Effect of motorcycle engine technology upon physical properties of nanoparticles

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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 m^3/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

1. Directive 97/24/EC of the European Parliament and of the Council of 17 June 1997 on certain components and characteristics of two or three-wheel motor vehicles, OJ L 226, pp.1-454, 1997.
2. Martini Giorgio, Bonnel Pierre, Krasenbrink Alois, De Santi Giovanni, Particulate Emissions from Mopeds: Effect of Lubricant and Fuel, ETH-Conference on Combustion Generated Particles 18th - 20st August 2003, Zurich
3. Astorga-Llorens C., et al.: Chemical characterization of particulate emissions from 2-stroke and 4-stroke motorcycle engines, J. Aerosol Sci., 2003.

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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

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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

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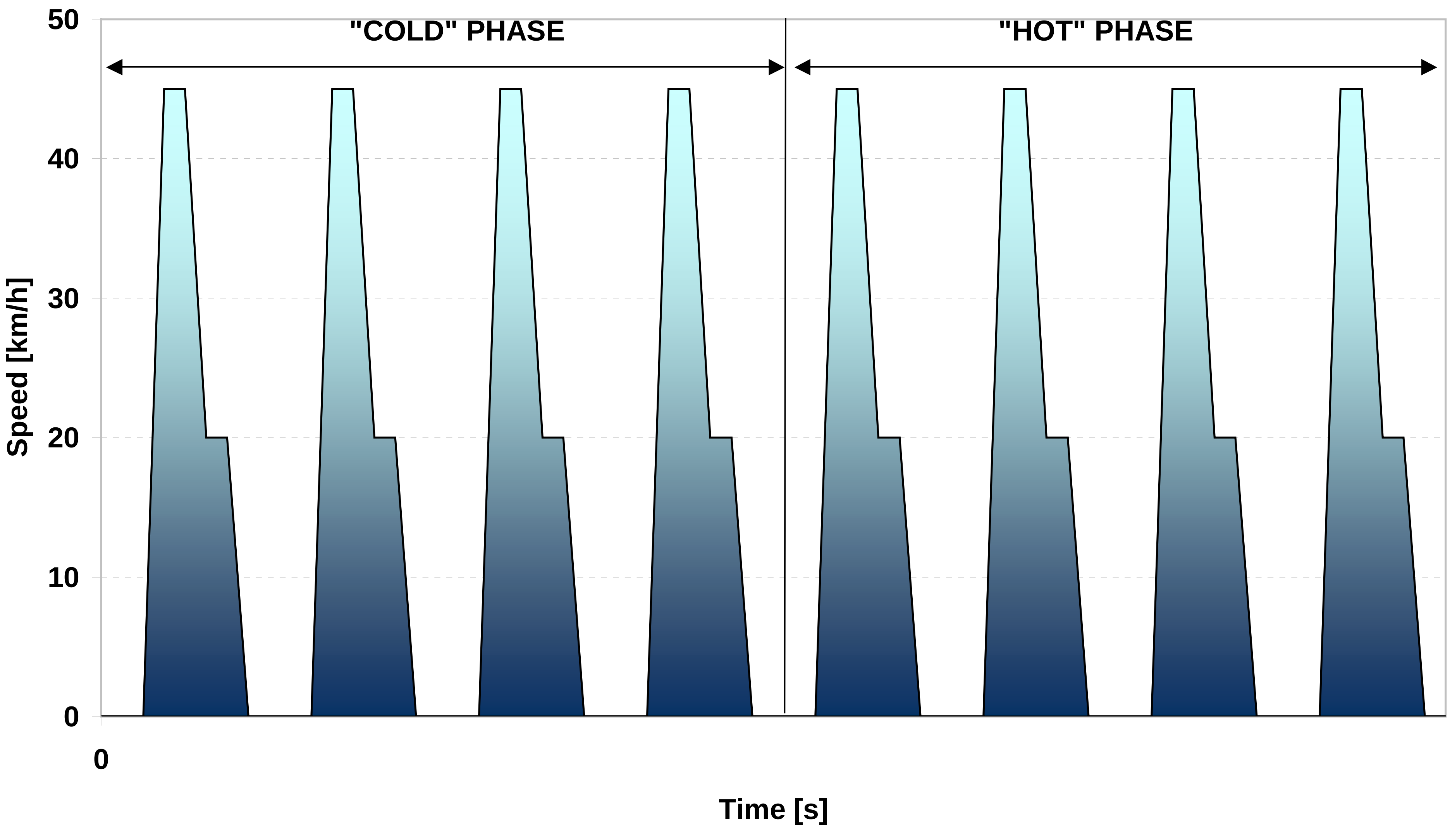
Test Fleet:

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

EFI = Electronic Injection
SAI = Secondary Air Injection
OC = Oxidation Catalyst
TWC= Three Way Catalyst

