Characterization of Emissions from Handheld Two-stroke Engines

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ABSTRACT

Despite their extremely high organic and particulate matter emission rates, two-stroke engines remain among the least studied of engine types. Such studies are rare because they are costly to perform. Results reported in this paper were obtained using a facility that shares exhaust emission sampling and analytical systems with an adjacent automotive emissions test laboratory. This enabled a comprehensive examination of emissions from three hand-held, two-stroke, engines. In addition to the determination of routine regulated pollutant emission rates, organic emissions are speciated and particulate matter emission rates are measured. Each engine was tested using two fuels: 1990 Baseline Gasoline and a reformulated gasoline. One engine was run for an extended period to assess durability effects on exhaust emissions, and another was operated at a leaner air-fuel ratio setting to examine enleanment effects. In the durability testing, organic and particulate matter emissions actually appear to decrease slightly with increased operating time. In the enleanment test, organic and carbon monoxide emission rates decreased significantly, as expected, with the increase in air-fuel ratio. Large decreases in particulate matter also ensued. Fuel selection strongly influenced composition of organic emissions. With reformulated gasoline, gaseous toxic and ozone potential emissions were consistently lower compared to emissions with the Baseline fuel.

INTRODUCTION

Small gasoline nonroad engines (below 19 kilowatts) contribute about five percent of the summer volatile organic compounds (VOCs) in the 19 nonattainment areas nationwide [1]. In July 1995, U. S. Environmental Protection Agency (EPA) finalized the first federal regulations affecting these engines as a first step toward reducing their emissions. The regulations, commonly known within the industry as "Phase 1" , took effect in the 1997 model year and apply to gasoline engines below 19 kilowatts. The most common applications which use these engines are lawn mowers and other garden equipment.

The string trimmer, after the lawn mower, is the second most common small gasoline nonroad application in the United States. A typical string trimmer is powered by a two-stroke gasoline engine that has a hydrocarbon (HC) emission rate approximately six times that of the typical four-stroke lawn mower engine[1]. Unburned HC emissions from string trimmer engines are extremely high due to fresh mixture (fuel-air) short-circuiting the cylinder during scavenging. Carbon monoxide (CO) emissions also tend to be elevated but are comparable with the high levels measured on small four-stroke engines [1,2,3,4].

String trimmers and other small two-stroke engines are categorized as small spark-ignition nonroad handheld engines. Proposed Phase 2 standards for these engines are currently being considered and would reduce HC and nitrogen oxide (NO_x) another 80 percent below the Phase 1 standards. These standards would be effective beginning in 2002.

Small, hand-held engines have an impact on the atmospheric environment that is accounted for in current emission inventories. But perhaps a more cogent concern is their potential as a source for air toxic exposure to operators. Laborers in the landscape industry frequently operate these devices for extended periods, thus exposing themselves to high concentrations of exhaust gases over prolonged periods of time. Since the exhaust gases consist of large fractions of unburned gasoline, there is a likelihood that workers are being adversely exposed to benzene, 1,3-butadiene, and other possible toxic compounds contained in gasoline. Toxic compounds produced during combustion may also present a hazard.

Toxic emissions from mobile sources are defined as benzene, 1,3 butadiene, formaldehyde, acetaldehyde, and particulate poly-aromatic hydrocarbon (PAH) emissions. All except the particulate PAH emission rates were determined in this study by speciating the organic emissions from the engines. The speciation was carried out to assess ozone potential of the emissions since the study was sponsored by EPA's North American Research Strategy for Tropospheric Ozone (NARSTO). Specifically, this study develops speciation profiles from nonroad, small two-stroke utility engines. Only a few papers describe such characterization efforts for small two-stroke engines [5,6,7] because the studies are rare and costly. Facilities that characterize emissions from roadway vehicles are best equipped to economically perform the same analyses on small engine emissions.

