Effect of motorcycle engine technology upon physical properties of nanoparticles

BONNEL Pierre, MARTINI Giorgio, KRASENBRINK Alois, DE SANTI Giovanni
European Commission – Joint Research Center
Via Enrico Fermi,1 – 21020 Ispra (VA) – Italy

Abstract
The purpose of the present exercise was to evaluate the effect of two-wheelers engine technology upon the physical properties of particles. The vehicle fleet included 11 motorcycles of different engine types (2 and 4-stroke), technologies (carburetor, direct injection, electronic fuel injection) and after-treatment systems. The dynamic tests were conducted on a chassis dynamometer following the regulated European test cycles (ECE R40 and 47). The sampling conditions were identical to those used for diesel passenger cars, i.e. a dilution tunnel whose flow rate was kept constant during the entire testing campaign. The total mass and the mass versus size distributions were measured using a Low Pressure Impactor (LPI). Some steady state measurements were also conducted with a Scanning Mobility Particle Sizer (SMPS) to investigate the effect of vehicle speed upon the particle concentration. The particulate matter emitted by motorcycles equipped with 4-stroke engines appeared to be of similar mass and size to that from the conventional gasoline passenger cars. The particulate emitted by two wheelers powered with two stroke engines were much higher in mass and strongly depend on the engine technology. Conventional 2-stroke engines exhibit mass-size distributions with peak towards 200-300 nanometers whereas the direct injection technology produced smaller diameters.

Introduction
The European institutions are preparing the amendment of the Directive 97/24/EC [1] on “Characteristics of two or three-wheel motor vehicles”. One of the objectives of the future legislation is to lower the particulate emissions from motorcycles, especially from the ones equipped with two-stroke engines. The main two objectives of the present study were to determine particulate mass emissions from 2-stroke engines and to assess particulate emissions for big four-stroke engines to check if they diverge significantly from passenger cars with similar engine sizes. The motorcycles considered for this study were chosen to best represent the wide range of engine and after treatment technologies existing for these vehicles. The effect of oil quality upon the results is discussed in a companion paper [2].

Test fleet and test conditions
The test motorcycles have been selected to best represent the variety of engine and after treatment technologies existing on the market. The fleet included 3 mopeds with 2-stroke engines and several motorcycles with 4-stroke engines. Amongst the mopeds, one was “pre-Euro1”, i.e. with no reduction system, whereas the second one was equipped with a catalytic converter and the third one with a direct injection engine. Within the 4-stroke family, the technology was ranging from the conventional engine with a carburetor to the most advanced one with electronic fuel injection and a three-way catalytic converter. Various engine capacities, ranging from 125cc to 1200 cc, were also considered.

The dilution of the exhaust gas was carried out using a constant volume sampler (CVS) whose flow rate was set to 7.5 m³/min for the entire testing campaign. The dilution air, taken from the test cell was maintained at constant temperature and humidity (22.5°C, 50%rH) throughout a test. Mass measurements have been conducted under dynamic conditions (different driving cycles) following the standard procedure for diesel passenger cars. The number size distributions have been obtained using a Scanning Mobility Particle Sizer (SMPS) at constant speeds (from 20 kph to 60 kph when possible).

Results
In terms of mass, the pre-Euro1 moped equipped with a 2-stroke engine emits a significant amount of particulate matter. The more advanced vehicles exhibit better results, close to the Euro4 limit for diesel passenger cars (0.025 g/km). The chemical composition of these particles is obviously very different
from the one emitted by diesel engines [3]. As far as 4-stroke engines are concerned, the particulate emission levels were very low and do not significantly diverge from those of modern gasoline passenger cars. The total masses collected with the Low Pressure Impactor were in good agreement with the filter results.

The engine technology has a strong influence on the properties of the particulate emissions from 2-stroke mopeds. The mass/size distribution of particulates emitted by these vehicles exhibit a peak in the range of about 200-300 nm (aerodynamic diameter). For the moped equipped with a direct injection engine, the distribution is shifted towards smaller diameters. The latter observation is consistent with the measurements of the number/size distributions performed with the SMPS.

Finally, the day-to-day repeatability of the latter type of measurements was proven to be excellent, as evidenced by the good agreement between the curves obtained for five consecutive days, each curve being the average of 5 consecutive scans with the apparatus.

**Conclusions**

The physical properties of particulate from motorcycles have been characterized using the pre-defined existing test procedures and “state of the art” instruments. The conclusions are that Pre-Euro1 conventional 2-stroke engines emit high masses and numbers of particulate matter and that there is some technological potential to reduce these levels using 2-stroke engines with direct injection and/or catalytic converters. All 4 stroke engines, even the less modern ones, emit masses of particulate matter comparable to those observed for gasoline passenger cars, at least in terms of mass per distance, which is the parameter considered by the policy maker.

**Acknowledgements**

These tests have been conducted with the essential contribution from the Vehicle and Engine Laboratory (VELA) staff. The authors also the European association of motorcycle manufacturers (ACEM) for providing test motorcycles.