Test Procedure: *1a. ECE 47 Test Cycle (Mopeds only)*



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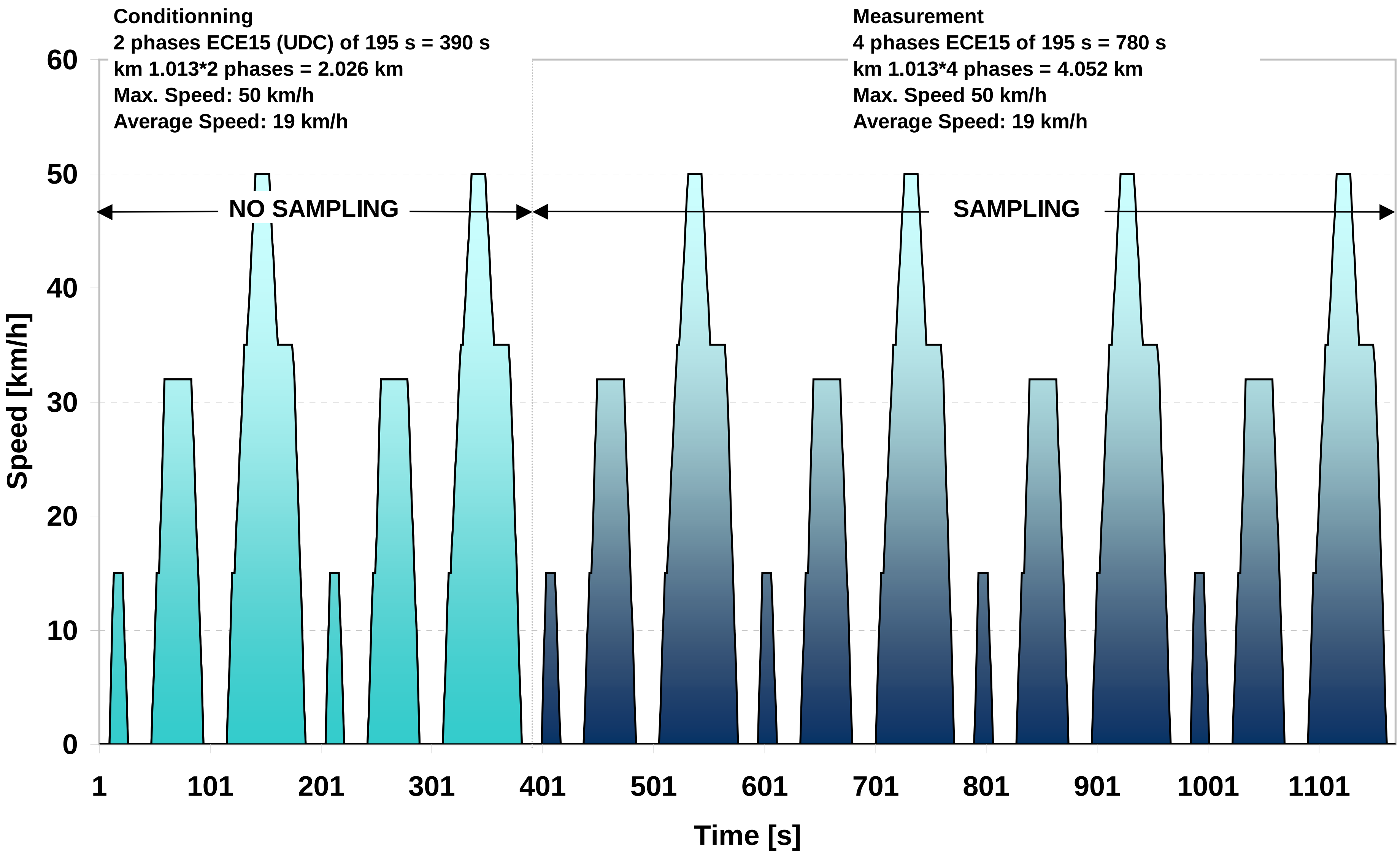
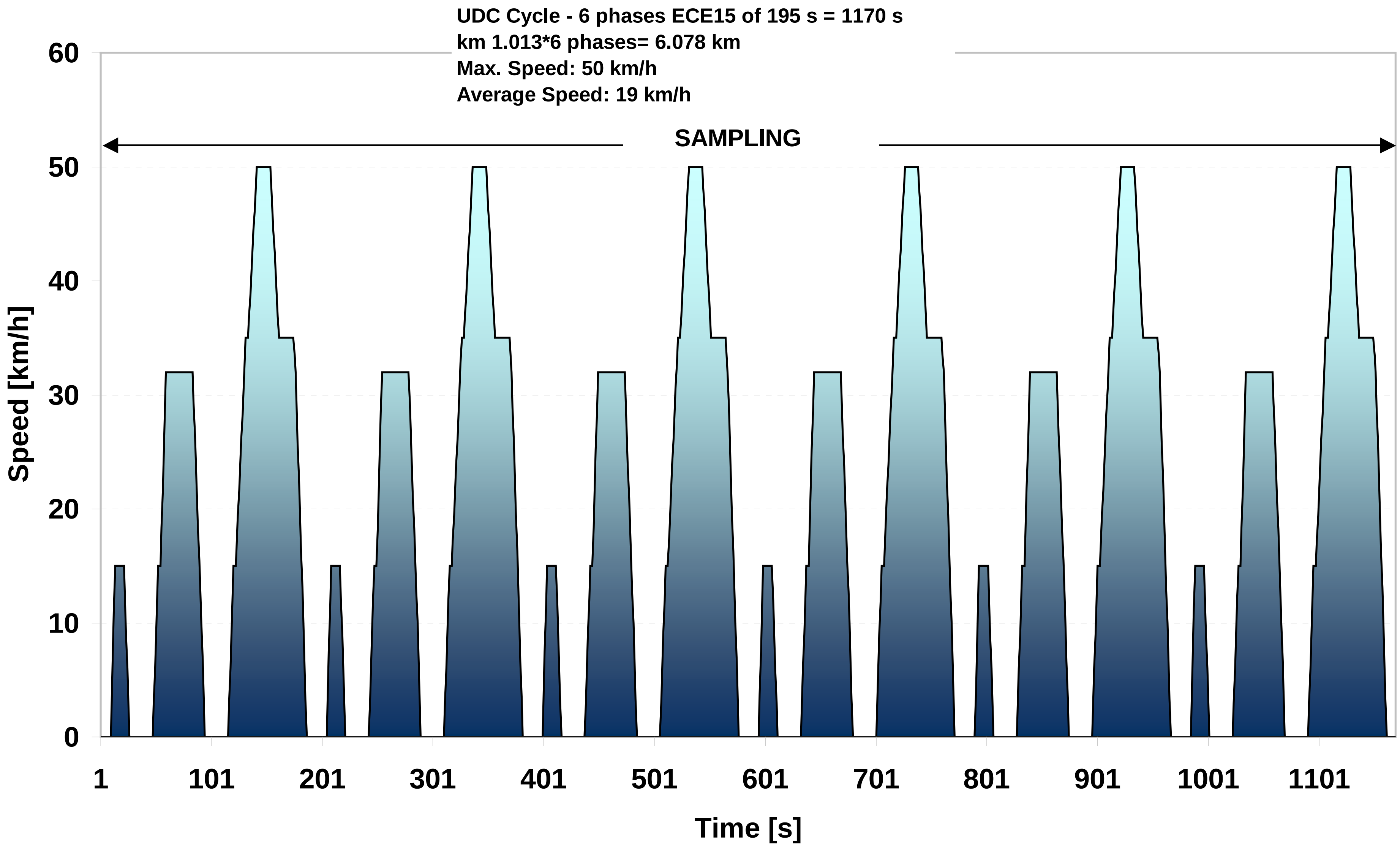
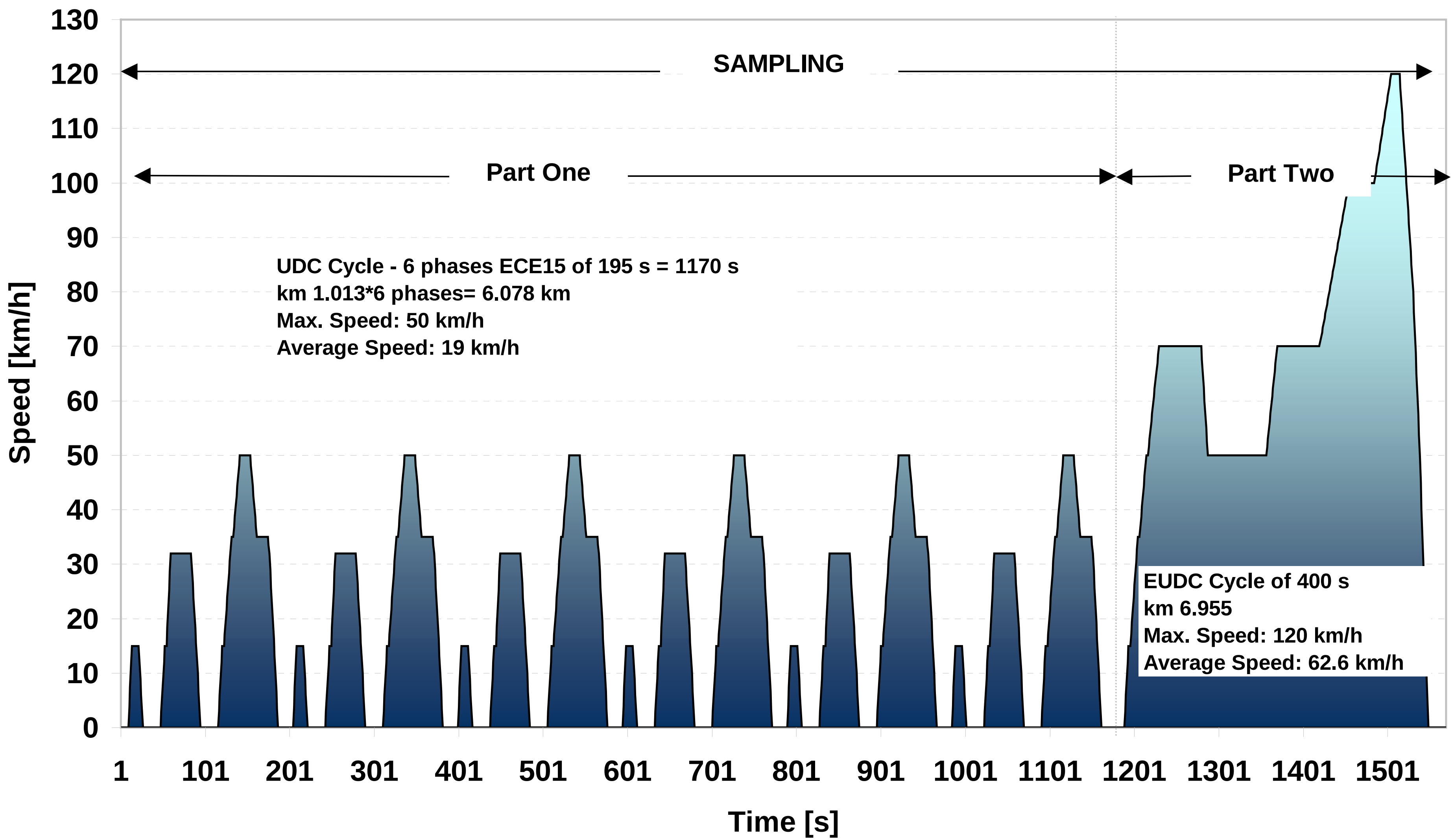
Test Procedure: *1b. EURO 2 Test Cycle*



Test Procedure: *1c. EURO 3 Test Cycle (<=150 cc)*



Test Procedure: *1d. EURO 3 Test Cycle (>150 cc)*



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

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Experimental programme details:

- **Lubricant**
  - As recommended by the manufacturer
  - Effect of lubricant quality studied separately
- **Fuel**
  - CEC-RF-02-99
- **Engine settings**
  - As delivered

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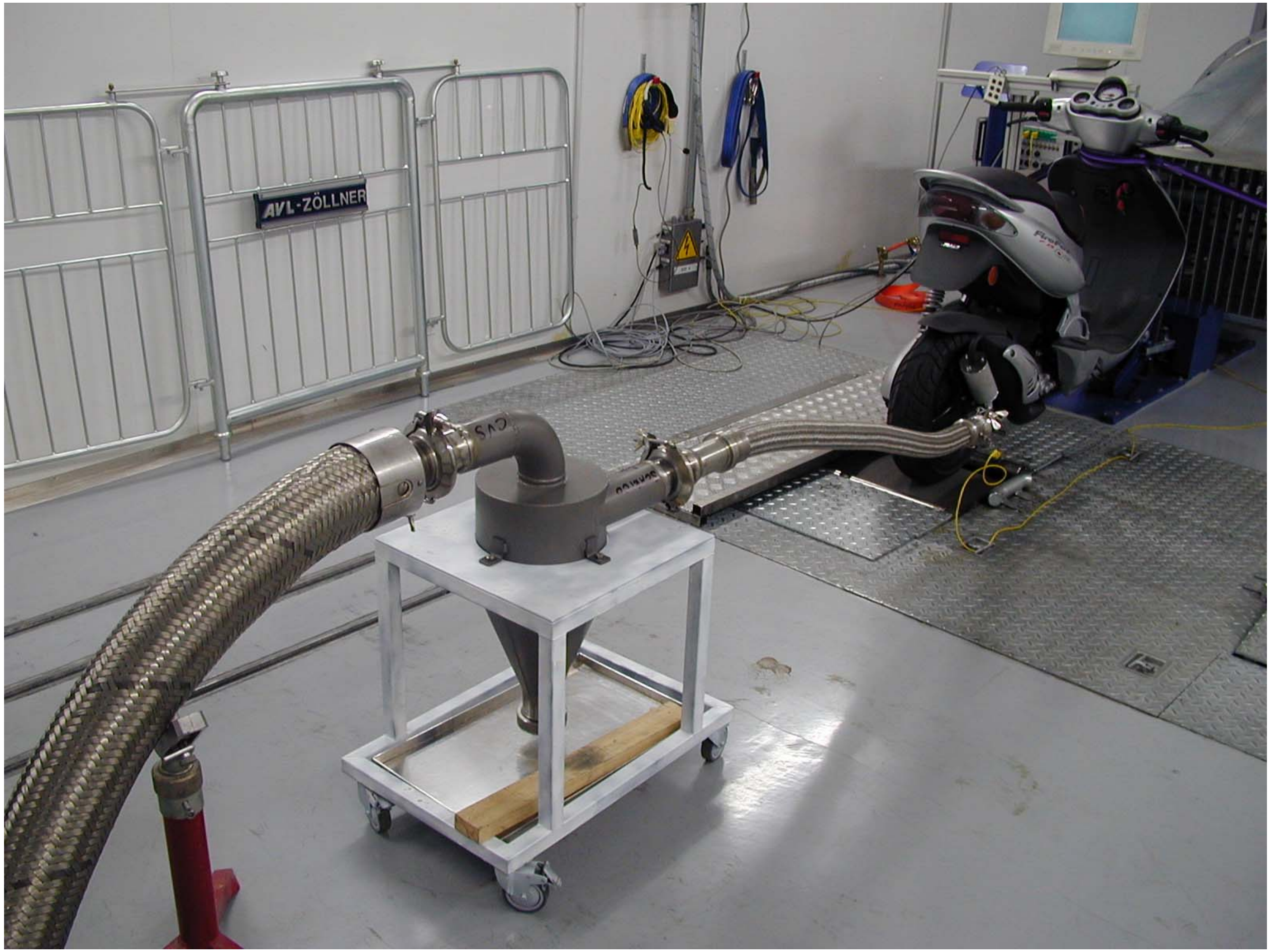
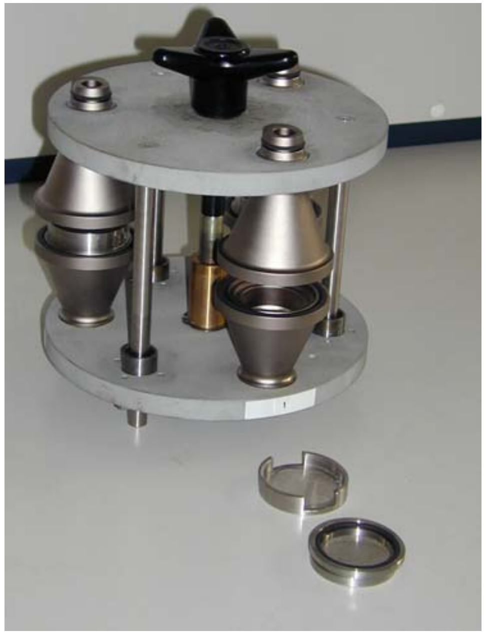
Test Matrix:

