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On-road measurement of scooter exhaust emissions

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The paper reports on experimental investigation of the exhaust emissions from a small motorcycle (a scooter) during regular on-road operation in urban and rural hilly terrain. The emissions of gaseous pollutants, total particle length and indicative particle mass emissions were measured continuously online by a portable, on-board monitoring system mounted on the luggage rack of the scooter.

Internal combustion engines are one of the principal sources of harmful particles in urban areas. While automobile and heavy vehicle engines have been subjected to a considerable scrutiny and their emissions have been substantially reduced, many technological advances cannot be easily implemented on low-cost, lightweight small engines in scooters, small motorcycles, yard equipment, and similar applications. Replacement of two-cycle engines with four-cycle ones, and introduction of oxidation catalysts on some models has brought improvements in particle emissions, which, however, still remain a concern.

Experience with field measurements of cars, trucks, buses, locomotives, and various mobile equipment has shown that the emissions in everyday operation can differ from emissions measured in a laboratory. Often, the emissions tend to be higher during real-world operation than in a laboratory, due to higher degree of optimization for conditions experienced during well understood laboratory operating conditions. For this reason, on-board monitoring systems are employed to measure real-world emissions as a complement to laboratory testing, or where laboratory testing is not possible for technological or economical reasons.

Small engine emissions have been, to date, virtually entirely measured in a laboratory, using engine and chassis dynamometers. This work represents the first attempt to use a compact portable, on-board emissions monitoring system to measure emissions from a small motorcycle during actual on-road operation.

For this work, portable, on-board monitoring system developed by the third author was used. This system samples undiluted raw exhaust and uses a non-dispersive infra-red spectrometer to measure the concentrations of hydrocarbons, carbon monoxide and carbon dioxide, an electrochemical cell to measure the concentrations of nitrogen monoxide (which, on engines without an oxidation catalyst, reasonably represents the emissions of nitrogen oxides), a semi-condensing forward scattering integrating nephelometer tuned to provide reading approximately proportional to particle mass concentrations, and two heated ionization chambers which have been shown to correlate to total particle length [1]. The intake air mass flow has been estimated from engine rpm measured by an optical tachometer, intake air temperature, measured intake manifold absolute pressure, engine displacement and compression ratio, and assumed engine volumetric efficiency of 0.9. Exhaust flow has been calculated based on intake air flow and air-fuel ratio derived from exhaust gas composition. Instantaneous position, speed and altitude were obtained from a Global positioning system. The system weighs approximately 14 kg and operates on 9-14 Volts.

The experiments were performed on a Coliber Fartt RHON LH50QT-6 scooter, model year 2009, empty weight 81 kg, with a single cylinder, four cycle, 0.049-liter, carbureted, forced air cooled engine (139QMB, Qingqi Group Ningbo Rhon Motorcycle Co., Ltd.) with a rated power of 2.0 kW at 7500 rpm and maximum torque 2.8 Nm at 6000 rpm, coupled with an automatic transmission, with a maximum speed of 45 km/h. This motorcycle has been registered first in the Czech Republic and was purchased used by the first author with approximately seven thousands km accumulated. The scooter was tested as-is, with no adjustments.

The monitoring system was strapped to the luggage rack of the scooter. The system was powered by a sealed gel cell lead-acid battery (17 kg), allowing for approximately six hours of autonomy, strapped to the scooter "floor" (footpad). (A smaller battery would have been sufficient.) The motorcycle load, comprised of the rider with gear and helmet (95 kg), monitoring system (14 kg) and battery (17 kg), a total of 126 kg, was within the 151 kg maximum load, and was considered not unreasonable for realistic operation.

It has been found that outside air penetrates well into the muffler, notably at idle, and for this reason, a special sampling adapter was fabricated out of aluminum and inserted between the muffler inlet and the manifold of the exhaust pipe mating the muffler.

The motorcycle was tested eight times on a 1.9 km local loop on principal and local streets of Liberec, and twice on a 14 km winding semi-rural loop ascending from the university campus (440 m above sea level) to Rudolfov (640 m above sea level).

The data was synchronized by adjusting for delay in the individual analyzers, after which exhaust flow and mass emissions were computed in a spreadsheet program for each second of the trip. GPS data was found to be missing on large part of the uphill trip due to shading of the signal by the terrain (travel in deep hollows).

The data is plotted in Fig. 1 as a function of engine rpm and intake manifold absolute pressure, which was taken as a surrogate of the engine torque. Each point represents one second of the test, with the area proportional to the value of the displayed quantity.

