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A PRELIMINARY ASSESSMENT OF VARIANCE IN PARTICULATE MASS EMISSIONS FROM A LAWNMOWER UNDER REAL DRIVING CONDITIONS

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Abstract

Particle emissions from small non-road and hand-held spark ignition engines have not been and are not regulated, but can be considerable, and given the immediate proximity of the operator to the exhaust, can pose a substantial health risk. In this study, the emissions from a recent production lawnmower have been measured and sampled during real driving conditions using a portable off-board system and an experimental full-flow dilution and sampling tunnel. Particle mass emission rates determined gravimetrically from samples collected on quartz fiber filters exhibited a variance on the order of tens of percent. Variability in engine operating conditions attributed to varying lawn properties is believed to be the prime source of the observed test-to-test variance.

1. INTRODUCTION

Particulate matter in the ambient air is, together with tropospheric ozone, responsible for approximately 430 thousands premature deaths in the EU [1], an order of magnitude more than traffic accidents. Ultrafine particles released by internal combustion engines are considered to constitute a substantial part of this health risk,

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due to the close proximity of citizens to the sources, and due to their small size. Most of the particles emitted by internal combustion engines are typically in the size range of tens of nanometers [2,3]. Particles of this size readily deposit in human lung alveoli [4,5], have the capacity to penetrate cell membranes, and are known to cause a widespread damage to the body [6]. Proximity to sources of internal combustion engine exhaust has been associated with increased risks of various chronic health problems [7-9].

Historically, the smoke opacity and the total mass of particulate matter emitted has been regulated only for compression ignition (diesel) engines. Only recently, particulate mass and particle number emissions have been introduced for positive ignition (spark ignition) automobile engines. It has been known, however, that spark ignition engine can produce relatively high levels of particulate matter of sizes similar to diesel exhaust particles [3], notably during cold starts [10-11] and transient operation [12-13]. Also, it has been known that gasoline engines, while producing less particulate matter by mass and less visible black soot, produce similar or higher levels of benzo[a]pyrene than diesel engines [14-18], with most of these particles being smaller than 180 nm [19].

Small spark ignition engines are not subject to any PM limit whatsoever. At the same time, not only they often lack sophisticated engine controls coupled with catalytic converters, but also, they are operated in the immediate proximity of their operators. Therefore, they may pose a potentially substantial health risk both for their operators and to a lesser extent to the population in general.

This work is a part of measurement of small engine emissions under real driving conditions, which have been proven to be much more representative of realistic operation compared to established test cycles used in certification and in research studies. A downside of real driving studies is generally lower repeatability of measurements, given by the limitations of the instrumentation as well as variances due to atmospheric, climatic, technical, operating, and other conditions.

The goal of this work was to assess the test-to-test variability of emissions from a lawnmower during real-world operation, as measured by a portable measurement system deployed in the field. The study was performed as a baseline in order to assess the feasibility of comparing the emissions from multiple fuels during real driving conditions.

2. EXPERIMENTAL

For this study, an off-board monitoring and sampling system designed by the authors has been used. The sampling system constitutes of a full-flow dilution tunnel, from which diluted exhaust is drawn through a sampling media by an industrial vacuum cleaner turbine at a relatively constant flow. Ideally, all of the exhaust is drawn into the tunnel through an insulated transfer line, plus the balance of filtered dilution air. The flow through the dilution tunnel is measured by a mass flow meter located on the exit side of the tunnel (Sierra Instruments, model 620S), and can be regulated by regulating the turbine motor power. In this study, no regulation of the power output took place, and the tunnel was operated at flow rates varying over approximately

10%. Particulate matter was sampled on 150 mm diameter quartz fiber filters (QMA, Whatman), which were conditioned and weighed under laboratory conditions before and after the measurement. Online measurements of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2) and particulate matter (PM) were carried on using a portable on-board monitoring system (PEMS) [20]. The fuel consumption was calculated from the total emissions of carbon obtained from HC, CO, CO_2 and PM emissions and from the assumed carbon content of fuel of 86.6% by mass. The PEMS was sampling downstream of the filter media to check for penetration of the filters by small particles and to avoid double-counting of part of semi-volatile hydrocarbons as both PM and gaseous HC. Therefore, only gaseous pollutant data were available from the PEMS. The system has been described in detailed in [21]. The installation of the system is shown in Figure 1.