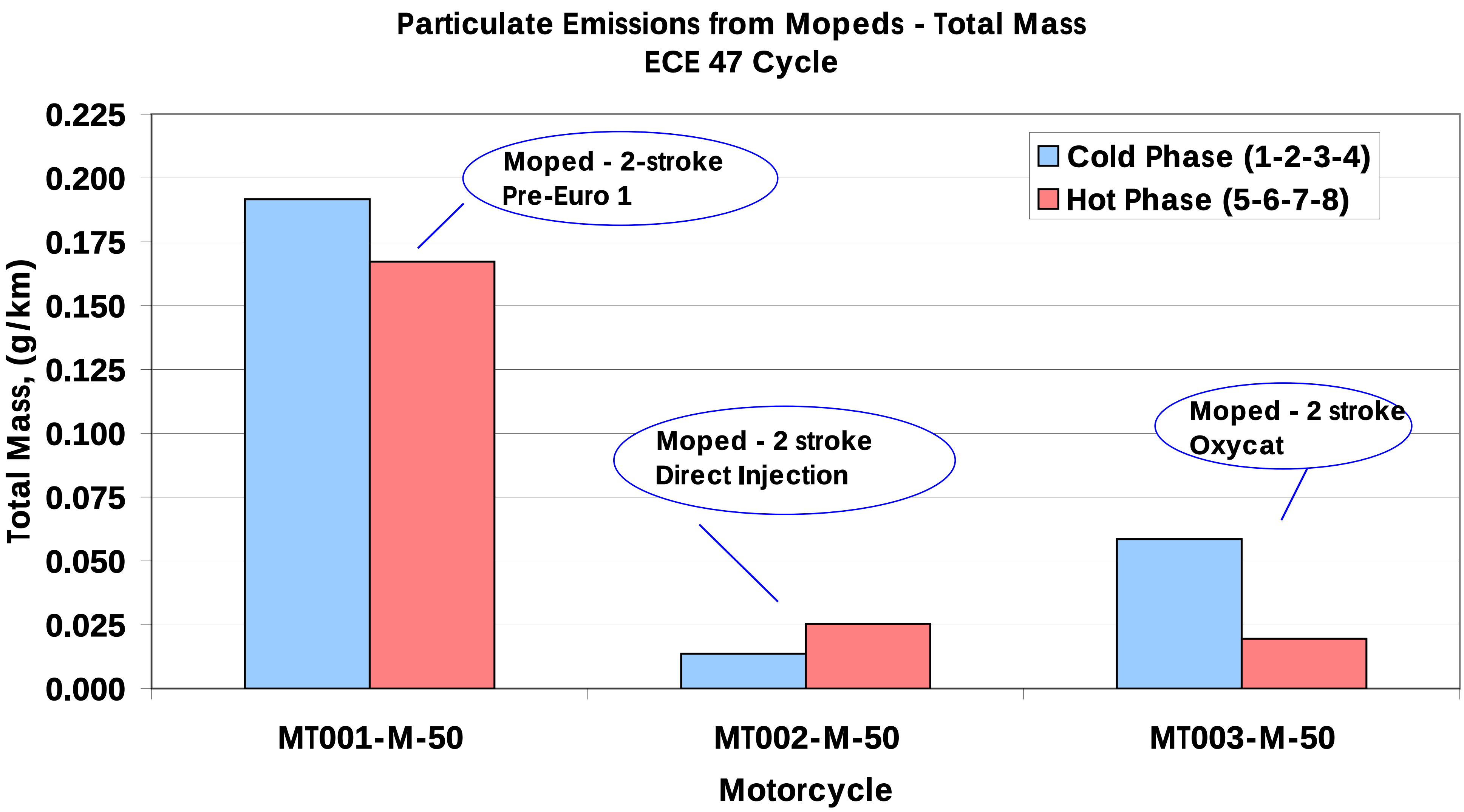
Motos	EURO2		EURO3		NEDC	WMTC
	ECE47	ECE 40	6UDC	6UDC+EUDC	(*)	(**)
MT001-50	✓	✓	✓			
MT002-50	✓	✓	✓			✓
MT003-50	✓	✓	✓			
MT004-125		✓	✓			✓
MT005-125			✓			✓
MT006-200			✓			✓
MT007-500		✓		✓	✓	✓
MT008-1150				✓	✓	✓
MT009-1200				✓	✓	✓

(*) Passenger car test cycle (4UDC+EUDC)
(**) Worldwide Motorcycle Test Cycle


AVL-ZÖLLNER
CVS

Total Mass




Particulate Emissions from Mopeds - Total Mass
ECE 47 Cycle
Total Mass, (g/km)
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Moped - 2-stroke
Pre-Euro 1
Moped - 2 stroke
Direct Injection
Moped - 2 stroke
Oxycat
Cold Phase (1-2-3-4)
Hot Phase (5-6-7-8)
MT001-M-50
MT002-M-50
MT003-M-50
Motorcycle

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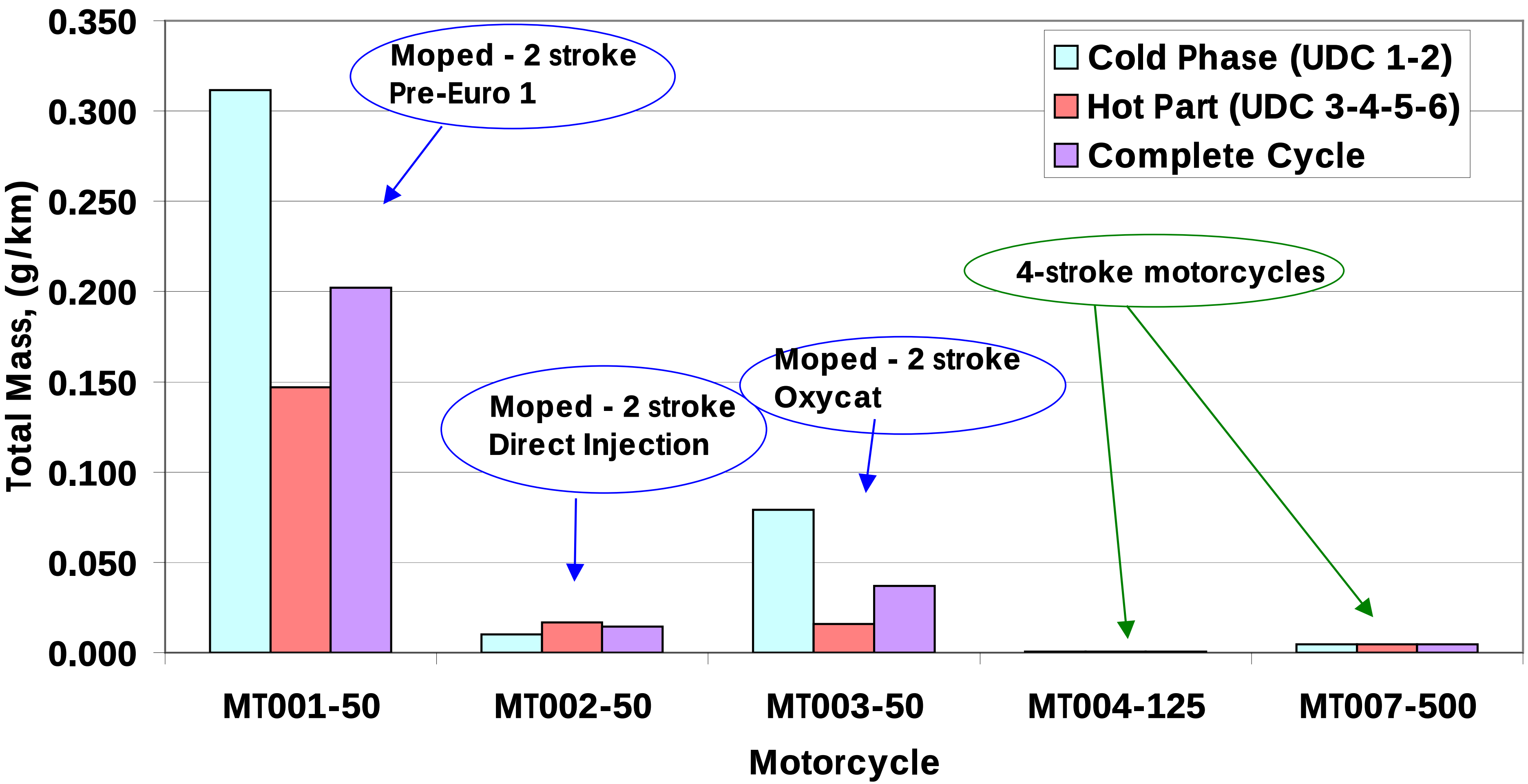
Particulate Emissions from Mopeds and Motorcycles - Total Mass
Euro 2 Cycle (ECE 40)



