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On-board Monitoring of Small Engine Emissions

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Introduction

Exhaust emissions from internal combustion engines are one of the primary sources of fine particulate matter in urban areas. While on-road vehicles and larger non-road engines are subject to increasingly strict emissions standards, and numerous retrofit programs are in place to reduce emissions from existing engines, small engines in hand-held machinery, lawnmowers, cultivators, mopeds, and similar equipment are not nearly as strictly regulated. Small engines are designed with cost as one of the primary factors, and generally do not feature electronic fuel injection, computer controlled fuel metering, catalytic devices, or particle filters. They were reported to have relatively large emissions per unit of fuel consumed during laboratory tests. Less than ideal operating practices, maintenance, and durability and discrepancy between real-world operating conditions from those prescribed for laboratory tests have been known to result in on-road engine emissions being often higher during regular use than in the laboratory. A question therefore arises as to the real-world emissions of particles from small engines relative to their larger counterparts, and to the relative economy of reducing emissions from the small engines compared to further reductions in on-road vehicle emissions. To investigate the issue, a miniature portable, on-board emissions monitoring system (PEMS), normally mounted on the tested vehicle, has been constructed and utilized on various yard and hand-held equipment.

Experimental

A miniature version of a portable, on-board emissions monitoring system (PEMS) has been constructed, using relatively robust, low-cost, miniature instrumentation. This system is battery powered and could be either fit in a backpack worn by the operator, or placed on the tested equipment, or carried by a helper or on a cart. The system utilizes a “garage-grade” gas analyzer to measure concentrations of hydrocarbons, carbon monoxide and dioxide and nitrogen monoxide, and two technologies adopted from industrial smoke detectors: measuring ionization chamber and light-scattering instrument. An approximate value of the exhaust flow is calculated from measured engine rpm, engine displacement, assumed or experimentally determined engine volumetric efficiency, and intake air pressure or other qualitative indicator of engine load. The system samples raw exhaust gases without dilution, with only moderate heating to prevent condensation.

Trial runs have been conducted on a Castelgarden riding lawnmower with a 13.5 hp, one-cylinder, four-cycle Briggs & Stratton gasoline engine, a Stihl 029 chainsaw with a two-cycle gasoline engine, a Stihl MS361 chainsaw with a two-cycle gasoline engine, and an Oleo-Mac

746T weedwhacker with a two-cycle gasoline engine. All equipment was tested during typical operation, that is, mowing a suburban garden lawn, sawing 25-40 cm diameter seasoned logs from coniferous trees, and clearing an overgrown ditch.

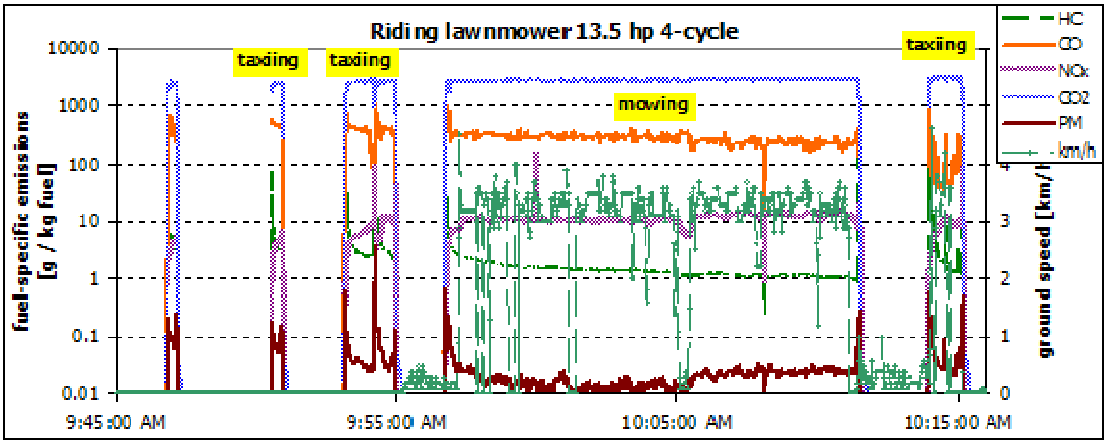
The instrument could fit in a backpack (small enough to be considered a carry-on luggage); in this study, it was strapped to the riding lawnmower, which followed the operators of the hand-held equipment. This was done to allow visual observations of the changes in measured values under different operating conditions.