The results presented in this paper can be used to perform exposure assessments to gaseous toxic emissions (aggregate toxic minus the particulate PAH emissions) and to model source contributions to ozone pollution from small two-stroke engines. The studies, which characterize exhaust emissions from new and in-use, two-stroke string trimmer engines, were carried out at EPA's mobile source emissions laboratory in Research Triangle Park, North Carolina. Exposure and ozone impacts from similar two-stroke engines can be inferred from the results in this study because the organic composition of their emissions can be assumed to be similar. The impact of reformulated fuel on emission rates and composition is examined by testing two fuels: a 1990 baseline gasoline (RFA) and a reformulated gasoline (RFG).

EXPERIMENTAL METHOD

Test Equipment

The test cell has an eddy-current dynamometer that can absorb up to four horsepower. An engine-dynamometer controller consists of two separate units: a dynamometer controller that varies excitation current to the dynamometer maintaining speed or torque, and a throttle controller that controls the engine's throttle to maintain desired torque, speed, or throttle position. The engine-dynamometer controller is interfaced to a computer that commands second-by-second speed, torque, or throttle position called for by the test cycle.

Engine exhaust is directed to a constant volume sampler (CVS) via a large hood near the engine's exhaust outlet (see Figure 1). Dilution air from the engine room forms an envelop around the exhaust and the diluted exhaust mixture is drawn into the CVS at a rate of about 470 SCFM. Heated sample lines are used to collect diluted exhaust gas samples for aldehyde, real-time, and bag analyses. The bags are first analyzed for regulated emissions (HC, CO, and NO_x), then a sample is drawn off for HC speciation. Particulate matter (PM) emissions, currently unregulated for small gasoline nonroad engines, were also collected and measured.

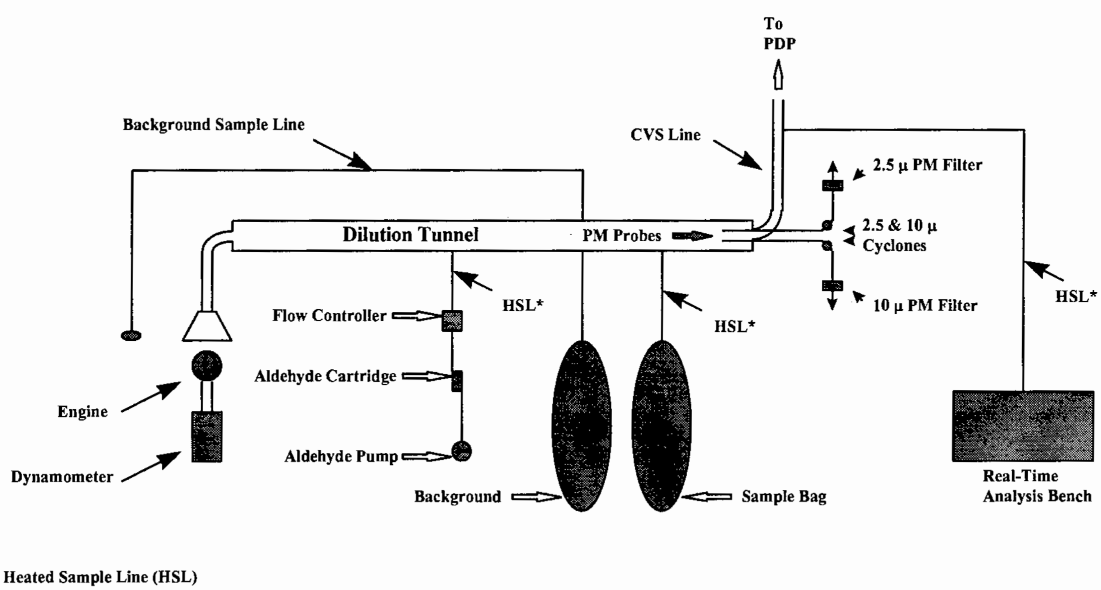

Figure 1. Sampling system schematic.

During the test, data needed to calculate emission rates from emission analyzers, the engine-dynamometer controller, and the CVS are brought into a computer in real-time (one sample per second). This enables the calculation of real-time or modal regulated emissions following the test.