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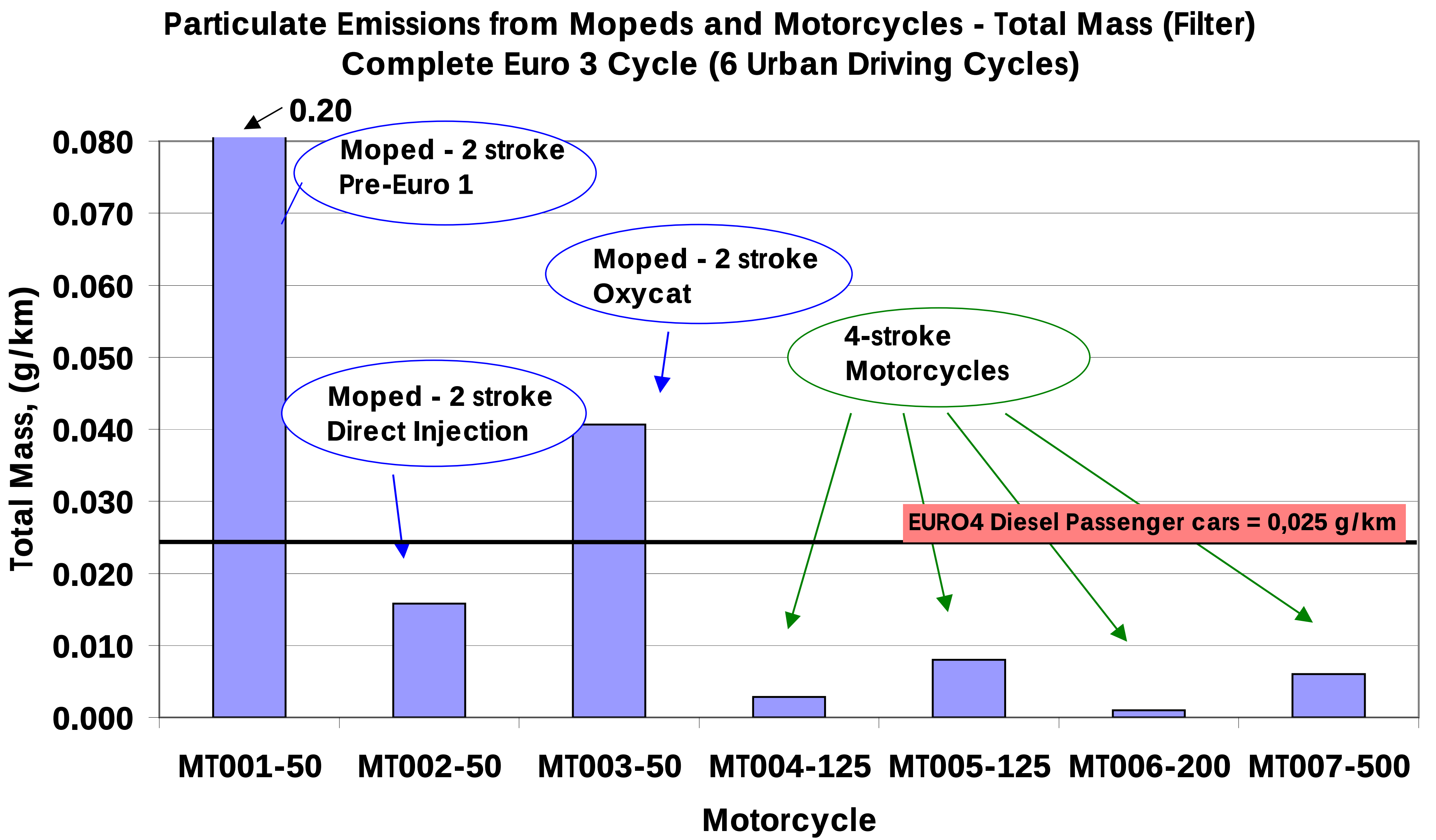
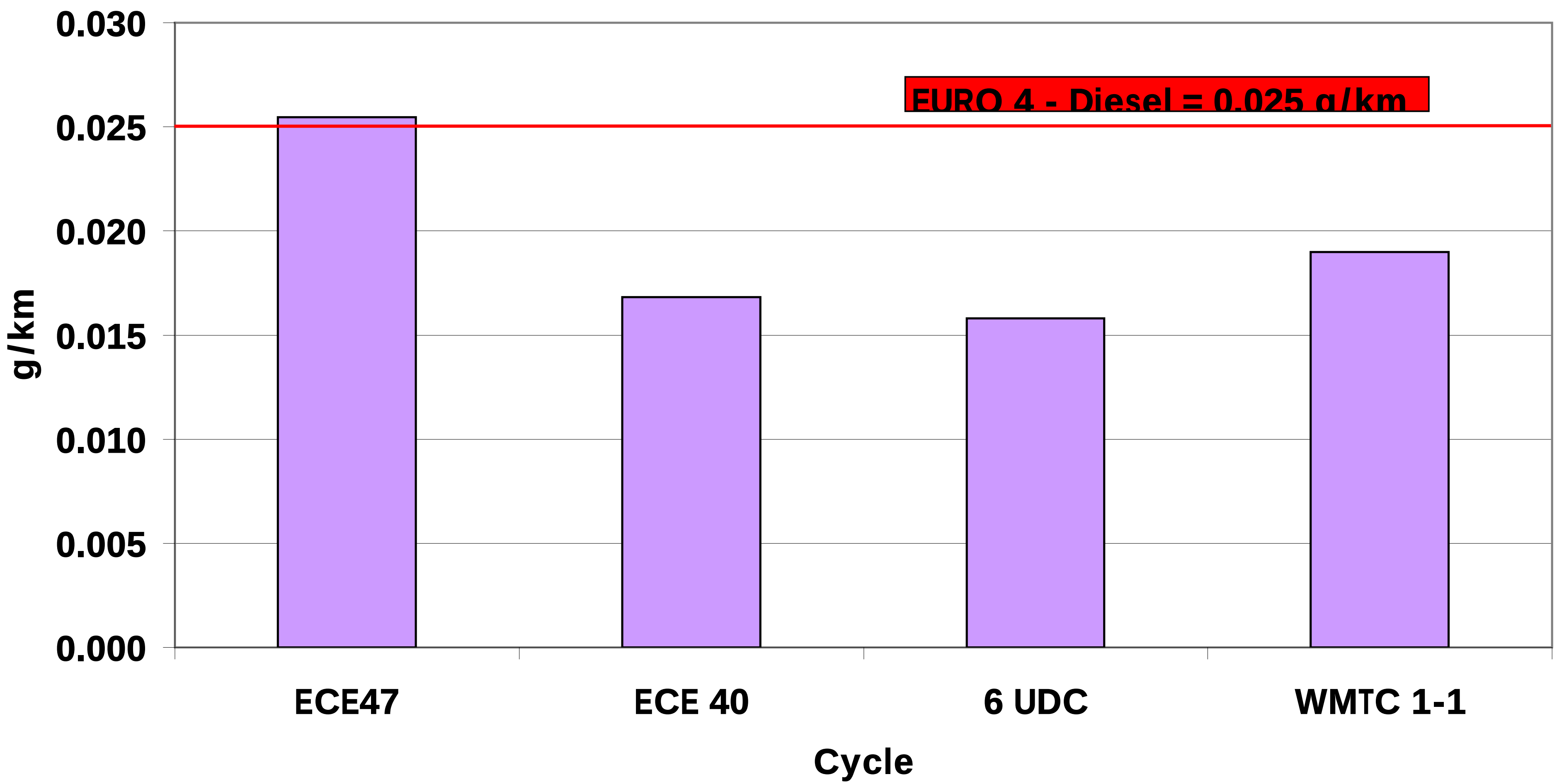
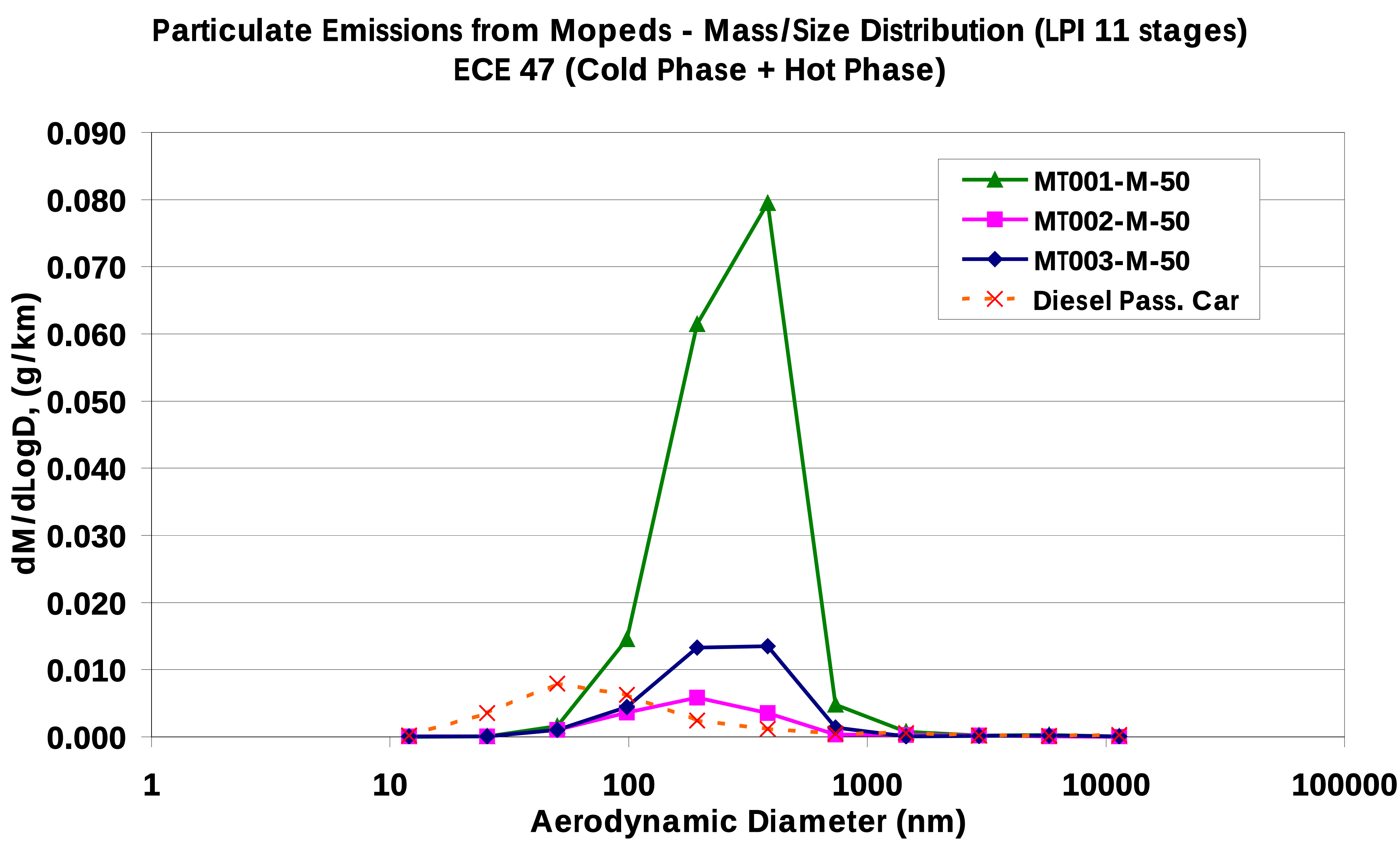