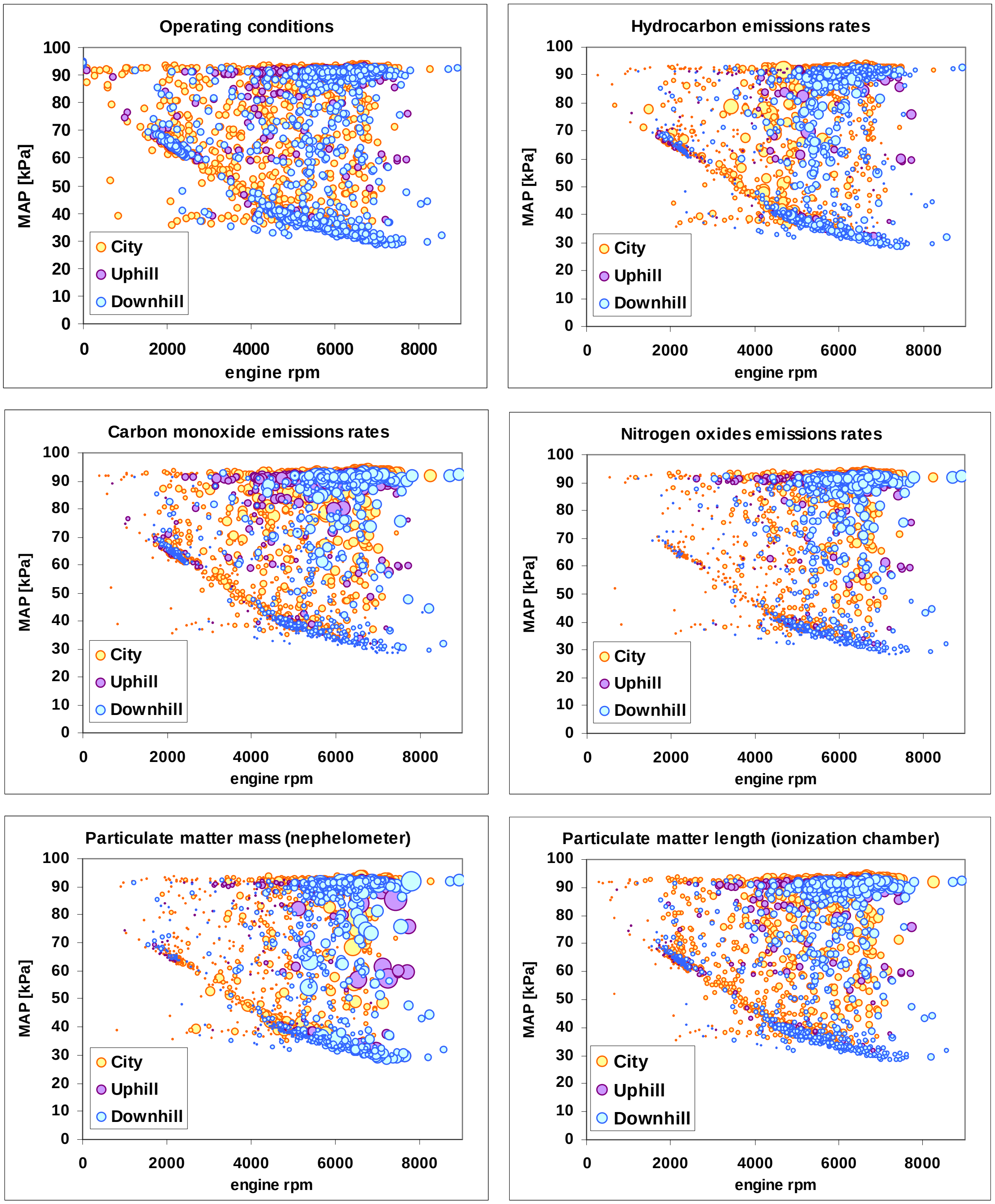

Fig. 1: Instantaneous emission values for each second of the test as a function of engine rpm and intake manifold pressure (a surrogate of engine load).

Examination of the data reveals four major groups of operating conditions: (1) idle at around 2000 rpm, (2) operation at full throttle mostly in the 5000-7000 rpm range, (3) engine braking at 4500-7500 rpm range, and (4) transitions among the above regimes and to/from a standstill. This corresponds to the typical way of operating a scooter with an automatic transmission: The rider typically alternates between zero and full power, using full power at cruise, and addressing any "partial load" needs by short bursts of full power. The decision whether and when to decouple the engine during deceleration is done automatically.

The HC, CO and NO concentrations were typical for those of a carbureted automobile gasoline engine without aftertreatment, with absolute values commensurate to the engine power. The indicative total particle mass emissions were highest during transitions, and were also significant during decelerations. The particle length concentration values were more uniformly distributed and have shown a positive correlation to engine rpm and CO and NO concentrations. The total particle length values were correlated to CO (R^2 = 0.84-0.85) and NO (R^2 = 0.87-0.92) emissions, although large part of this correlation is due to the exhaust flow factor.

All experiments reported here were run with a warmed-up engine and do not include a cold start. The cold start at 15-25 ºC has been unstable and problematic, with engine failing to start or stalling shortly after the start on some attempts, and exhibiting unsteady run following a cold start during some other attempts. Exceptionally high concentrations of particulate matter were recorded during and following some cold starts.

The experiences were generally favorable, suggesting that on-road measurement of scooter emissions using a highly compact portable on-board emissions monitoring system are feasible.

This work represents the first insight into the real-world, on-road emissions of scooters and small motorcycles, and should be viewed as work in progress, with data reported being preliminary.

References:

1. Vojtisek-Lom, M.: Total Diesel Exhaust Particulate Length Measurements Using a Modified Household Smoke Alarm Ionization Chamber. Journal of the Air and Waste Management Association, ISSN 1047-3289, 61, 2011, 126-134.

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