Test Procedure

Three engines (see section below for a more complete description of the engines) taken from string trimmers were selected as test engines for the study. One was an in-use engine that had been used by a consumer for about one year before it was tested, the other two were new. Of the two new engines, one was examined at a leaner (higher air-fuel ratio) setting in addition to its "as received", richer, setting. The other new engine was operated over an extended period of time to examine durability effects on emissions.

Table 1. Test matrix showing number of replicates for each test condition.

	RFA	RFG	RFA		RFG
			32h	48h	48 h
J1088 tests					
Ryobi (rich)	4	2	x	x	x
Ryobi (lean)	4	x	x	x	x
Weed Eater	6	x	x	x	x
Homelite	4	5	x	x	x
C2M tests					
Ryobi (rich)	4	9	x	x	x
Ryobi (lean)	7	x	x	x	x
Weed Eater	6	6	1	4	3
Homelite	3	6	x	x	x

Back-to-back composite two-mode (C2M) duty cycles were used to accumulate operation time on the engine. The C2M is a composite of the 2-mode, SAE J1088 recommended practice, that was adopted as the federal certification cycle for handheld engines.

Exhaust gas emissions were generated by operating the engines using the 2-mode version of the SAE J1088 and the C2M duty cycle. Replicate tests were conducted throughout the study except for tests on the Weed Eater for the 32 hour durability checks. Table 1 shows the test conditions examined using both duty cycles and the number of successful replicates performed in each case. The RFA and RFG fuels were alternated after every three tests.

The SAE J1088 duty cycle - The SAE J1088, or the certification duty cycle, is conducted by taking exhaust gas samples while the engine is operating at two steady-state modes or conditions. The first condition is defined as 100 percent of rated torque and 85 percent of rated speed; the second is at idle or no load. After all engine and sampling system readings have stabilized for the mode to be tested, the sample is taken for a 600 second period.

The C2M duty cycle - The engine is run through two modes (same modes as in the J1088) while emissions are sampled continuously. The time spent in each mode is proportional to the weight given the mode in the certification procedure: 90 percent is spent at full load and 10 percent at idle. The C2M has a duration of ten minutes and it is a quasi-steady-state duty cycle since emissions are collected during the transient that occurs when shifting from mode 1 to mode 2. Instead of having four (two samples and two background) bags to analyze following the test, the C2M has only two (a sample and a background) bags. This reduces the cost and simplifies the analysis component. During the C2M test, the engine is maintained at rated speed except at idle when it decreases to the lowest speed inside a smooth operating regime.

Gaseous and Particulate Emissions Measurement

Exhaust emission rates were determined for HC, CO and NO_x using standard bag sampling, analytical, and calculation procedures [8]. They were compared for QC purposes to emission rates obtained using integrated results from the real-time sampling and analysis system. The non-methane organic gaseous (NMOG) emissions were determined by taking the sum of the individual non-methane HC emissions following analysis with a gas chromatography-flame ionization detector (GC/FID), then adding in the oxygenate and aldehyde emissions. Samples for GC/FID analysis were collected in 60-L Tedlar bags from the CVS dilution system and from room air (background). The GC speciation methodologies were those used in the Auto/Oil Air Quality Improvement Research Program [9]. Integrated GC-FID peak measurements were compared to the HC measurements obtained using the standard FID procedure for QC purposes.

Aldehydes were sampled through a heated sample line (110 °C) and collected on dinitrophenylhydrazine (DNPH) -coated silica gel cartridges. Two cartridges were drawn during each test: one from the exhaust gas and one from the background. The aldehyde samples, trapped on the cartridge as individual DNPH aldehyde derivatives, were then analyzed by high-performance liquid chromatography [9].