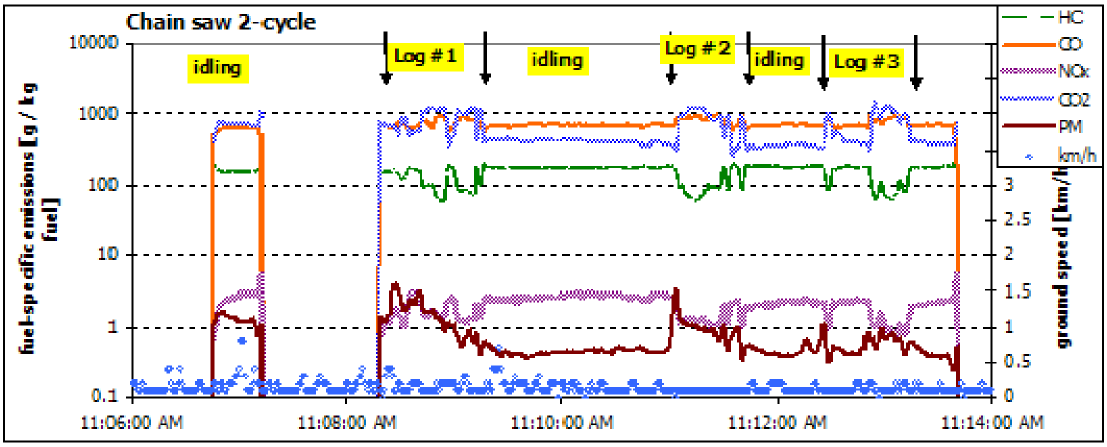
Results

Sample results from the riding lawnmower and one chainsaw operation are listed in the figures below. As the fuel consumption is the most reliable and universal metric of equipment utilization, all results are calculated in grams of pollutants per kg of fuel.

For PM, only the light scattering data are reported here; the ionization chamber output is reported in the poster. This output is approximately proportional to total particle length, a parameter which cannot be easily compared to other measurements.

The data from the second chainsaw and the weedwhacker show similar patterns of the emissions, except for the magnitude of PM emissions, which were highest on the older engine reported on in the graph below, and lower on the two other engines.





Discussion

The results reported here should be treated as preliminary and work in progress, with many issues to be addressed. For example, selections of the machinery tested, equipment operators, and lawn, logs and weeds which were worked on were random, and with no detailed assessment of their properties and the degree to which they are representative.

For the interpretation of the PM measurements, calibrations gained experimentally on a range of diesel engines were used (relationship of the light scattering signal to the total particulate mass measured by gravimetric method, and of the ionization chamber signal to the total particle length measured by a particle spectrometer). On the two-cycle engines, high hydrocarbon emissions, on the order of tens to hundreds of grams per kg of fuel consumed, pose a question as to what part of the particulate matter is volatile (unburned fuel, unburned lube oil), and, due to the highly peculiar and non-linear phase transitions of volatile matter between gaseous and aerosol phase, what fraction of the total volatile organic compounds (a sum of gaseous hydrocarbons and organic aerosol) was measured as particles.

The PM emissions might not be high per se, but the proximity of the source to the machinery operator, and very low speed of travel which may result in a slower dilution compared to vehicles, represent additional concerns.

Another issue that is currently being addressed by the authors is what is being inhaled by the equipment operators; the technical feasibility of simultaneous on-board measurement and sampling with a personal sampler is being evaluated.

The main message of the results gained so far is that in-use, field tests appear to be technically and economically feasible, opening a way for larger set of measurements spanning machinery of different design, emissions certification categories, age, and technical conditions, and different operators and operating conditions.