PARTICULATES - Total Mass
MT002-M-50 : Effect of Driving Cycle



Mass/Size Distribution


Particulate Emissions from Mopeds - Mass/Size Distribution (LPI 11 stages)
ECE 47 (Cold Phase + Hot Phase)
dM/dLogD, (g/km)
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
1
10
100
1000
10000
100000
Aerodynamic Diameter (nm)
MT001-M-50
MT002-M-50
MT003-M-50
Diesel Pass. Car

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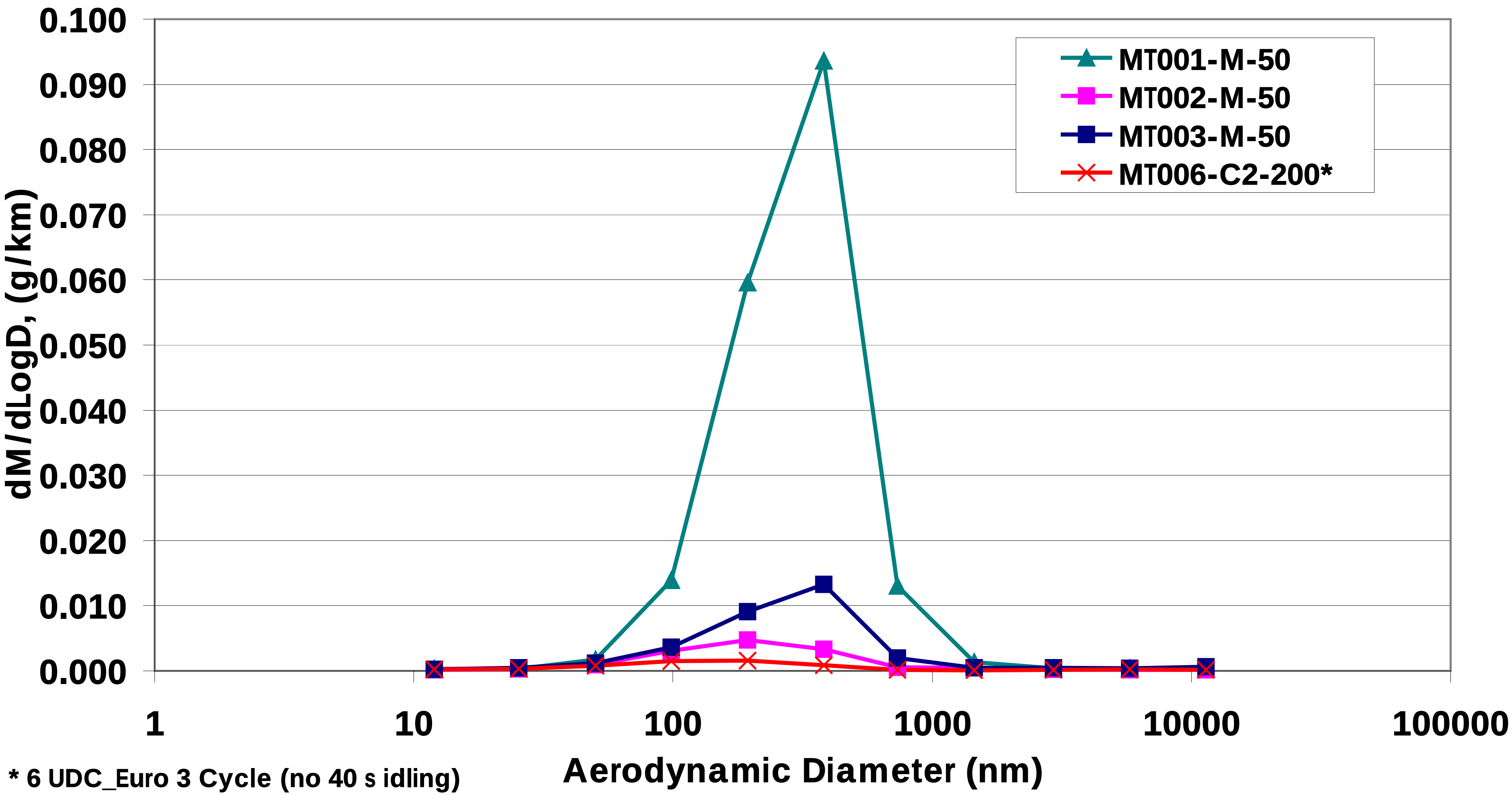
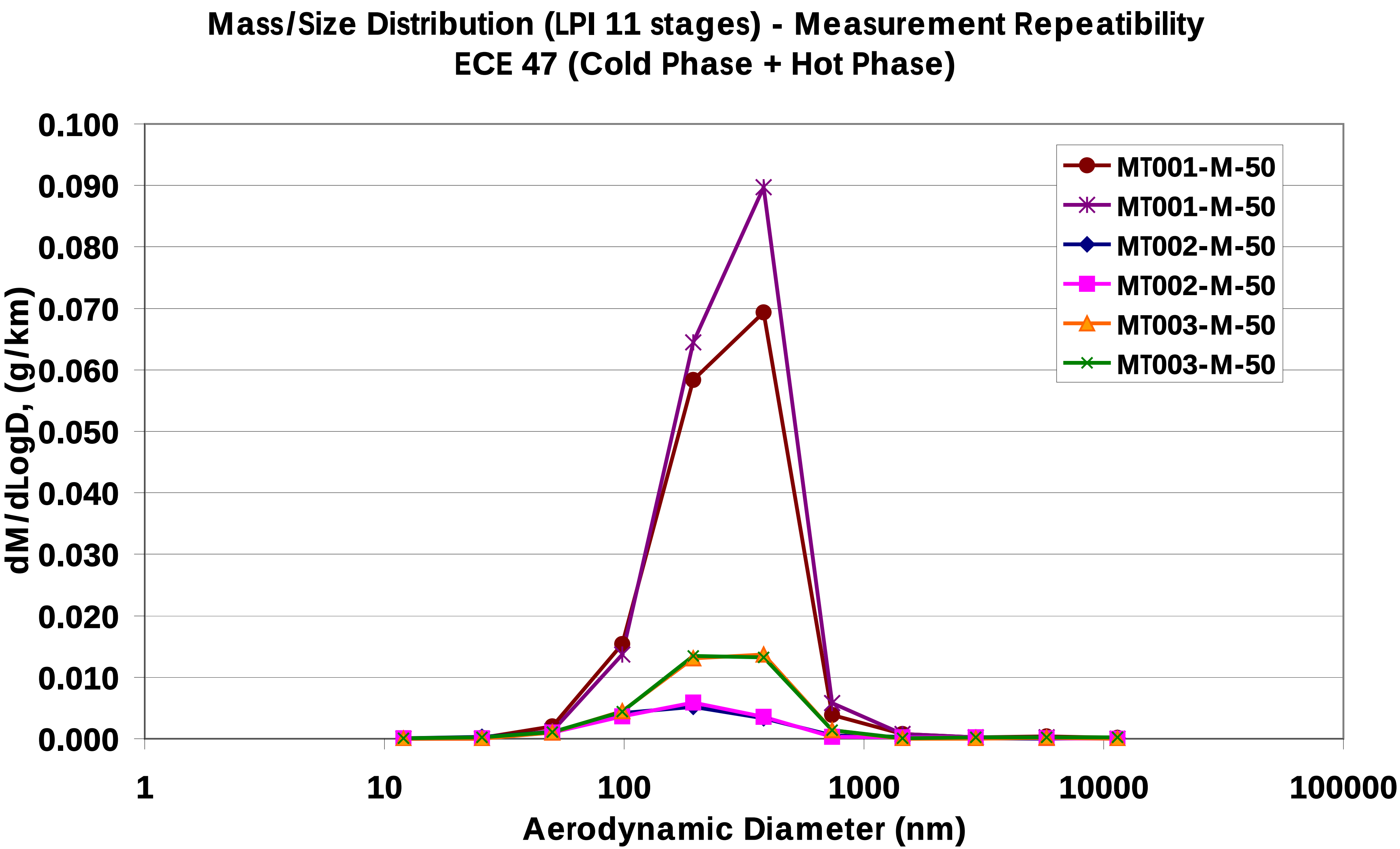
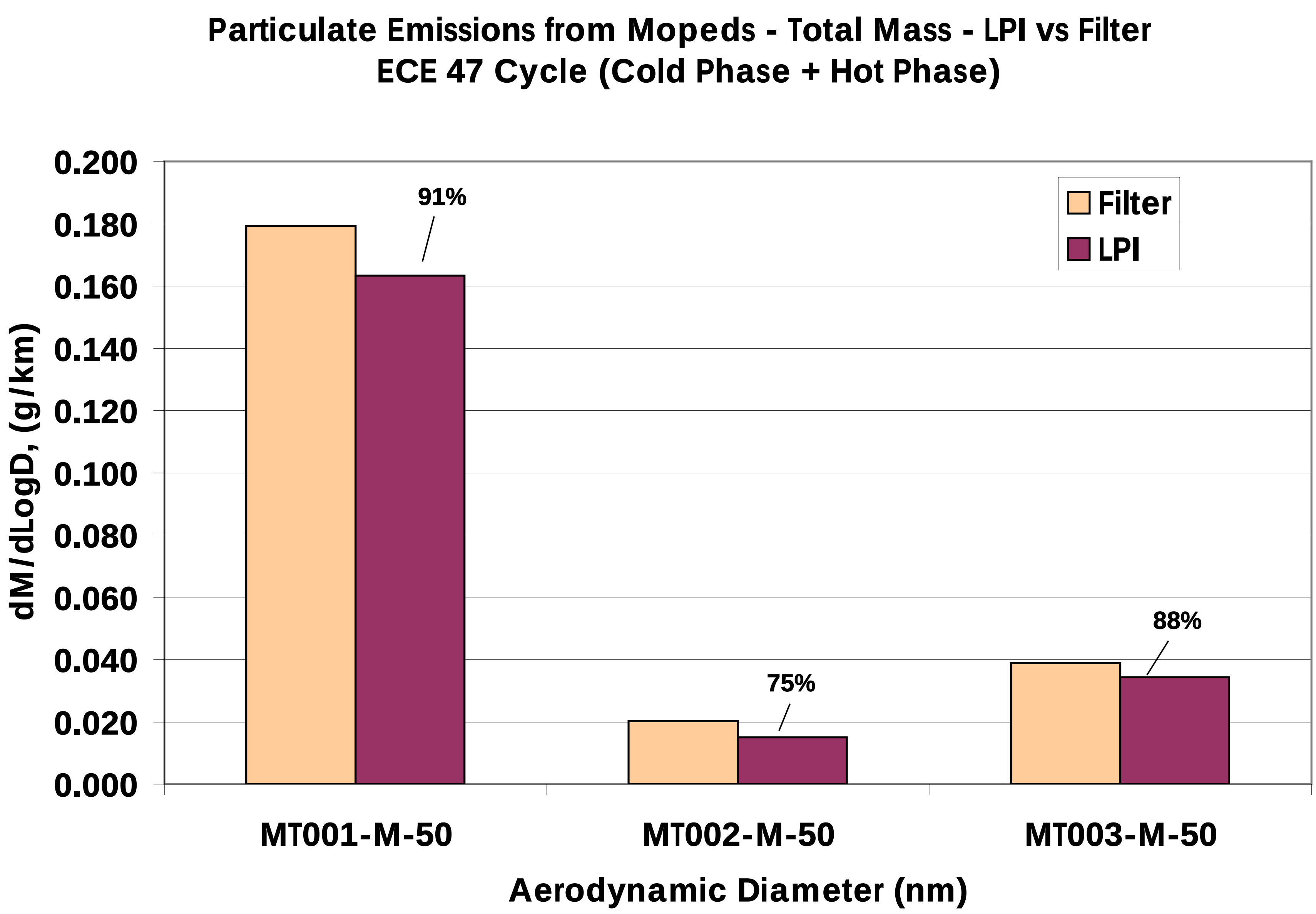
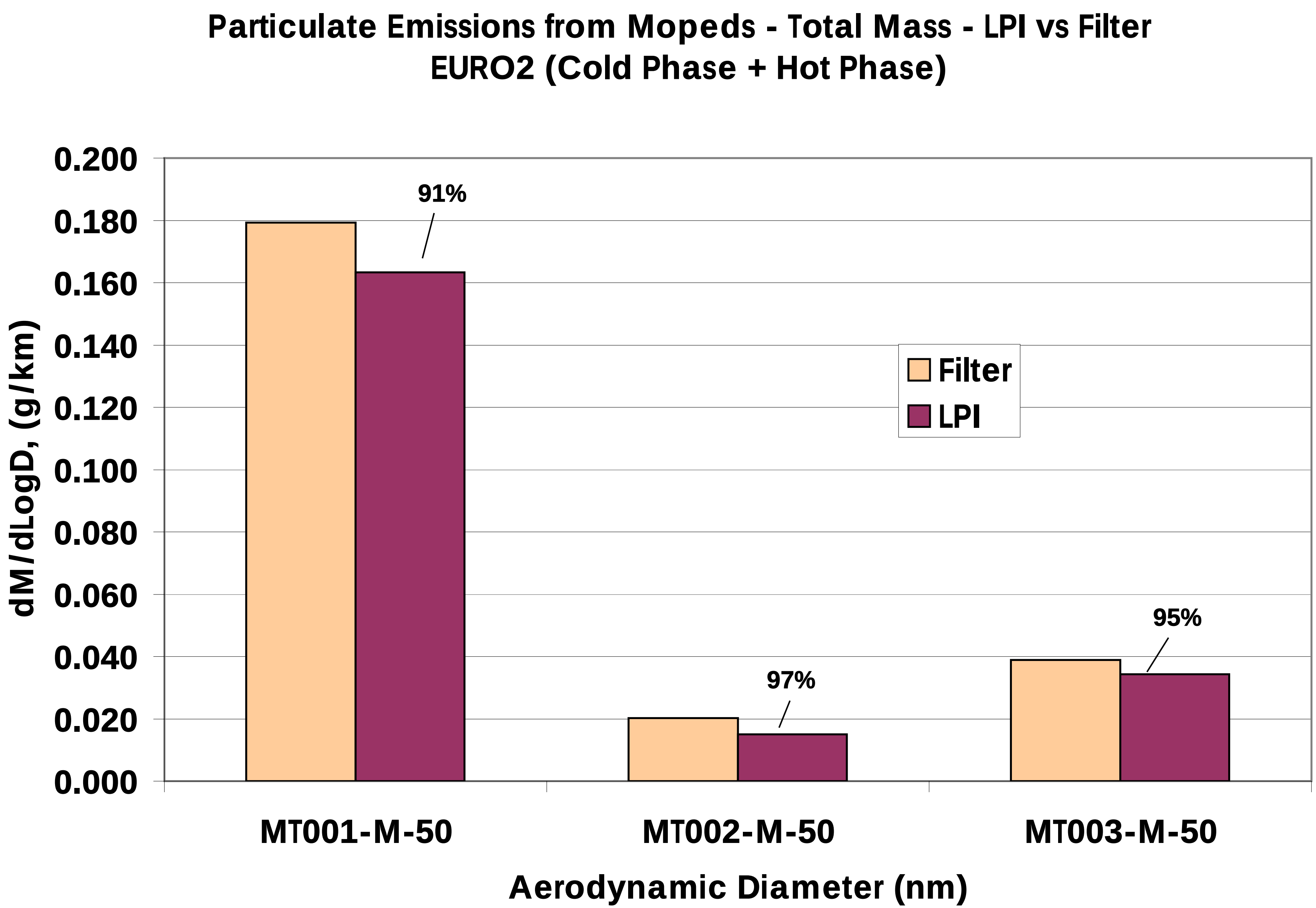
Particulate Emissions from Mopeds and Motorcycles
Mass/Size Distribution (LPI 11 stages) - EURO2 (Cold+ Hot Phase) Cycle