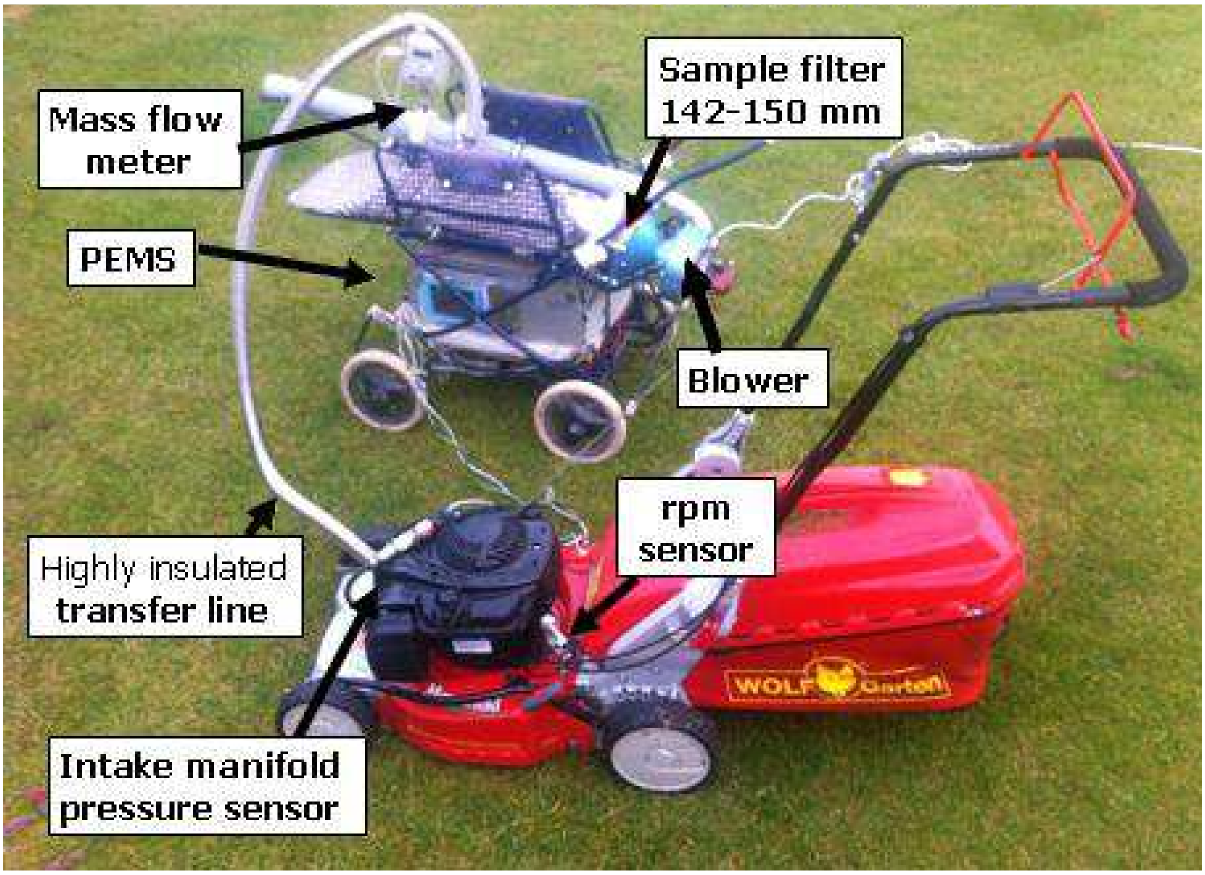

Figure* 1*:* *Off-board monitoring and sampling system [21]

The engine tested in this study was a Briggs & Stratton model 09P7 8 ½ cubic inches (140 cm^3), 2 ½" bore, 1 ¾" stroke, single-cylinder air-cooled four-cycle spark ignition engine certified to the EU Stage II small spark ignition engine standards (16.1 g/kWh HC+NO_x, 10 g/kWh NO_x, 610 g/kWh CO, per European Commission Directive 2002/88/EC). Also, the same model of engine was certified by the California Air Resources Board with certification values of 8.5 g/kWh HC+NO_x and 482 g/kWh CO [22]. The engine was relatively new and was operated on regular gasoline.