**References**

Effect of motorcycle engine technology upon physical properties of nanoparticles

P. Bonnel, G. Martini, A. Krasenbrink, G. De Santi
Institute of Environment and Sustainability
European Commission – Joint Research Centre
ISPRA (Italy)

Vehicle Emissions Laboratory (VELA) - Institute for Environment and Sustainability
Presentation Contents:

• Background and Objectives
• Motorcycle fleet
• Test procedure (Test cycles, sampling conditions, instruments)
• Effect of engine technology upon physical properties of PM
  • Total Mass
  • Mass – Size distributions
  • Number – Size distributions
• Conclusions
Background and objectives of the study:

• **Background:**
  – Amendment of the European Directive 97/24/EC
  – EURO3 stage for two and three-wheelers from 2006
  – Reduction of particulate emissions

• **Main Objectives:**
  – To evaluate particulate measurement techniques
  – To determine particulate mass emissions from 2-stroke engines
  – To assess particulate emissions for big four-stroke engines to check if they diverge significantly from passenger cars with similar engine sizes
## Test Fleet:

<table>
<thead>
<tr>
<th>Motos</th>
<th>Eng. (cc)</th>
<th>2S</th>
<th>4S</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT001-50</td>
<td>50</td>
<td>X</td>
<td></td>
<td>Pre Euro1 Moped – No Cat</td>
</tr>
<tr>
<td>MT002-50</td>
<td>50</td>
<td>X</td>
<td></td>
<td>Direct Injection – No Cat</td>
</tr>
<tr>
<td>MT003-50</td>
<td>50</td>
<td>X</td>
<td></td>
<td>Conventional 2-stroke – With OxCat</td>
</tr>
<tr>
<td>MT004-125</td>
<td>125</td>
<td>X</td>
<td></td>
<td>Carburetor</td>
</tr>
<tr>
<td>MT005-125</td>
<td>125</td>
<td>X</td>
<td></td>
<td>Controlled TWC</td>
</tr>
<tr>
<td>MT006-200</td>
<td>200</td>
<td>X</td>
<td></td>
<td>Carburetor</td>
</tr>
<tr>
<td>MT007-500</td>
<td>500</td>
<td>X</td>
<td></td>
<td>SAI</td>
</tr>
<tr>
<td>MT008-1150</td>
<td>1150</td>
<td>X</td>
<td></td>
<td>Controlled TWC</td>
</tr>
<tr>
<td>MT009-1200</td>
<td>1200</td>
<td>X</td>
<td></td>
<td>Controlled TWC</td>
</tr>
</tbody>
</table>

EFI = Electronic Injection  
SAI = Secondary Air Injection  
OC = Oxidation Catalyst  
TWC= Three Way Catalyst
Test Procedure: 1a. ECE 47 Test Cycle (Mopeds only)
**Test Procedure: 1b. EURO 2 Test Cycle**

**Conditioning**
- 2 phases ECE15 (UDC) of 195 s = 390 s
- km 1.013*2 phases = 2.026 km
- Max. Speed: 50 km/h
- Average Speed: 19 km/h

**Measurement**
- 4 phases ECE15 of 195 s = 780 s
- km 1.013*4 phases = 4.052 km
- Max. Speed 50 km/h
- Average Speed: 19 km/h
Test Procedure: 1c. EURO 3 Test Cycle (<=150 cc)

UDC Cycle - 6 phases ECE15 of 195 s = 1170 s
km 1.013*6 phases= 6.078 km
Max. Speed: 50 km/h
Average Speed: 19 km/h
Test Procedure: 1d. EURO 3 Test Cycle (>150 cc)

UDC Cycle - 6 phases ECE15 of 195 s = 1170 s
km 1.013*6 phases= 6.078 km
Max. Speed: 50 km/h
Average Speed: 19 km/h

EUDC Cycle of 400 s
km 6.955
Max. Speed: 120 km/h
Average Speed: 62.6 km/h
Test Procedure: 2. Test Set-up

- Carried out at the JRC-VELA1 emissions test facility
- Roller bench 48” suitable for testing small two wheelers
- Conventional CVS system + dilution tunnel
Experimental programme details:

• Lubricant
  – As recommended by the manufacturer
  – Effect of lubricant quality studied separately

• Fuel
  – CEC-RF-02-99

• Engine settings
  – As delivered
## Test Matrix:

<table>
<thead>
<tr>
<th>Motos</th>
<th>EURO2</th>
<th>EURO3</th>
<th>NEDC (*)</th>
<th>WMTC (**)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECE47</td>
<td>ECE 40</td>
<td>6UDC</td>
<td>6UDC+EUDC</td>
</tr>
<tr>
<td>MT001-50</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MT002-50</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MT003-50</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>MT004-125</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MT005-125</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>MT006-200</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>MT007-500</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MT008-1150</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MT009-1200</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

(*) Passenger car test cycle (4UDC+EUDC)
(**) Worldwide Motorcycle Test Cycle
Total Mass
Particulate Emissions from Mopeds - Total Mass
ECE 47 Cycle

- MT001-M-50
  - Cold Phase (1-2-3-4)
  - Pre-Euro 1
  - Moped - 2-stroke

- MT002-M-50
  - Cold Phase (1-2-3-4)
  - Hot Phase (5-6-7-8)
  - Moped - Direct Injection