* 6 UDC_Euro 3 Cycle (no 40 s idling)


Mass/Size Distribution (LPI 11 stages) - Measurement Repeatibility
ECE 47 (Cold Phase + Hot Phase)
dM/dLogD, (g/km)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
1
10
100
1000
10000
100000
Aerodynamic Diameter (nm)
MT001-M-50
MT001-M-50
MT002-M-50
MT002-M-50
MT003-M-50
MT003-M-50


Particulate Emissions from Mopeds - Total Mass - LPI vs Filter
ECE 47 Cycle (Cold Phase + Hot Phase)
dM/dLogD, (g/km)
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Filter
LPI
91%
75%
88%
MT001-M-50
MT002-M-50
MT003-M-50
Aerodynamic Diameter (nm)


Particulate Emissions from Mopeds - Total Mass - LPI vs Filter
EURO2 (Cold Phase + Hot Phase)
dM/dLogD, (g/km)
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
91%
97%
95%
Filter
LPI
MT001-M-50
MT002-M-50
MT003-M-50
Aerodynamic Diameter (nm)

Number/Size Distribution

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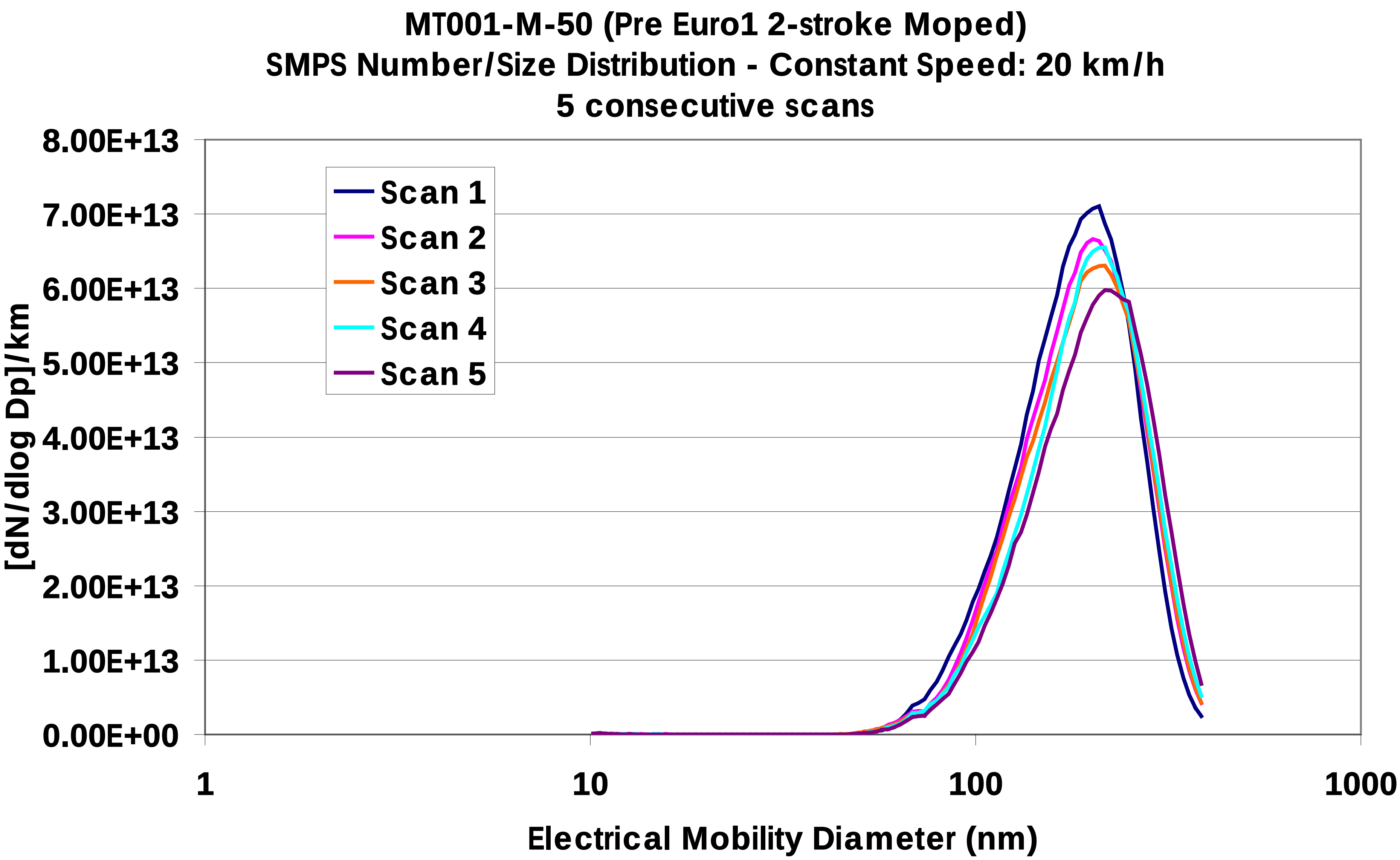

