Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH

Erratum note

(regarding PM measurements on small hand held machinery carried out by order of Association for Emissions Control by Catalyst AISBL in the period from Oct. 16th 2012 to Nov. 15th 2012)

The calculation of the absolutely emitted particulate mass based on the mass adherent to the filter plates shows a basic error. To be able to calculate the entire particulate mass, the overall volume through the dilution tunnel, as well as the partial flow over the filter plate is required.

The used CVS system records both volumes separately. The record of the overall volume being collected throughout an entire test is stopped after bag sampling time is over and is then automatically transferred to the data logging system.

To achieve sufficient deposits on the filter plates, the particulate mass sampling time had to be increased from 3 minutes (standard bag sampling time) to 10 minutes.

The automatic transfer of volume information derived from the bag sampling process (instead of the information from the particulate mass sampling process) led to a wrong dilution ratio which was used for the calculation of the overall particulate mass.

Since this calculation error is systematic and was not detected during the test campaign, all the results of particulate mass per volume, and kWh respectively, are incorrect. The effective PM values are by the factor 3.333 (10/3) higher than the previously published data. The relative relations between the different test carriers are not affected by this error.

Sincerely,

Ass.Prof. Dr. R. Kirchberger

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PARTICLES EMISSIONS OF COMMERCIALLY AVAILABLE SMALL HANDHELD EQUIPMENT

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INTRODUCTION

Small gasoline-powered handheld equipment such as chainsaws, brush-cutters, or leaf blowers may not contribute prominently to the EU-wide pollutant emissions inventory but their exhaust emissions cannot be neglected when considering the health of their operators, be they private or professional users. In Europe, emissions of such handheld tools are regulated by the Non-Road Mobile Machinery (NRMM) Directive 1997/68/EC, which defines emissions limits for HC, CO and NOx gaseous emissions. Particulate Matter (PM) emissions of small NRMM spark ignited engines are not regulated though; neither in mass nor in number. The Association for Emissions Control by Catalyst (AECC) conducted a test program in an independent lab to investigate gaseous and particulate exhaust emissions of this type of applications.

SELECTION OF TEST DEVICES

Since small handheld equipment engine technologies are very diverse, six different engines/machines were chosen, being representative of the European and US market, with engine capacities ranging from 22 to 72 cm³ and power outputs of between 0.6 and 4 kW as described in the table below. A low-cost Asian model was included in the engines selection (#4).

#	Engine specification					Oil/fuel mixture		Catalyst
	Working principle	Displacement [cm³]	Power [W]	Max speed [rpm]	Idle speed [rpm]	Preparation	Ratio	
1	4S dry sump lubricated	25	740	11000	2800	Carburetor	Separated lubrication 10W30	No
2	4S	28.4	960	10200	2800	Carburetor	Synthetic oil 1:50	No
3	2S	22	620	9000	2800	Carburetor	Synthetic oil 1:50	Wire-mesh
4	2S	45	1410	8000	2800	Carburetor	Synthetic oil 1:40	Wire-mesh
5	2S stratified scavenging	59	3400	13000	2800	Carburetor	Synthetic oil 1:50	No
6	2S	72.2	4030	10100	2500	Fuel Injection	Synthetic oil 1:50	No

TEST SET-UP AND EMISSIONS MEASUREMENT

For the engine bench tests, a flexible test rig was designed to be able to carry different types of power tools. In this configuration the open end of the crankshaft with its original flywheel clutch was connected to a flexible clutch, followed by an intermediate shaft and a torque measurement flange that is screwed to the shaft of an electric brake. The actuation of the throttle plate was done by a stepper motor. Exhaust gas was collected by an open CVS system. By using such an open setup, backpressure effects on the engine behaviour can be avoided; this mimics as much as possible in-field engine operation.

Emissions were measured over the regulatory test cycle G3. Cycle G3 is made of two steady-state engine points: wide-open throttle (WOT) and idle. In addition to regulatory gaseous emissions, PM mass and number were measured according to the UNECE light-duty PMP protocol. Gaseous emissions were weighted as required in the NRMM directive, emissions at WOT accounting for 85% and emissions at idle for 15%. The same approach was taken for PM mass and number emissions. Finally, collected particulate matter samples were subjected to a Thermo Gravimetric Analysis (TGA) to identify the mass fraction of organic and elemental carbon. A PM size distribution analysis was performed, using an SMPS instrument on two of the selected engines and finally, the impact of using OEM-recommended mineral oil on PM mass and number emissions were evaluated on the low-cost tool, in comparison with synthetic oil.