- MT003-M-50
  - Cold Phase (1-2-3-4)
  - Moped - Oxycat
Particulate Emissions from Mopeds and Motorcycles - Total Mass
Euro 2 Cycle (ECE 40)

- Cold Phase (UDC 1-2)
- Hot Part (UDC 3-4-5-6)
- Complete Cycle

Motorcycle Models:
- MT001-50
- MT002-50
- MT003-50
- MT004-125
- MT007-500

Moped Emisions:
- 2 stroke
- Pre-Euro 1
- Direct Injection
- Oxycat
Particulate Emissions from Mopeds and Motorcycles - Total Mass (Filter)
Complete Euro 3 Cycle (6 Urban Driving Cycles)

- Moped - 2 stroke Pre-Euro 1
- Moped - 2 stroke Oxycat
- Moped - 2 stroke Direct Injection
- 4-stroke Motorcycles
- EURO4 Diesel Passenger cars = 0.025 g/km
PARTICULATES - Total Mass
MT002-M-50 : Effect of Driving Cycle

<table>
<thead>
<tr>
<th>Cycle</th>
<th>g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE47</td>
<td>0.025</td>
</tr>
<tr>
<td>ECE 40</td>
<td>0.015</td>
</tr>
<tr>
<td>6 UDC</td>
<td>0.010</td>
</tr>
<tr>
<td>WMTC 1-1</td>
<td>0.020</td>
</tr>
</tbody>
</table>

EURO 4 - Diesel = 0.025 g/km
Mass/Size Distribution
Particulate Emissions from Mopeds - Mass/Size Distribution (LPI 11 stages)
ECE 47 (Cold Phase + Hot Phase)
Particulate Emissions from Mopeds and Motorcycles
Mass/Size Distribution (LPI 11 stages) - EURO2 (Cold + Hot Phase) Cycle

Aerodynamic Diameter (nm)
dM/dLogD, (g/km)

MT001-M-50
MT002-M-50
MT003-M-50
MT006-C2-200*

* 6 UDC_Euro 3 Cycle (no 40 s idling)
Particulate Emissions from Mopeds - Total Mass - LPI vs Filter
ECE 47 Cycle (Cold Phase + Hot Phase)

Aerodynamic Diameter (nm)

- MT001-M-50: 91%
- MT002-M-50: 75%
- MT003-M-50: 88%
Particulate Emissions from Mopeds - Total Mass - LPI vs Filter
EURO2 (Cold Phase + Hot Phase)

Aerodynamic Diameter (nm)

MT001-M-50  MT002-M-50  MT003-M-50

Filter  LPI

91%  97%  95%

\( \frac{dM}{d\log D}, \text{g/km} \)
Number/Size Distribution
MT001-M-50 (Pre Euro1 2-stroke Moped)
SMPS Number/Size Distribution - Constant Speed: 20 km/h
5 consecutive scans

[dN/dlog Dp]/km

Scan 1
Scan 2
Scan 3
Scan 4
Scan 5

Electrical Mobility Diameter (nm)
MT002-M-50 (2-stroke Moped - 50 cc Direct Injection)
Number/Size Distribution - Constant Speed: 40 km/h
5 consecutive scans

Electrical Mobility Diameter (nm)

[\frac{dN}{d\log D_p}] / km

Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
MT001-M-50
Number/Size Distribution - 20 km/h
Day to Day Repeatability
Each curve is the average of 5 daily scans
MT003-M-50
Number/Size Distribution - 40 km/h
Day to Day Repeatability
Each curve is the average of 5 daily scans

[Graph showing number size distribution with three curves labeled MT003-M-50 (Day 1), MT003-M-50 (Day 2), and MT003-M-50 (Day 3)].

Electrical Mobility Diameter (nm)

[dN/dlog Dp]/km

1 10 100 1000
Number/Size Distribution - Constant Speed 20 km/h
Effect of Engine Technology

Electrical Mobility Diameter (nm)

[dN/dlog Dp]/km

MT001-M-50 (Day 1)
MT002-M-50 (Day 1)
MT003-M-50 (Day 1)

Moped - 2 strokes
Number/ Size Distribution - Constant Speed: 40 km/h
Effect of Engine Technology

Effect of Engine Technology

- MT001-M-50 (Day 1)
- MT002-M-50 (Day 1)
- MT003-M-50 (Day 1)

[Electrical Mobility Diameter (nm)]

- Moped - 2 strokes

[dN/dlog Dp]/km

10 100 1000

Electrical Mobility Diameter (nm)
Conclusions:

• Pre-Euro1 conventional 2-stroke engines emit high masses and numbers of particulate matter.
• There is some potential to reduce these levels using 2-stroke engines with direct injection and/or catalytic converters technologies.
• All 4 stroke engines, even the less modern ones, emit masses of particulate matter comparable to those observed for gasoline passenger cars.

• On going works now focusing on:
  • 1. Toxicity of PM (also for passenger cars), performing chemical analysis of the PM emissions
  • 2. Limits of the instruments (Repeatability from test bench to test bench, Detection limits)