Conclusions

In this study, a miniature on-board system was used to measure in-use emissions of a riding lawnmower, two chainsaws, and a weedwhacker during typical operation. From the results gained so far, it appears that such measurements are technically feasible. Otherwise, these results are preliminary, with many open questions surrounding the entire hand-held equipment emissions issue.

Acknowledgments

The work was funded by the Czech Ministry of Education grant no. 1M0568, with in-kind contributions (loan of test instrumentation components, loan of the tested machinery) made by the authors.

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On-board Monitoring of Small Engine Emissions

Katedra vozidel a motorů
Fakulta strojní
Technická univerzita v Liberci

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Motivation:

- Exhaust emissions from internal combustion engines are a major source of urban air pollution and pose a threat to human health.
- As the society expends considerable resources to reduce them, on-road vehicle emissions limits were drastically reduced.
- But what about the large amount of lawnmowers, garden tractors, cultivators, weedwhackers, chainsaws, leaf blowers, and other hand held and portable equipment powered by cheap, small engines mostly with no electronic controls and no aftertreatment?
- Are they, like on-road vehicles, subject to off-cycle emissions, cycle beating, deterioration, high emissions due to malfunctions, variances due to "operating style" of individual operators, … ?

Goal: (work in progress)

Assessment of exhaust emissions from small engines used in households under real-world operating conditions using on-board measurement systems

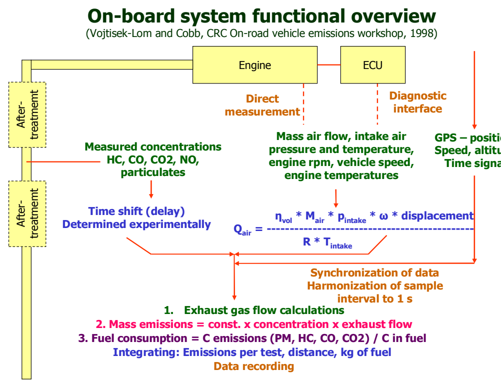
Methodology:
Direct in-use measurements with an on-board system mounted on the tested vehicle or on an accompanying vehicle or person.

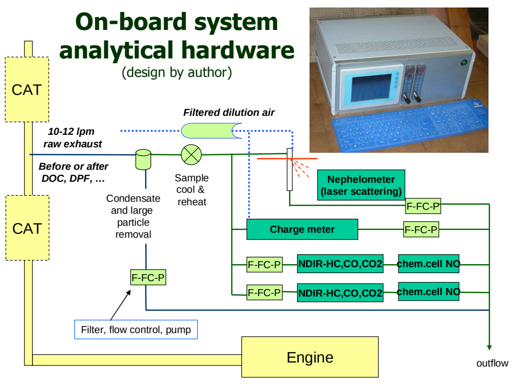
Results are preliminary and subject to discussion.

Caveats:

- Portable on-board system so far used for diesel exhaust studies (details below) and verified on diesel engines, including those running on vegetable oils (high fraction of organic carbon).
- So far little comparative tests have been done on spark ignition engines.
- High concentrations of unburned fuel may encourage nucleation. No denuder to strip volatile particles was used.

Measurement of particulate matter emissions during real-world on-road operation using a portable, on-board monitoring system





Measurement of total PM length with ionization chamber

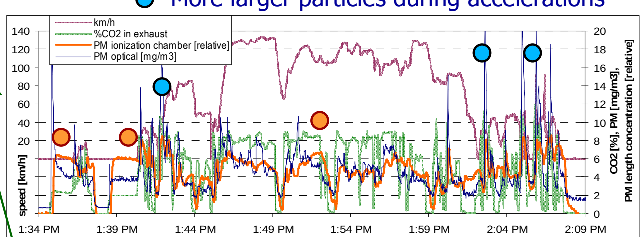
- A time-proven, robust, inexpensive technology used in building smoke alarms
- Alpha-particles generated by radioactive decay of ^{241}Am generate small ionization current in free air – this current is decreased as particles intercept ions
- Response proportional to total particle length (verified on diesel engines with and without DPF, running on diesel fuel and non-esterified vegetable oil)

[Vojtisek-Lom, Journal of the Air and Waste management Association, 61, 2001, 126-134.