Particulate matter was isokinetically sampled using two straight stainless steel probes that extend from the rear of an 20.3 cm diameter, 3 m long dilution tube. One of the sample probes was connected to a PM_{10} and the other to a $PM_{2.5}$ cyclone (University Research Glassware, Carrboro, NC). Particles exiting the cyclones were collected onto 47 mm diameter, 2.0 μm pore size Gelman Zefluor filters that were equilibrated for 24 h before being weighed.

Emissions' Reactivity

Ozone-forming potential of the exhaust VOC is based upon the incremental reactivity approach developed by Carter and Atkinson [10]. Application of this concept has led to the development of the Maximum Incremental Reactivity (MIR) method, that expresses the reactivity of exhaust NMOG and CO from the test engine [11]. The method assigns a specific reactivity level to each of the organic species and to CO, and calculates a reactivity-weighted emission (RWE) rate for each specie by multiplying the specie's specific reactivity times its emission rate. The RWE rate for an exhaust sample is obtained by summing all of the individual RWE rates for each specie present. The RWE rate, expressed in units of grams ozone per kilowatt-hour, is a useful measure of the ozone potential of the CO and organic emissions in urban atmospheres where the VOC-to-NO_x ratios are relatively low (approximately 6). The specific reactivity of the organic emissions can easily be obtained by dividing the organic RWE rate by its emission rate.

Test Engines and Fuels

Three two-stroke engines were used in this study: two new and one in-use engine. A description of the engines is given in Table 2. The in-use engine, a Homelite (produced by John Deere), was used regularly around a heavily landscaped, one acre home-site for about one year before being tested. It complies with 1995-98 California regulations pertaining to utility, lawn and garden equipment. The Ryobi engine, also certified to the 1995-98 California regulations, was tested first. In its initial test series, the engine was operated "as received". However, the uncharacteristically high organic emission rates that ensued may have been caused by an inadvertent turning of the mixture adjustment screw. In the final test series, the carburetor (mixture adjustment screw) was adjusted to a leaner setting in order to lower the organic emission rates. The carburetor was adjusted so that the engine continued to operate smoothly without misfire, and was able to be tested at approximately the same power settings used before the engine's combustion was made leaner. The other new engine, a Weed Eater (produced by Poulan), was tested over a particularly long period of time to determine durability effects on emissions. This engine was certified to the 1997 California regulations.

Table 2. Engine descriptions.

Engine ID	Model #	Age & Time In- Use (years)	Displace-ment (cc)	Rated Power @ rpm	Max. Test Torque @ rpm	Bore/ Stroke
Ryobi (TN4031UB24 RA:EM)	725REZ	New	31cc	0.94 hp@6500	0.44 ft-lb@5910 0.43 ft-lb@5170 (rich)	35 mm/ 32.5 mm
Weed Eater (VPW021UB2 4RA:EM)	-	New	24cc	0.65 hp@7000	0.61 ft-lb@6230	34.5mm/ 26.4 mm
Homelite (SH2025UB24 RA)	UT#2060 1C	4 yr. In use 1 year	25cc	0.75 hp@7500	0.45 ft-lb@6205	33.3 mm/ 28.6 mm

Two test fuels were examined in this study: 1990 Baseline Gasoline designated RFA, and a reformulated gasoline (California certification gasoline), designated RFG. Compared to the RFA gasoline, the RFG has lower levels of olefin and aromatic compounds, lower T_{90} (temperature at which 90 percent of the fuel boils-off), lower Reid vapor pressure (RVP), lower sulfur, and a presence of oxygenate (about 10 percent MTBE). A more detailed description of the fuels is given in Table 3.

Table 3. Fuel descriptions.