The mower was transported to site in a van and subjected to a total of twelve successive mowing runs on ordinary lawns surrounding the staff housing building (Ještědská 341, Liberec) and nearby houses (Táborská street, Liberec). Each run started with an empty clipping bag and a fresh filter in the dilution tunnel, and continued until either the clipping bag became full, or until the operator has run out of lawn that has been readily mowable considering the off-board monitoring system installed on an auxiliary vehicle. In accordance with the established lawn mowing safety precautions as well as with common sense, the engine was shut down prior to emptying the clipping bag. Therefore, each mowing run includes a start and a shutdown of the engine. The first run started with a cold engine.

3. RESULTS AND DISCUSSION

The aggregate results for all twelve runs are shown in Table 1. The first three runs were taken as affected by the "cold start", during which PM emissions were several times higher than after the engine has warmed up. The variance among the last nine "warm" runs was, for absolute emissions per hour, lowest for CO, CO_2 and fuel consumption (around 15%), higher for HC (33%) and NO_x (35%), and highest for PM mass (48%). The fuel consumption ranged from 305 to 534 g/h, NO_x over a factor of three and PM over a factor of four. Slightly lower variances were observed for emissions expressed per kg of fuel consumed.

Run no.	Duration [s]	HC [g/h]	CO [g/h]	NO_x [g/h]	PM [g/h]	CO_2 [g/h]	Fuel [g/h]	HC [g/kg]	CO [g/kg]	NO_x [g/kg]	PM [g/kg]
1	272	4.3	294	0.9	1.65	1159	520	8.3	565	1.8	3.17
2	197	3.8	305	0.7	0.61	1099	506	7.5	603	1.3	1.20
3	217	0.8	241	1.0	0.22	921	415	2.0	582	2.3	0.53
4	63	2.5	313	1.8	0.14	1134	520	4.8	602	3.4	0.26
5	91	2.6	306	2.0	0.14	1141	519	5.1	590	3.9	0.26
6	122	4.0	321	2.3	0.17	1163	534	7.5	600	4.3	0.31
7	130	3.9	190	0.9	0.09	647	305	12.8	624	3.0	0.31
8	146	6.3	278	1.2	0.08	1088	491	12.9	565	2.5	0.16
9	121	5.6	279	0.9	0.07	1019	469	12.0	594	1.9	0.16
10	129	4.3	240	1.1	0.06	1056	460	9.4	522	2.3	0.12
11	127	6.1	303	1.7	0.22	1089	504	12.1	601	3.4	0.44
12	136	6.6	309	2.2	0.24	1150	527	12.5	586	4.2	0.45
Mean all runs	*146*	*4.3*	*282*	*1.4*	*0.31*	*1055*	*481*	*8.9*	*586*	*2.9*	*0.62*
COV all runs	*39%*	*41%*	*14%*	*41%*	*146%*	*14%*	*14%*	*41%*	*4%*	*34%*	*139%*
Mean runs 4-12	**118**	**4.7**	**282**	**1.6**	**0.13**	**1054**	**481**	**9.9**	**587**	**3.2**	**0.28**
COV runs 4-12	**22%**	**33%**	**15%**	**35%**	**48%**	**15%**	**15%**	**33%**	**5%**	**26%**	**42%**

***Table* 2:** *Emissions during twelve runs of a lawnmower*

During the stabilized portion of the run, the fuel consumption has varied over a factor of two, suggesting that the lawnmower engine load was uneven even during each run. Likewise, the emissions of HC, CO and NO_x have varied over each run, as well as among the runs. In addition, HC emissions were dominated by spikes during engine startup and notably during engine shutdown, which was facilitated by disabling the ignition, while the fuel continued to be delivered into the cylinder.

The results show that the test-to-test variance in PM mass measurements, even with the same operator, on the same day, and in the same area, is relatively high, with coefficient of variance being 48% for g/h data and 42% for g/kg fuel data. These variances are substantially higher than the variance among emissions during repeated runs over the same route with an automobile with a spark ignition engine [23], suggesting that the instrument uncertainty is not the principal source of measurement variance.

For many measures resulting only in modest reduction in PM emissions, effective comparison of various scenarios is therefore not straightforward, and it is sure reckoned that it is likely to necessitate a larger number of test runs to be performed and the collection of additional information about operating conditions of the engine, such as engine rpm and load.

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