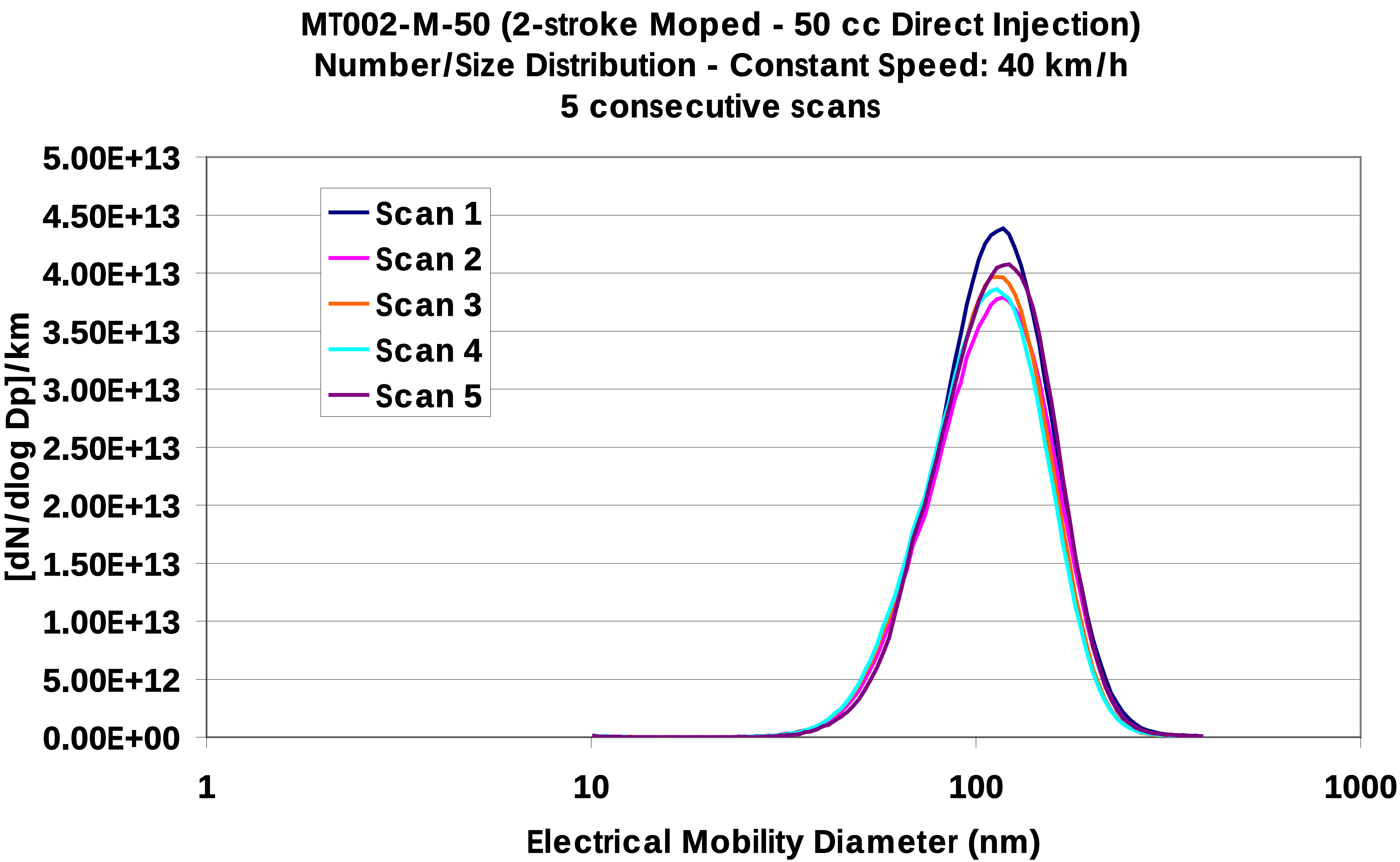
MT002-M-50 (2-stroke Moped - 50 cc Direct Injection)
Number/Size Distribution - Constant Speed: 40 km/h
5 consecutive scans
[dN/dlog Dp]/km
5.00E+13
4.50E+13
4.00E+13
3.50E+13
3.00E+13
2.50E+13
2.00E+13
1.50E+13
1.00E+13
5.00E+12
0.00E+00
Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
1
10
100
1000
Electrical Mobility Diameter (nm)