Fuel Type	RFA	RFG
Specific Gravity	0.7469	0.7394
Sulfur, wt %	0.0315	0.0045
Benzene, ppmC%	2.11	1.19
Aromatics, vol. %	31.8	27.0
Olefins, vol. %	11.5	5.1
Paraffins, vol. %	56.7	55.1
MTBE, vol. %	0.1	12.6
Research Octane No.	92.2	96.6
Motor Octane No.	83.8	87.3
Octane Index	88.1	92.0
Carbon, wt %	13.3	13.8
Hydrogen, wt %	86.7	86.2
Reid vapor pressure, psi	8.65	6.65
Distillation, °C IBP	35	40
10%	51	58
50%	102	94
90%	165	150
EP	216	193

RESULTS AND DISCUSSION

Regulated and Particulate Matter Emissions

The routinely gathered emission rates, including those for regulated pollutants, are given in Table 4. In general, emission rates varied more between engines than between fuels. The Ryobi engine is treated as two separate "engines" because the two mixture settings that were tested represent two entirely different engine configurations. The standard deviations included in Table 4 provide a measure of the data repeatability in the study. Two of the test engines, the Weed Eater and the Homelite, comply with the Phase I federal emission standards for Class IV handheld engines. These Phase I standards for HC, CO, and NO_x were 241 g/kW-h, 805 g/kW-h, and 5.36 g/kW-h, respectively. The Ryobi (Ryobi-rich) engine's emissions exceeded the standard when it was operated "as received". However, it is possible that the mixture adjustment screw had been inadvertently turned to a richer setting prior to testing. Its emission rates came close to certification levels when the air-fuel mixture screw was adjusted to a leaner setting (Ryobi-lean) for additional testing. The dramatic difference in emission rates between the lean and rich mixture settings illustrates the important effect that air-fuel ratio has on emissions. Increasing the air-fuel mixture away from stoichiometry results in decreased emissions of hydrocarbons and CO, but increased emissions of NO_x. That classic trend is apparent here and it is noted that PM emission rates also decrease substantially with increasing air-fuel ratio.

Table 4. Regulated emission rates (standard deviations in parentheses).

	HC g/kW-h	CO g/kW-h	NOx g/kW-h	CO_2 g/kW-h	NMOG g/kW-h	PM10 mg/kW-h	PM2.5 mg/kW-h
Ryobi-rich RFA							
J1088	614 (71)	980 (17)	0.02 (.05)	772 (150)	572	39.4 (1.6)	35.5 (2.8)
C2M	649.5 (32)	1018 (12)	0 (0)	835 (8.4)	662 (4.1)	42.2 (0.3)	38.5 (2.7)
Ryobi-rich RFG							
J1088	604 (90)	961 (79)	0 (0)	867 (166)	503	46.9 (8.8)	25.9 (8.6)
C2M	664 (21.8)	980 (30)	0 (0)	720 (53)	673 (31)	39.2 (.5)	36.6 (1.8)
Ryobi-lean RFA							
J1088	265 (40)	646 (71)	2.2 (1.5)	976 (88)	249	17.9 (2.2)	16.9 (3.3)
C2M	290 (60)	633 (70)	3.4 (1.2)	1074 (61)	238 (0.6)	18.8 (3.3)	18.0 (4.1)
Weed-Eater RFA							
J1088	170.5 (9.4)	527 (22)	1.6 (0.9)	889 (50)	192.6	15.7	16.3
C2M	185.4 (9.3)	518 (17)	1.1 (0.8)	930 (36)	188.0 (6.2)	15.2 (0.8	15.2 (0.8)
32-h	172.3	497	2.0	993	163.8	11.4	16.0
48-h	176.6 (4.1)	486.0 (63.4)	2.3 (0.7)	947 (63)	163.9 (18.5)	12.8 (3.3)	12.7 (3.2)
Weed-Eater RFG							
C2M	180.0 (5.6)	488 (14)	1.0 (0.7)	1018 (71)	186.9 (8.6)	15.0 (0.9)	15.1 (0.9)
48-h	130.2 (6.9)	300.5 (69.0)	1.5 (0.5)	1057 (53)	136.4 (4.0)	11.1 (1.3)	11.0 (1.3)
Homelite RFA							
J1088	173.9 (11.8)	377.4 (38.3)	2.4 (1.0)	1176 (41)	159.4 (10.1)	9.0 (1.5)	9.7 (2.9)
C2M	208.1 (24.1)	401.9 (29.7)	2.1 (0.6)	1250 (139)	197.7 (11.7)	8.0 (2.4)	8.0 (3.0)
Homelite RFG							
J1088	157.9 (31.4)	315.1 (134.3)	2.8 (0.5)	1237 (57)	167.5	10.3 (1.0)	10.8 (1.4)
C2M	204.7 (25.7)	357.2 (97.4)	2.4 (2.2)	1458 (89)	208.6 (29.8)	11.2 (3.8)	11.4 (3.2)

