0.8174	------	0.8104	----	0.8418	------	0.8532	------	0.8639	------	0.8961	------
Fluidity:												
Freezing point, °C (°F)	-57(-70)	------	-45(-49)	----	-26(-15)	------	-25(-14)	------	-24(-11)	------	-22(-8)	------
Viscosity, at -23 °C (-10 °F), cS	5.9	------	8.0	----	9.2	------	7.9	------	7.0	------	4.6	------
Thermal stability:												
JFTOT - pass/fail (TDR, 13 at 260 °C (500 °F) and ΔP, 25 mm Hg)	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Fail

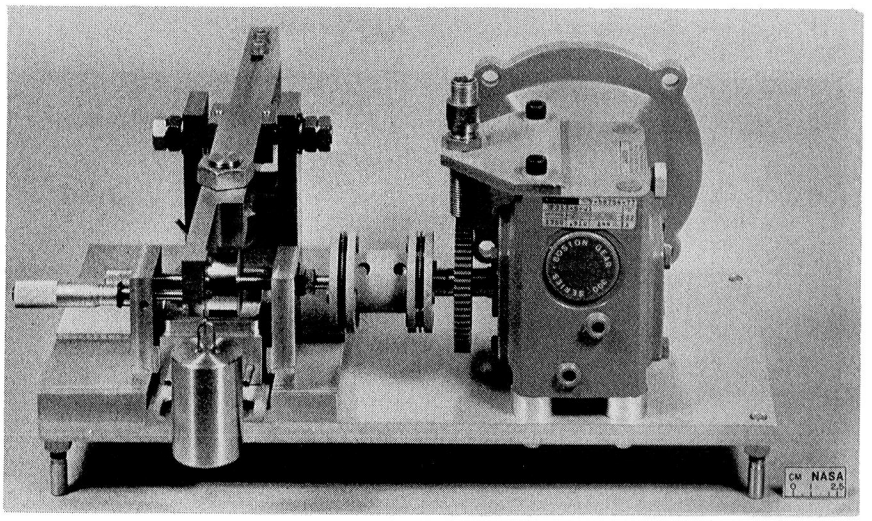
Fuel property	Paraho JP-5		Coker distillate Jet-A		Geokinetics		Occidental		TOSCO		Paraho	
	Untreated	Clay treated	Untreated	Clay treated	Jet-A cut	Broad cut	Jet-A cut	Broad cut	Jet-A cut	Broad cut	Jet-A cut	Broad cut
Composition:												
Hydrogen, wt %	13.84	13.87	14.42	14.40	13.81	13.68	13.78	13.66	13.78	13.34	13.85	13.76
Aromatics, vol %	24.1	------	9.5	------	19.4	21.8	20.1	19.5	24.4	24.6	19.0	17.0
Sulfur, total, wt %	0.021	0.021	0.019	0.020	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Nitrogen, total, wt %	0.0006	0.0004	0.0004	0.0002	0.130	0.125	0.0384	0.0443	0.366	0.396	0.122	0.150
Naphthalenes, wt %	0.82	------	0.06	------	1.17	1.73	0.58	2.1	2.15	4.06	1.38	2.06
Volatility:												
Distillation temperature, °C (°F)												
Initial boiling point	180(356)	------	161(322)	------	163(326)	167(333)	147(299)	218(425)	155(311)	161(322)	159(318)	168(335)
10 percent	193(380)	------	172(342)	------	191(376)	199(390)	173(344)	233(451)	175(347)	187(369)	182(360)	194(382)
50 percent	205(401)	------	189(372)	------	234(453)	254(489)	218(425)	272(522)	226(439)	249(480)	252(450)	253(488)
90 percent	232(450)	------	212(414)	------	261(502)	297(566)	243(469)	302(573)	271(520)	303(577)	272(522)	298(569)
Final boiling point	242(467)	------	226(438)	------	273(524)	307(587)	256(493)	312(594)	319(607)	344(651)	287(548)	311(592)
Residue, percent	0.5	------	1.0	------	--------	--------	--------	--------	--------	--------	--------	--------
Loss, percent	2.5	------	3.0	------	--------	--------	--------	--------	--------	--------	--------	--------
Flashpoint, °C (°F)	60(140)	------	47(117)	------	54(130)	58(136)	44(112)	>93(>200)	48(118)	54(129)	50(122)	58(137)
Gravity, API (15 °C)	45.6	------	49.7	------	41.7	39.3	42.3	36.8	41.3	37.6	41.6	39.5
Gravity, specific (15/15 °C)	0.7990	------	0.7810	------	0.8170	0.8285	0.8142	0.8408	0.8189	0.8368	0.8175	0.8275
Fluidity:												
Freezing point, °C (°F)	-50(-58)	------	-61(-78)	------	-31(-24)	17(1.5)	-46(-51)	-15(4.5)	-33(-28)	-16(2.5)	-28(-18)	-17(2)
Viscosity, at -23 °C (-10 °F), cS	2.9	------	2.2	------	7.5	--------	3.8	--------	6.2	--------	8.0	--------
Thermal stability:												
JFTOT - pass/fail (TDR, 13 at 260 °C (500 °F) and ΔP, 25 mm Hg)	Pass	Pass	Pass	Pass	--------	--------	--------	--------	--------	--------	--------	--------