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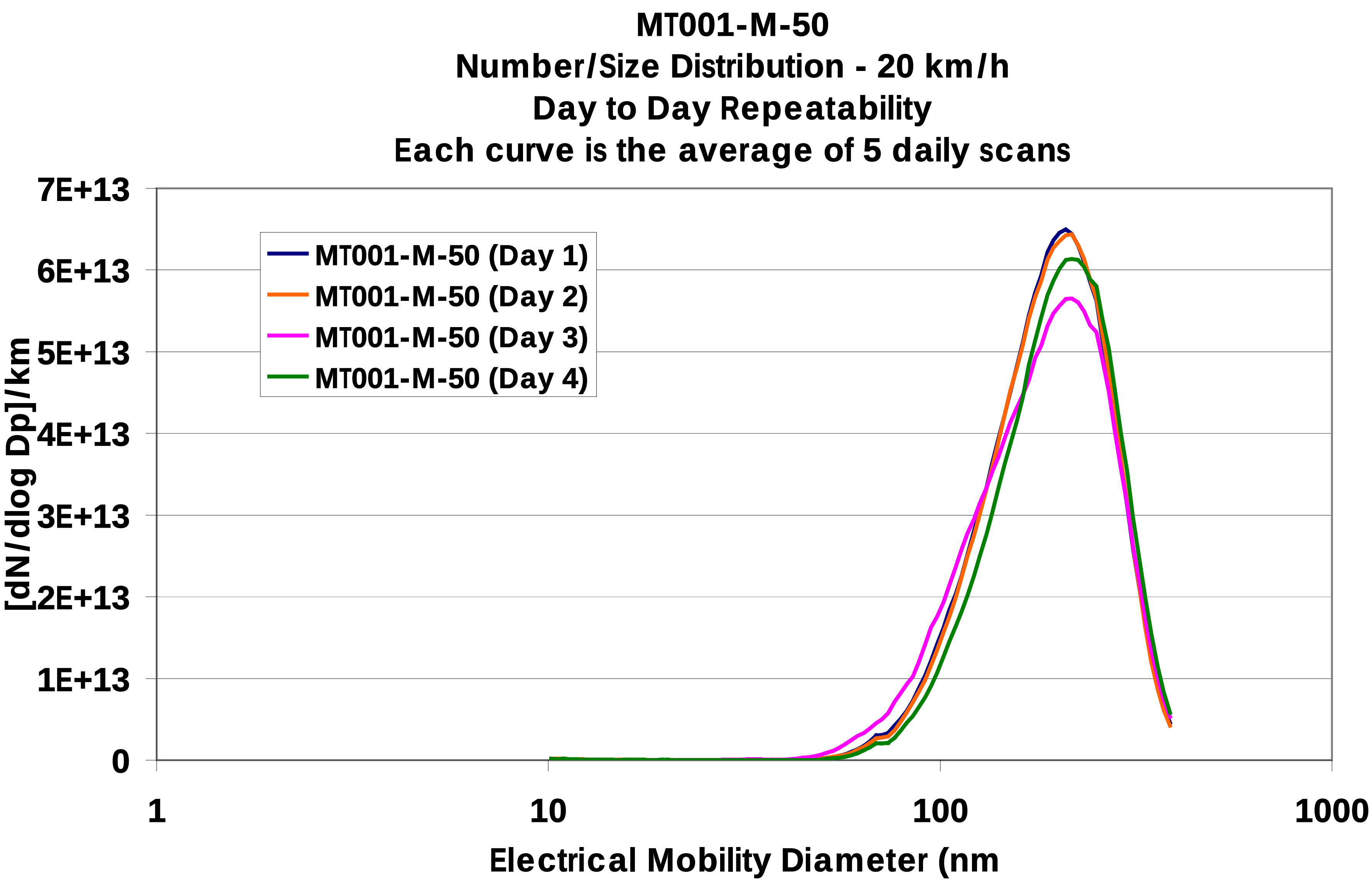
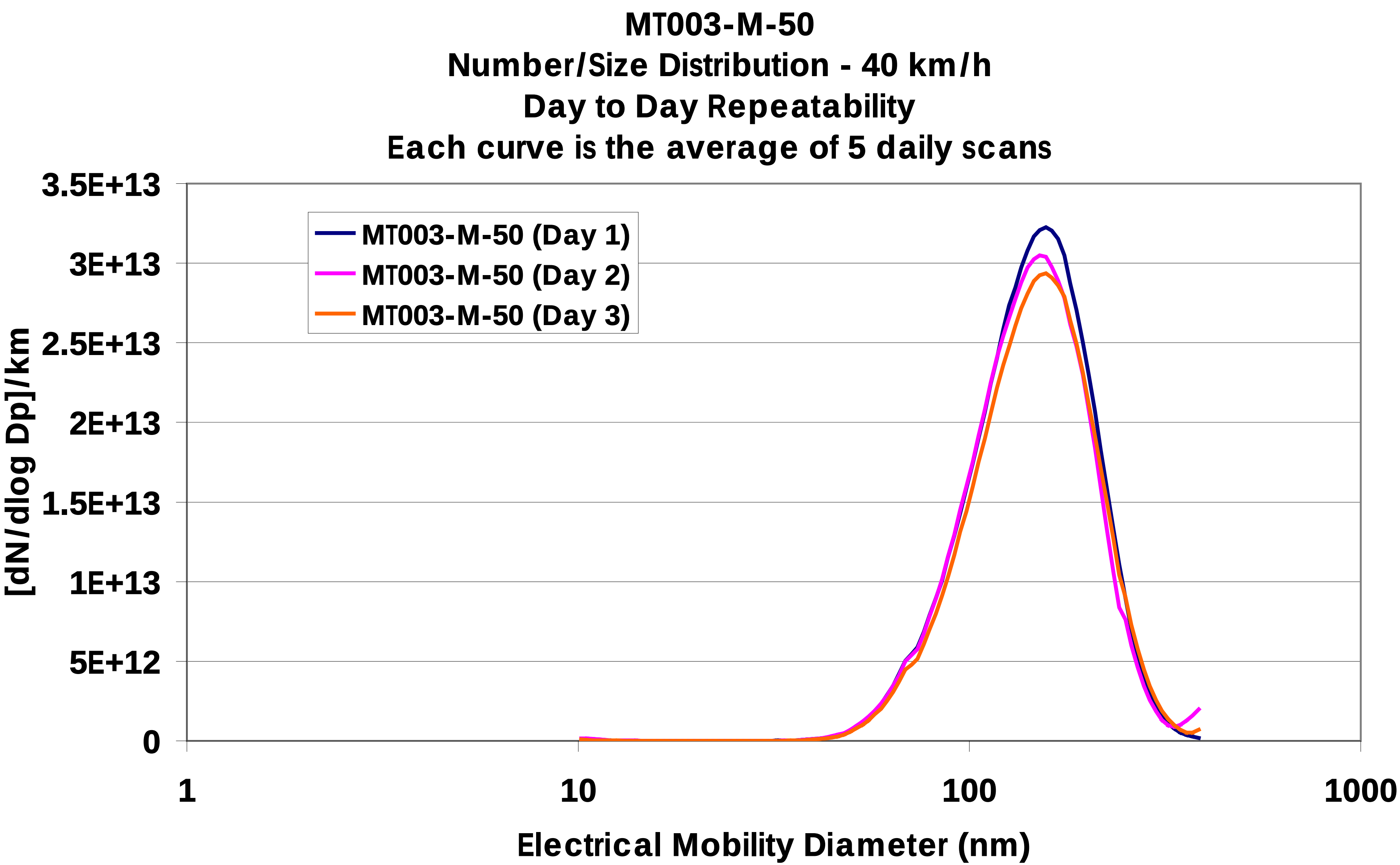
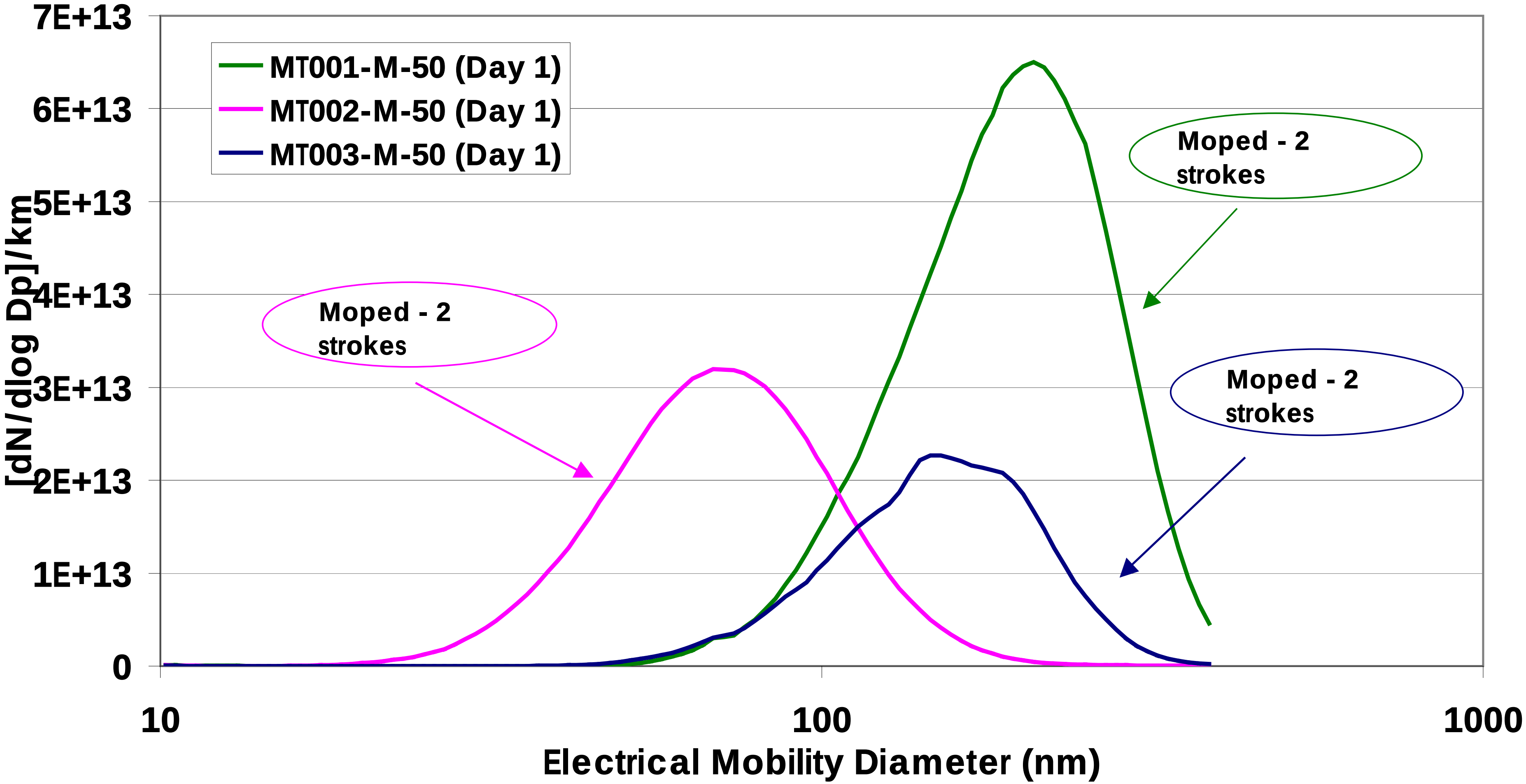
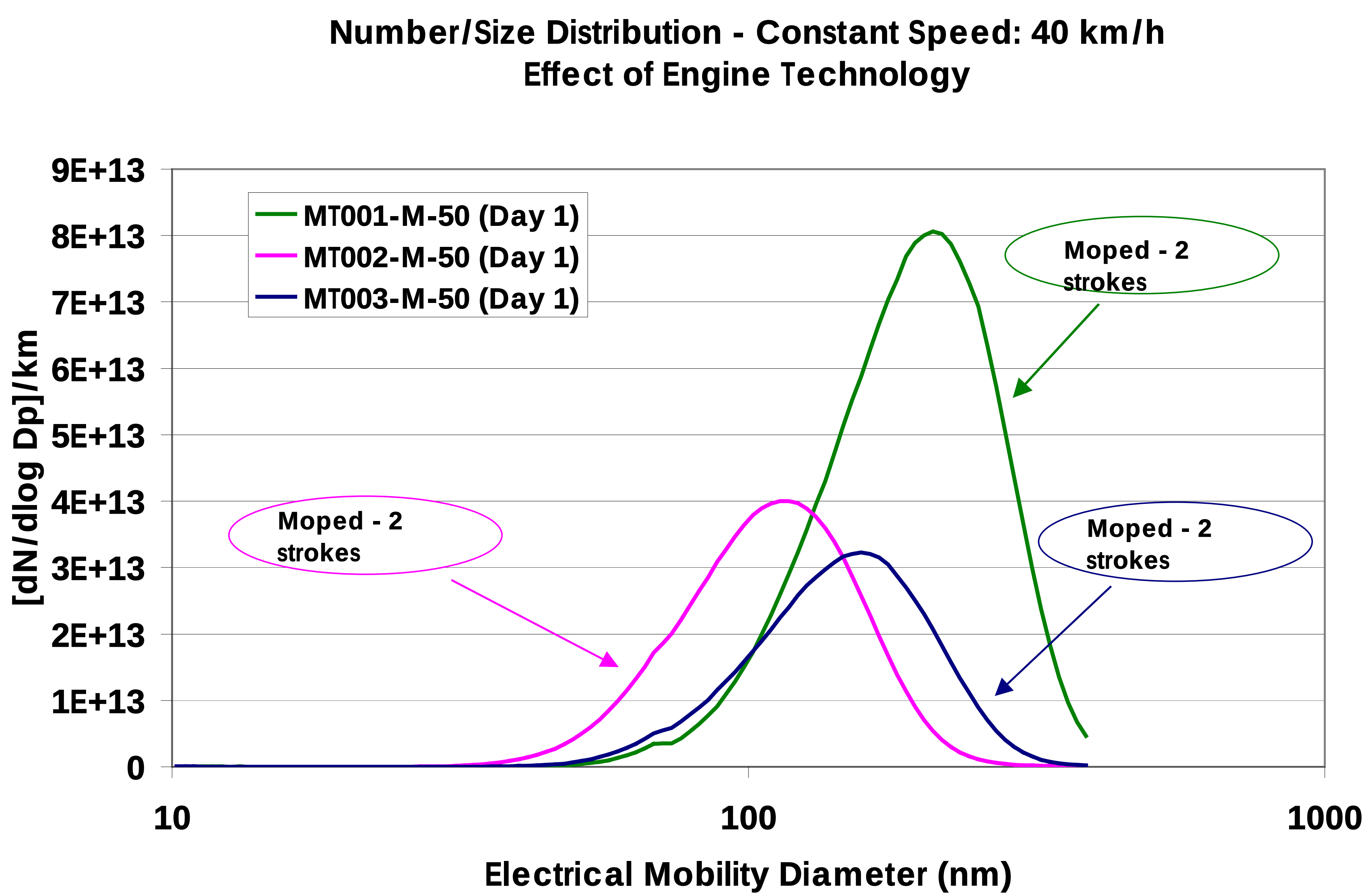



MT003-M-50
Number/Size Distribution - 40 km/h
Day to Day Repeatability
Each curve is the average of 5 daily scans
[dN/dlog Dp]/km
3.5E+13
3E+13
2.5E+13
2E+13
1.5E+13
1E+13
5E+12
0
1
10
100
1000
Electrical Mobility Diameter (nm)
MT003-M-50 (Day 1)
MT003-M-50 (Day 2)
MT003-M-50 (Day 3)

Number/Size Distribution - Constant Speed 20 km/h
Effect of Engine Technology




Number/Size Distribution - Constant Speed: 40 km/h
Effect of Engine Technology
MT001-M-50 (Day 1)
MT002-M-50 (Day 1)
MT003-M-50 (Day 1)
Moped - 2 strokes
Moped - 2 strokes
Moped - 2 strokes
9E+13
8E+13
7E+13
6E+13
5E+13
4E+13
3E+13
2E+13
1E+13
0
[dN/dlog Dp]/km
10
100
1000
Electrical Mobility Diameter (nm)

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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)