This trend associated with leaned-out combustion is observed in an examination of the durability data reported on the Weed Eater engine. Here there are slight decreases in HC and CO, accompanied by slight increases in NO_x emission rates as run-time for the engine increased. The decreases in PM rates are even more apparent. All this suggests that the engine's air-fuel ratio was increasing slowly as the engine aged. This enleanment could occur if deposits began obstructing passageways in the carburetor over time.

Both PM10 and PM2.5 emission rates were measured during testing. Emission rates are about equal for both implying that the particles being generated are predominately less than 2.5 microns. This is not to say that the engines were not spraying oil during the tests. An aerosol spray was emitted that impacted on the transfer tube and tunnel walls. Virtually none of this aerosol made it to the cyclones which were situated at the end of the tunnel. The interior surfaces of the cyclones were surprisingly dry following a test.

The NMOG emission rates vary both above and below the reported HC emission rates because they are determined using a different method. Integrated non-methane readings from the GC/FID are added to oxygenate and aldehyde emissions also determined using a GC/FID.

Use of RFG fuel resulted in lower HC and CO emission rates in eleven of twelve head-to-head comparisons. Most are statistically insignificant due to variability of the data, but overall there appears to be a trend. Particulate matter emission rates are more of a mixed bag with no trend emerging due to usage of the two fuels.

Table 5. Gaseous toxic emission rates.

	1,3-buta-diene g/kW-h	Benzene g/kW-h	Form-aldehyde g/kW-h	Acetalde-hyde g/kW-h	Gaseous Toxics g/kW-h
Ryobi-rich RFA					
J1088	0.6	14.3	0.6	0.2	15.7
C2M	0.6	14.9	1.5	0.7	17.7
Ryobi-rich RFG					
J1088	0.5	6.5	0.9	0.2	8.1
C2M	0.7	9.5	1.6	0.4	12.2
Ryobi-lean RFA					
J1088	0.5	6.5	0.5	0.2	7.7
C2M	0.5	5.8	1.0	0.4	7.7
Weed-Eater RFA					
J1088	0.4	4.1	0.5	0.2	5.2
C2M	0.3	3.8	0.4	0.1	4.7
32-h	0.3	3.4	0.3	0.1	4.1
48-h	0.3	3.7	0.5	0.2	4.6
Weed-Eater RFG					
C2M	0.3	2.5	0.6	0.1	3.5
48-h	0.3	1.9	0.5	0.1	2.7
Homelite RFA					
J1088	0.2	3.2	0.8	0.3	4.5
C2M	0.4	4.0	1.1	0.4	5.9
Homelite RFG					
J1088	0.4	1.8	1.6	0.4	4.1
C2M	0.3	2.2	1.6	0.4	4.5

Gaseous Toxic Emissions

Gaseous toxic emissions from these engines are dominated by benzene. Benzene emissions are closely related to benzene levels in the gasoline. Benzene emission rates with RFG, which contains about half the benzene contained in an equal measure of RFA, are nearly half the levels with RFA. Generally, formaldehyde emission rates are higher with RFG. This is consistent with results from other studies that have examined emissions using the same two fuels.[12] Most oxygenates will produce some increase in aldehyde emissions due to fragmentation of their carbon-hydrogen-oxygen groups that closely resemble aldehydes. Formaldehyde emissions with MTBE occur when its methoxy group is broken off during combustion.