TABLE II. - WEAR SCAR DIAMETERS

Test fuels	Air purge gas		Nitrogen purge gas	
	Untreated fuel	Clay-treated fuel	Untreated fuel	Clay-treated fuel
	Wear scar diameter, mm			
Jet-A	0.382	0.532	0.356	0.481
Jet-A (twice filtered)	.488	.669	.431	.613
ERBS fuel (12.8 percent H)	.338	.500	.332	.438
ERBS blend (12.3 percent H)	.325	.500	.306	.450
ERBS blend (11.8 percent H)	.332	.475	.300	.462
Blend stock	.350	.500	.331	.500
Paraho JP-5	.488	.662	.438	.662
Coker distillate (hydrotreated Jet-A cut)	.550	1.075	-----	-----
Geokinetics (Jet-A cut)	.338	-----	-----	-----
Geokinetics (broad cut)	.325	-----	-----	-----
Occidental (Jet-A cut)	.388	-----	-----	-----
Occidental (broad cut)	.319	-----	-----	-----
TOSCO (Jet-A cut)	.400	-----	-----	-----
TOSCO (broad cut)	.450	-----	-----	-----
Paraho (Jet-A cut)	.338	-----	-----	-----
Paraho (broad cut)	.300	-----	-----	-----

TABLE III. - TENTATIVELY IDENTIFIED HYDROCARBON COMPONENTS

Retention time, min	Component	Retention time, min	Component
5.80	Methylene chloride solvent	24.73	p-Cymene
6.60	Hexane	24.94	Indan
7.49	Cyclohexane	25.83	n-Butylcyclohexane
8.02	Cyclohexene	26.33	1.3-Diethylbenzene
8.32	3-Ethylpentane	26.47	1-Methyl-3-Propylbenzene
8.67	Heptane	26.76	n-Butylbenzene
11.26	trans-1.4-Dimethylcyclohexane	27.45	1-Methyl-2-Propylbenzene
11.63	2.2.5-Trimethylhexane	28.00	1.4-Dimethyl-2-Ethylbenzene
11.79	1-Octene	28.27	1.3-Dimethyl-4-Ethylbenzene
12.02	trans-1.2-Dimethylcyclohexane	28.43	2-Methyldecane
12.30	Octane	28.51	2.2.4.6.6-Pentamethylheptane
13.28	2.2-Dimethylheptane	28.61	1.2-Dimethyl-4-Ethylbenzene
13.74	2.6-Dimethylheptane	28.76	1-Ethylpropylbenzene
14.01	1.1.4-Trimethylcyclohexane	28.96	1.3-Dimethyl-2-Ethylbenzene
15.02	m-Xylene	29.92	1-Undecene
15.11	p-Xylene	30.00	1-Ethyl-3-Isopropylbenzene
16.09	3-Methyloctane	30.73	Undecane
16.28	2.4.6-Trimethylheptane or o-Xylene	30.94	1.2.3.5-Tetramethylbenzene
16.64	cis-1-Ethyl-3-Methylcyclohexane	31.20	3-Methylbutylbenzene
17.69	Nonane	31.67	1-tert-Butyl-2-Methylbenzene
17.91	1-Ethyl-1-Methylcyclohexane	33.45	n-Pentylbenzene
18.24	Cumene	34.45	Naphthalene
18.49	Isopropylcyclohexane	34.87	1-tert-Butyl-3,5-Dimethylbenzene
18.94	4.4-Dimethyloctane	35.02	1-tert-Butyl-4-Ethylbenzene
19.20	n-Propylcyclohexane	36.57	1-Dodecene
19.58	2.7-Dimethyloctane	37.27	Dodecane
19.79	2.6-Dimethyloctane	38.70	1,2,4-Triethylbenzene
20.53	1-Ethyl-3-Methylbenzene	41.16	Pentamethylbenzene
21.06	1.3.5-Trimethylbenzene	41.53	2-Methylnaphthalene
21.17	4-Methylnonane	42.01	1,1-Diethylpropylbenzene
21.58	4-Ethylnonane	42.87	1-Tridecene
21.91	3-Ethyloctane	43.64	Tridecane
22.11	trans-1-Methyl-4-Isopropylcyclohexane	46.49	n-Heptylbenzene
22.20	3.3.4.4-Tetramethylhexane	47.62	2-Ethylnaphthalene
22.62	1.2.4-Trimethylbenzene	47.75	1-Ethylnaphthalene
23.05	cis-1-Methyl-4-Isopropylcyclohexane	49.10	1,3-Dimethylnaphthalene
23.34	1-Decene	49.62	Tetradecane
23.63	3-Ethylnonane	51.31	Hexamethylbenzene
23.77	sec-Butylbenzene	55.33	Pentadecane
24.07	Decane		



C-84-2897

Figure 1. - Ball-on-cylinder machine.