All engines except #1 were lubricated by an oil/fuel mixture; therefore some influence on particulate matter measurement was expected from the sampling method, especially in terms of oil droplets possibly counted as particles. In absence of specific regulatory procedure to measure particle emissions from hand-held tools, the PMP protocol was used. The temperature of the heated tube used to remove volatiles adsorbed on particles is set to 350°C in the light-duty UN Regulation 83; this means a gas temperature of about 200°C. The impact of pre-heating on the particulate number measured was evaluated by comparing different temperatures of the evaporation tube. The maximum technically achievable temperature was 500°C (i.e. 300°C gas). Within this range (350-500°C), no significant impact on particle numbers was measured. Tests were therefore conducted using the regulatory 350°C.

ENGINE OPERATION

All tested engines operated under rich conditions both at WOT and at idle. The rich tuning of engines aims at increasing the power output and managing thermal stress at WOT and at enhancing stability at idle. The low-cost 2-stroke (#4) showed the richest combustion at WOT (~λ=0.7), followed by the 2S engine with stratified scavenging (#5) below λ=0.8. The other engines showed comparable λ-values at WOT, between 0.8 and 0.9. A higher variability of the air-fuel ratio was observed on the low-cost engine #4, indicating a less-well controlled combustion.

PM MASS EMISSIONS RESULTS

Particulate mass measurements were repeatable and showed big differences for the various engine working principles. The dry sump lubricated 4-stroke (#1) produces the lowest amount by far (18 mg/kWh); this may be explained by the separation of fuel and oil. Next in line are the 2-strokes with exhaust gas aftertreatment (#3 and 4 around 100 mg/kWh) which indicates a certain reduction of particles - or of the more heavy volatiles adsorbed onto PM - in the catalyst. Finally, all the engines with mixture lubrication produced much higher PM emissions (around 250 mg/kW for #2 and #5 and 410 mg/kWh for #6).

PM NUMBER EMISSIONS RESULTS

PM number emissions varied from $2x10^{12}$ to $5x10^{14}$/kWh, depending on the engine working principle. These levels are of the order of magnitude of non-DPF equipped diesel engines. Engine #1 produced the lowest number of particles. This value was one order of magnitude lower than for the second-best engine #3. Despite similar PM mass to engine #3, the low-cost engine (#4) produced almost the same number of particles (> 10^{14}/kWh) as engines #2 and #6 which are not equipped with a catalyst. Engine #5 with stratified scavenging emitted a lower PM number, at similar level to the catalyst-equipped engine #3 (~ 10^{13}/kWh).

Engine #4 was tested with fully synthetic oil and with mineral oil. Using mineral oil almost doubled the PM mass, but the already high PM number remained identical. Oil may be mainly influencing the size of particles.

PM SIZE DISTRIBUTION

As they differ in working principle and exhaust gas aftertreatment, engines #2 and #3 were chosen for the evaluation of their particles size distribution using a Scanning Mobility Particle Sizer (SMPS). Particles emitted during idle were smaller than during WOT operation for both engines whereas the difference was much bigger for engine #3. Generally, particles emitted by the mixture lubricated 4-stroke (#2) were bigger than the ones emitted by the 2-stroke with catalyst (#3). However, there was no clear evidence whether the difference in mean particle size relates to the different combustion process or to the catalytic oxidation.

PM COMPOSITION

The PM composition analysis by TGA showed that elemental carbon weight shares were only about 10-20 % at idle and 10% at WOT for all six engines. This can result from the high amount of unburned fuel in the exhaust gas due to comparatively poor combustion or from the oil coming from the mixture lubrication. However, the dry sump lubricated engine (#1) showed a similar behaviour. Using the mineral oil increased the content of organic carbon compared to synthetic oil.

CONCLUSION

PM mass and number results were high due to the rich operation of the small handheld equipment engines. The separation of fuel and oil as in the 4-stroke engine #1 with dry sump lubrication strongly helps reducing both PM mass and number. In general, PM mass and number results were equivalent or higher than for typical diesel engines without DPF. One of the main challenge fur future engine development activities in the field of NRMM will be the control of particulate matter emissions, provided future legislation tackles the issue.

With regard to the oil and unburned fuel in the exhaust gas it can be assumed that measurement results would be influenced by the sampling method (evaporation and heating). The tests reported here were conducted as close as possible to existing automotive PMP standards.

The high shares of organic carbon in the particulate matter (between 70% and 90%) are an indicator of the influence of oil and unburned fuel in the exhaust gas. Further analysis to evaluate the content of oil in the OC fraction could be of interest.