The gaseous toxic emission rates from engine-to-engine and from the two fuels vary in the same direction as the HC emission rates. Both the gaseous toxic and HC emission rates are ordered as follows: Weed Eater < Homelite < Ryobi-lean < Ryobi-rich, and RFG < RFA. Higher emissions of unburned fuel (HC) translate to higher emissions of benzene, the principal component of the gaseous toxic pollutants.

Table 6. Ozone potential emissions and related measurements.

	MIR g O_3/kW-h	Specific Reactivity	Principal MIR Fractions			
			Paraffin	Olefin	Aromatic	CO
Ryobi-rich RFA						
J1088	1976	3.35	19%	22%	55%	3%
C2M	2388	3.52	17%	20%	59%	2%
Ryobi-rich RFG						
J1088	1490	2.86	20%	19%	52%	3%
C2M	1909	2.76	23%	20%	50%	3%
Ryobi-lean RFA						
J1088	909	3.51	17%	26%	52%	4%
C2M	891	3.63	16%	25%	53%	3%
Weed-Eater RFA						
J1088	732	3.68	15%	24%	56%	4%
C2M	721	3.69	16%	26%	53%	4%
32-h	650	3.80	14%	24%	55%	4%
48-h	622	3.65	15%	26%	52%	4%
Weed-Eater RFG						
C2M	641	3.29	16%	24%	52%	4%
48-h	454	3.21	19%	26%	48%	4%
Homelite RFA						
J1088	616	3.74	15%	26%	54%	4%
C2M	774	3.81	15%	27%	52%	3%
Homelite RFG						
J1088	594	3.44	15%	32%	45%	3%
C2M	681	3.18	18%	29%	45%	3%

Ozone Potential Emissions

Ozone potential emissions are a function of the organic and CO emission rates, and of their reactivity. The reactivity of the organic emissions (specific reactivity) varies with their composition, and for a given engine configuration is largely dependent upon the type of fuel being burned. In every case the specific reactivity is less with RFG than with RFA because it contains fewer reactive hydrocarbon compounds. The specific reactivity of the two fuels themselves is 3.47 for RFA and 2.82 for RFG. Fuel selection with these two-stroke engines influences the emissions' reactivity more than with four-stroke engines tested in a separate study using the same two fuels.[12] In that study the average specific reactivity was reduced only two percent with RFG compared to an average decrease of over 14 percent here. Organic emissions resemble the fuel more with the two-stroke engines because combustion is less complete resulting in high unburned fuel fractions being emitted. Figure 2 shows the carbon number distributions for HC emissions from both engine types burning RFA and from the RFA fuel itself. The distributions illustrate the particularly close similarity between RFA composition and composition of the two-stroke HC emissions.

Lower organic and CO emission rates obtained with RFG team with the lower specific reactivities to produce lower ozone potential emission rates. On average, ozone potential emission are reduced over 16 percent by using RFG.