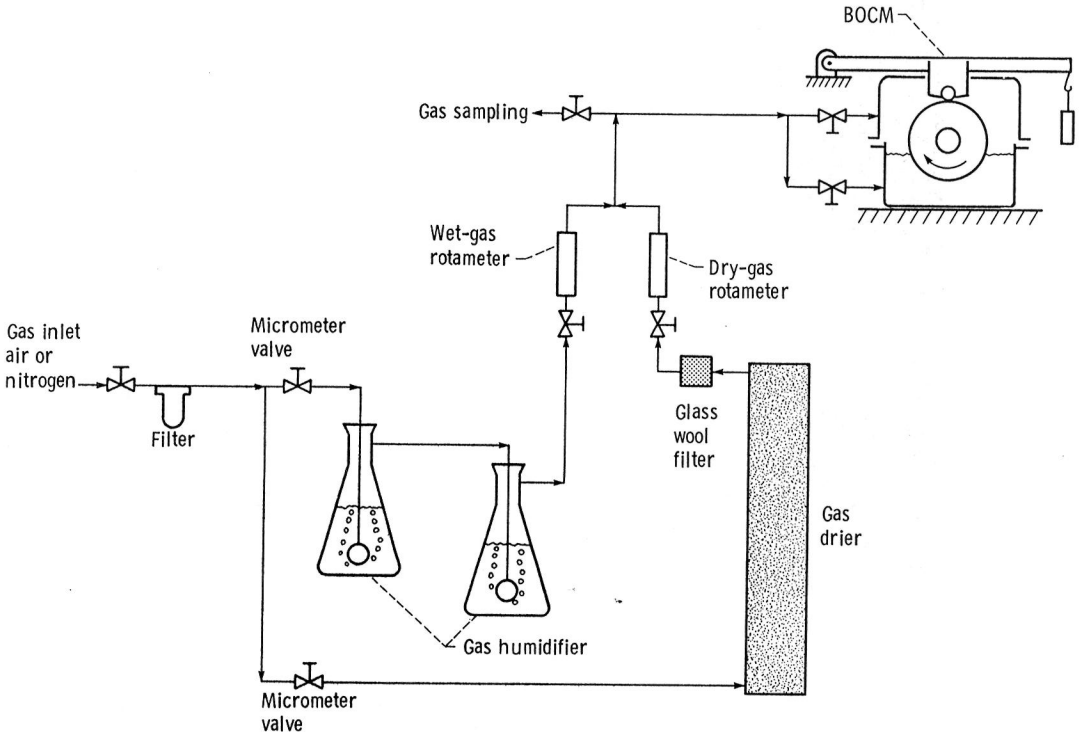
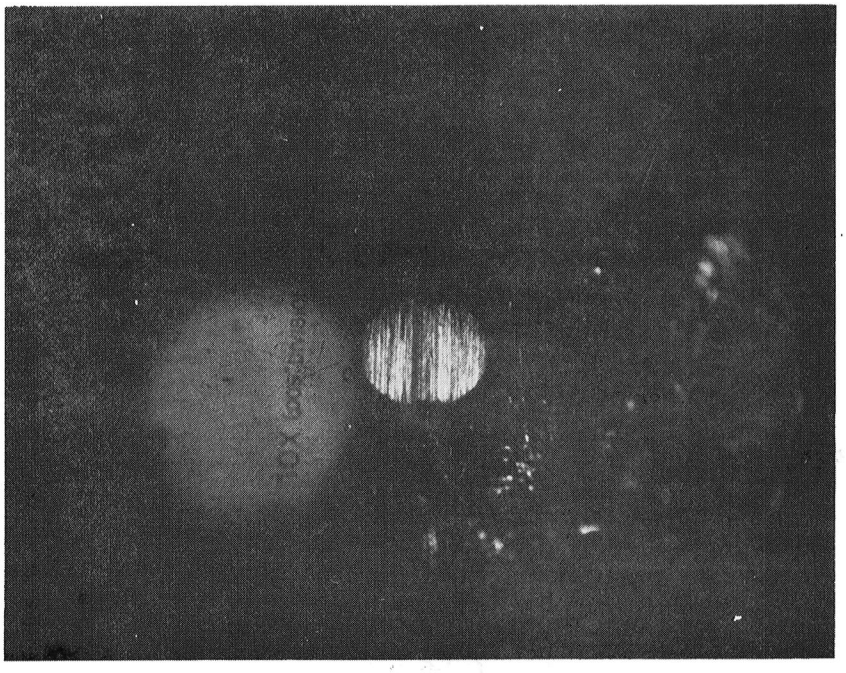


Figure 2. - Ball-on-cylinder-machine (BOCM) testing system.

(a) Untreated fuel.



(b) Clay-treated fuel.

Figure 3. - Wear scars for ERBS blend (11.8 percent H) with air as purge and cover gas.

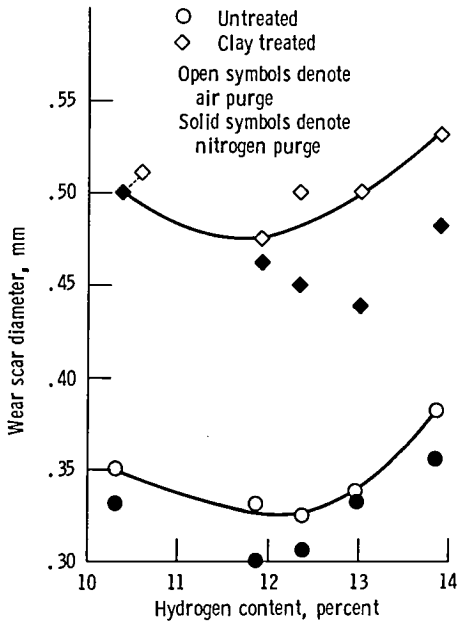


Figure 4. - Variation of wear scar diameter with hydrogen content.