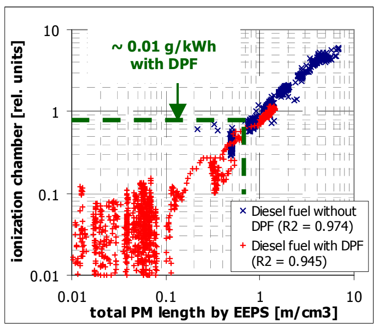
- **Supplemental measurement to provide qualitative indication of mean particle size or relative fraction of nanoparticles.**

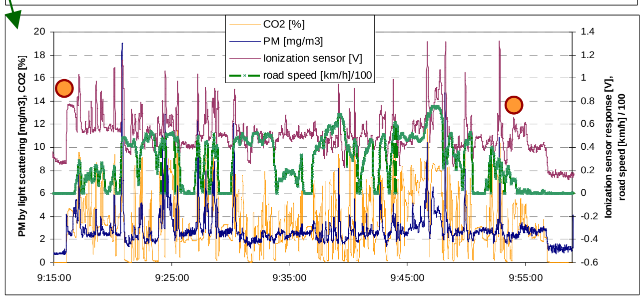
More smaller particles at idle, light load
More larger particles during accelerations

Measurement of PM length in urban driving (Renault Trafic van, Euro 4 diesel)



Laboratory comparison of PM length measurement: EEPS vs. ionization chamber





Acknowledgments: *The work was funded by the Czech Ministry of Education grant no. 1M0568, with in-kind contributions (loan of test instrumentation components, loan of the tested machinery) made by the authors.*

„Typical" equipment was tested under „typical" conditions.

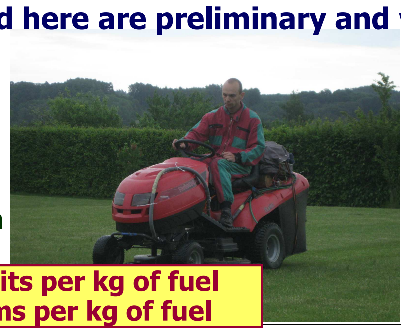
No characterization of equipment maintenance, operating practices, fuel, properties of lawn, logs, weeds, etc. has been made.

Measurements were taken with on-board system installed on the riding lawnmower, which has followed other equipment as needed.
(Equipment can also be fitted in a backpack worn by the operator.)

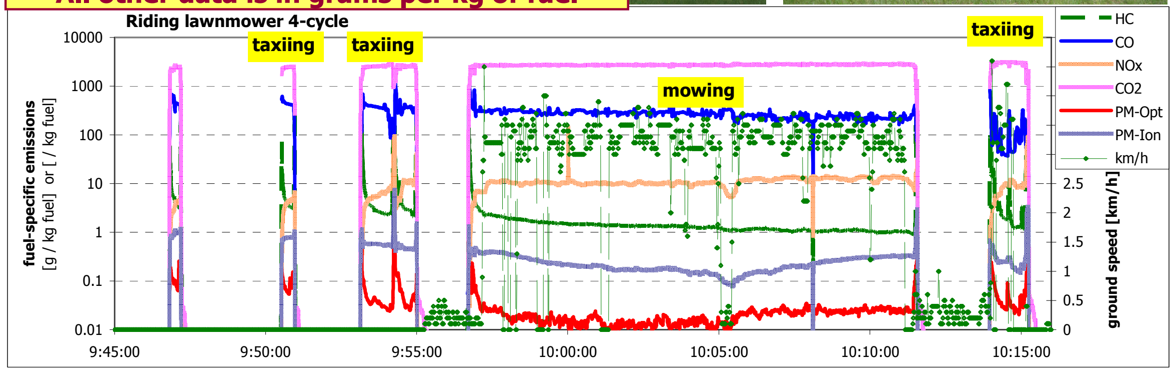
Results reported here are preliminary and work in progress.