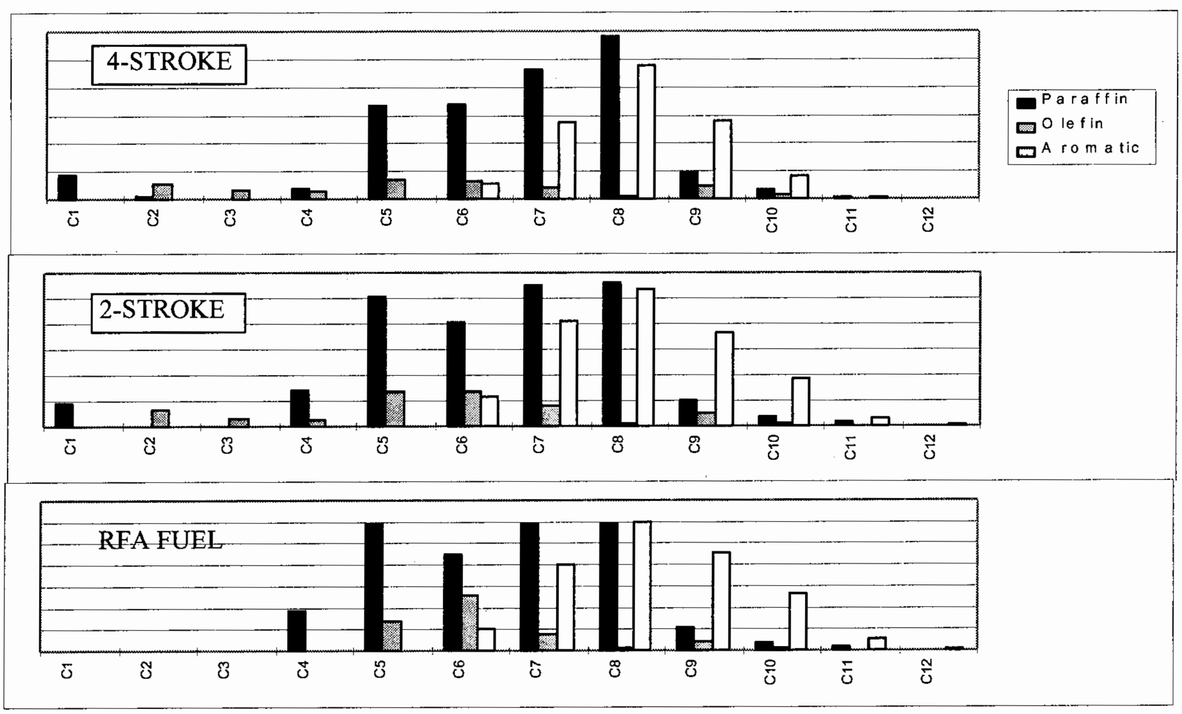

Figure 2. Carbon number distributions for 4-stroke, 2-stroke, and RFA hydrocarbons.

CONCLUSIONS

The study examines emissions from three handheld, two-stroke engines. Results are from a rather limited test matrix that may not lead to representative emissions from such engines nationwide. However, composition of the emissions, which is similar from engine-to-engine despite large differences in emission rates, probably can be assumed to be approximately the same for other small, two-stroke engines burning similar fuels. With this understanding, the following conclusions drawn from the study and relative to the two-stroke engines tested are:

- Specific reactivity of organic emissions was significantly decreased when fuel was switched from RFA to RFG.
- RFG was effective in lowering the ozone potential emissions because of lower specific reactivity and lower HC and CO emission rates.
- Emission rates are extremely sensitive to air-fuel ratio which can change as an engine is operated for extended periods.
- Particulate matter emission rates tend to decrease with increases in air-fuel ratio.
- RFG resulted in sharply lower benzene, but somewhat higher formaldehyde emission rates.
- Gaseous toxic emissions are dominated by benzene which follows trends for total HC emission rates.
- Particles emitted are predominately less than 2.5 microns in diameter.
- Composition of organic emissions resembles the composition of the fuel more than with four-stroke engines.

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Disclaimer

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16. Abstract

Despite their extremely high organic and particulate matter emission rates, two-stroke engines remain among the least studied of engine types. Such studies are rare because they are costly to perform. Results reported in this paper were obtained using a facility that shares exhaust emission sampling and analytical systems with an adjacent automotive emissions test laboratory. This enabled a comprehensive examination of emissions from three hand-held, two-stroke, engines. In addition to the determination of routine regulated pollutant emission rates, organic emissions are speciated and particulate matter emission rates are measured. Each engine was tested using two fuels: 1990 Baseline Gasoline and a reformulated gasoline. One engine was run for an extended period to assess durability effects on exhaust emissions, and another was operated at a leaner air-fuel ratio setting to examine enleanment effects. In the durability testing, organic and particulate matter emissions actually appear to decrease slightly with increased operating time. In the enleanment test, organic and carbon monoxide emission rates decreased significantly, as expected, with the increase in air-fuel ratio. Large decreases in particulate matter also ensued. Fuel selection strongly influenced composition of organic emissions. With reformulated gasoline, aggregate toxic and ozone potential emissions were consistently lower compared to emissions with the Baseline fuel.

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