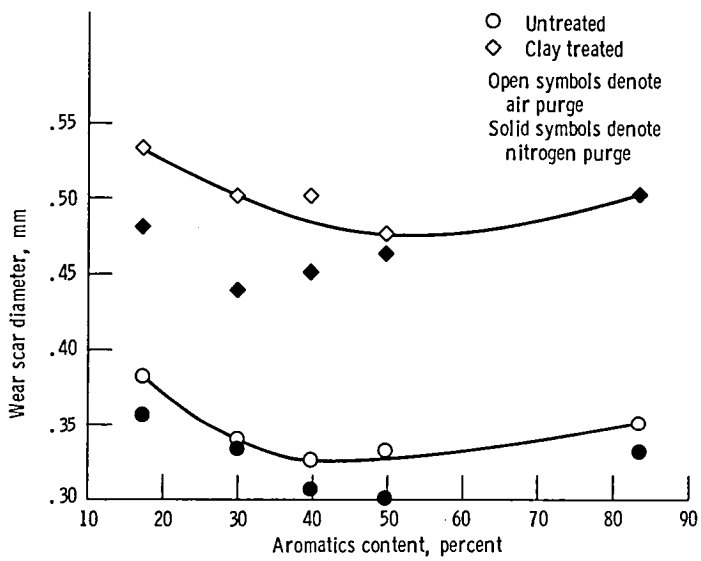
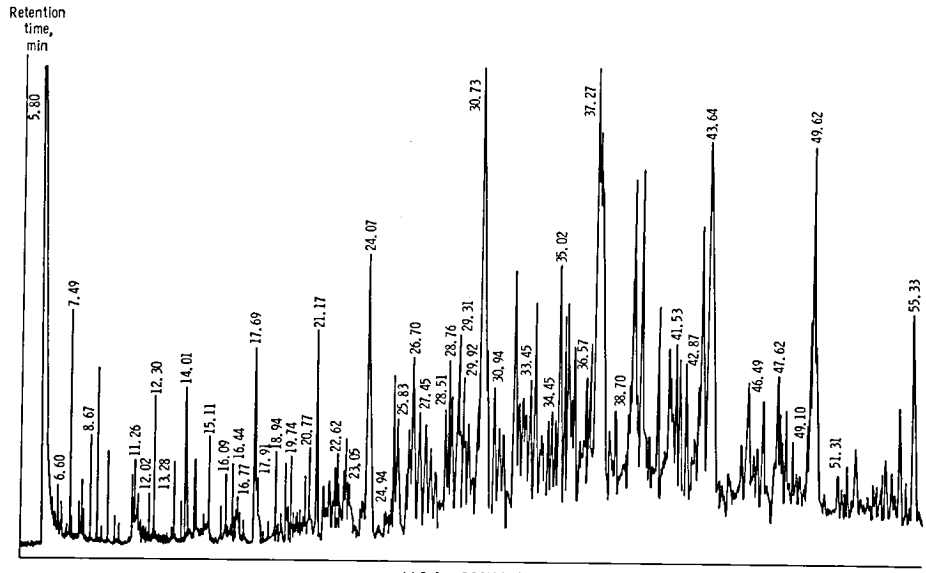
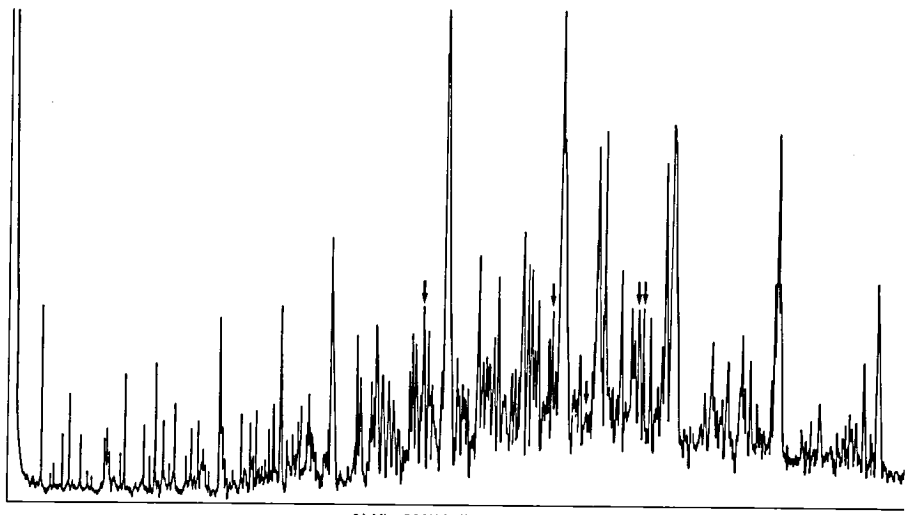