Riding lawnmower
TCP 102, Castelgarden, Italy, mfg. in 2001, 4-cycle gasoline

Mowing family house lawn

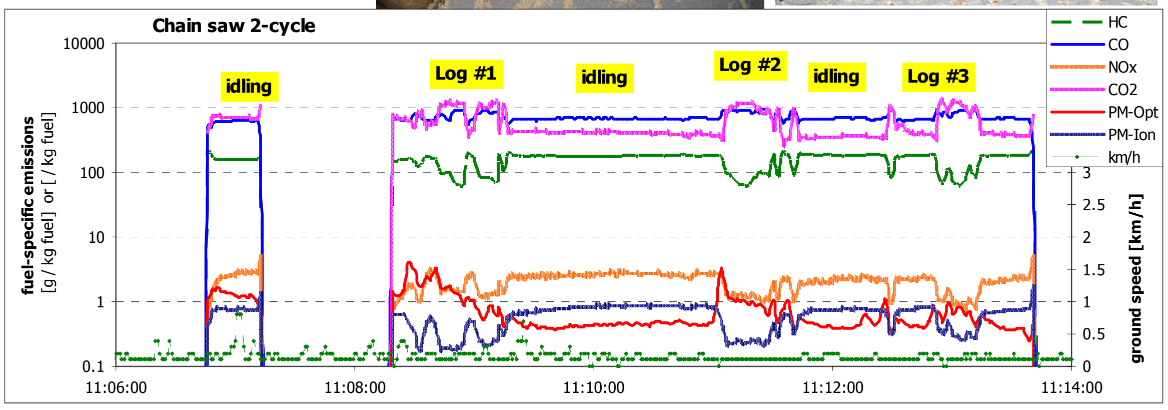


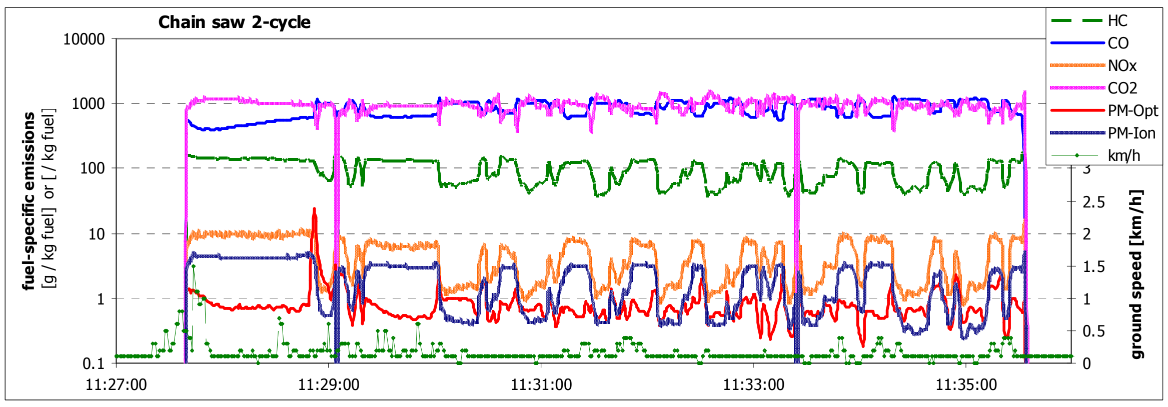
PM length is relative units per kg of fuel
All other data is in grams per kg of fuel



Chainsaws
Stihl 029 (top)
Stihl MS361 (bottom)
2-cycle gasoline

Cutting firewood (logs)
On-board system mounted on accompanying tractor





Weed-whacker
Oleo-Mac 746T
2-cycle gasoline

Cutting /clearing an overgrown ditch
On-board system mounted on accompanying tractor