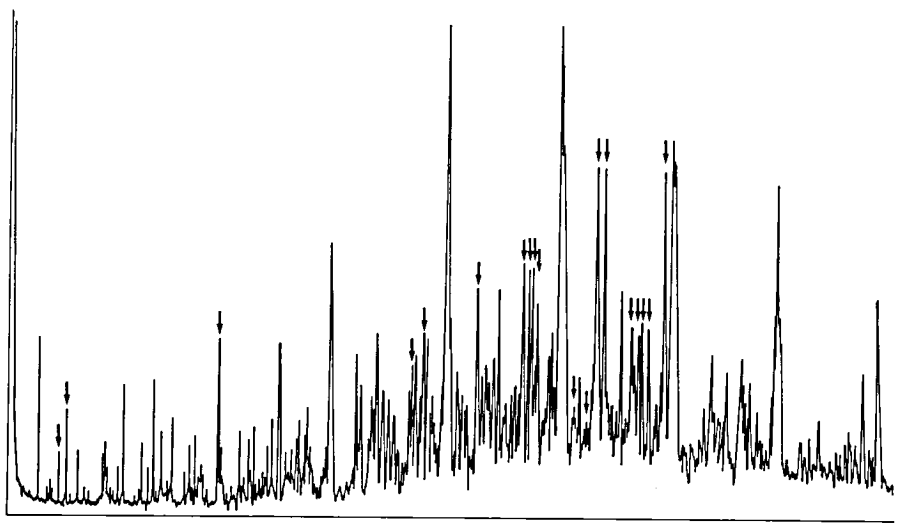
Figure 5. - Variation of wear scar diameter with aromatics content.



(a) Before BOCM testing.



(b) After BOCM testing with air purge.



(c) After BOCM testing with nitrogen purge.

Figure 6. - Chromatograms of Jet-A. Arrows denote where changes occur.

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15. Supplementary Notes

16. Abstract

A ball-on-cylinder machine (BOCM) was used to measure the lubricity of fuels. The fuels tested were well-characterized fuels available from other programs at the NASA Lewis Research Center plus some in-house mildly hydroprocessed shale products. The fuels from other programs included Jet-A, ERBS fuel, ERBS blends, and blend stock. The BOCM tests were made before and after clay treatment of some of these fuels with both humidified air and dry nitrogen as the preconditioning and cover gas. As expected, clay treatment always reduced fuel lubricity. Using nitrogen preconditioning and cover gas always resulted in a smaller wear scar diameter than when humidified air was used. Also observed was an indication of lower lubricity with lower boiling range fuels and lower aromatic fuels. Gas chromatographic analysis indicated changes in BOCM-stressed fuels.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Lubricity Wear friction Fuel Jet fuel	Unclassified - unlimited STAR Category 28

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