Particle Emissions of Powered Two Wheelers

Cambridge Particles Meeting
13 May 2011

Association for Emissions Control by Catalyst (AECC) AISBL

AECC members: European emissions control companies

BASF

CORNING

EMITEC

IBIDEN CO., LTD.

JM Johnson Matthey

NGK

NGK Europe GmbH

Rhodia

umicore Automotive Catalysts

Technology for exhaust emissions control on all new cars (OEM and Aftermarket) and an increasing number of buses & commercial vehicles, non-road applications and motorcycles.

Current L category types (Motorcycles and Mopeds)

Category	Vehicle Name	Characteristic Vehicles
L1e	Moped	 
L2e	Three-Wheel Moped	
L3e	Motorcycle	 
L4e	Motorcycle+ Side Car	

Category	Vehicle Name	Characteristic Vehicles
L5e	Motor Tricycles	 
L6e	Light Quadricycles	 
L7e	Heavy Quadricycles	 

Mopeds: max. speed 45km/h
max capacity 50cc (or 4kW electric motor)

Source: European Commission, Citizens summary: EU proposal for a Regulation on L-category vehicles, October 2010

Commission proposal for new emissions stages - COM 2010/542

- 3 new stages of emissions limits for all L category vehicles including powered cycles (but excludes ATVs and trials and enduro bikes).

Euro level	Enforcement dates		
	New Types (optional)	New Types (obligatory)	Existing Types (obligatory)
Euro 3 (4)	1 July 2013	1 January 2014	1 January 2015
Euro 4 (5)	1 January 2015	1 January 2017	1 January 2018
Euro 5 (6)	1 January 2018 (7)	1 January 2020 (7)	1 January 2021 (7)

(4) Euro 4 for motorcycles (Category L3e) (5) Euro 5 for motorcycles (6) Euro 6 for motorcycles
(7) Subject to Commission review

- 1st step includes 100 mg/km PM limit on WMTC for CI and CI hybrid motorcycles, trikes, quads and mini-cars (Classes L3,4,5,6,7).
- 2nd step reduces this to 80 mg/km.
- 3rd step introduces 4.5mg/km PM limit for all categories including mopeds and powered cycles and extends it to GDI engines. Cycle would be a revised WMTC (so as to include mopeds etc).

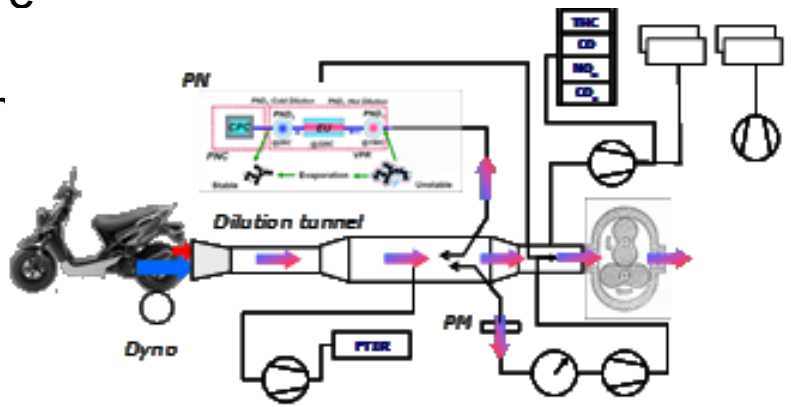
AECC motorcycle and mopeds test programmes

1. Test programme at Ricardo on 5 motorcycles
   - 3 Euro 3 bikes from European and Japanese OEMs
   - 1 Euro 3-homologated scooter from Asian OEM
   - 1 Indian specification bike
2. Test programme at TU Graz on 5 European mopeds
   - Conventional 4-stroke with carburettor and oxidation catalyst.
   - Fuel injected 4-stroke with TWC.
   - Conventional 2-stroke with carburettor and oxidation catalyst.
   - Low pressure DI with oxidation catalyst.
   - Air-supported DI with oxidation catalysts.

- All homologated to Euro 2, but two designed with Euro 3 in mind.
- Tested on WMTC and ECE Reg.40 (m/c) or 47 (mopeds)
- Both test programmes included PM and PN measurement.

Particulate measurements

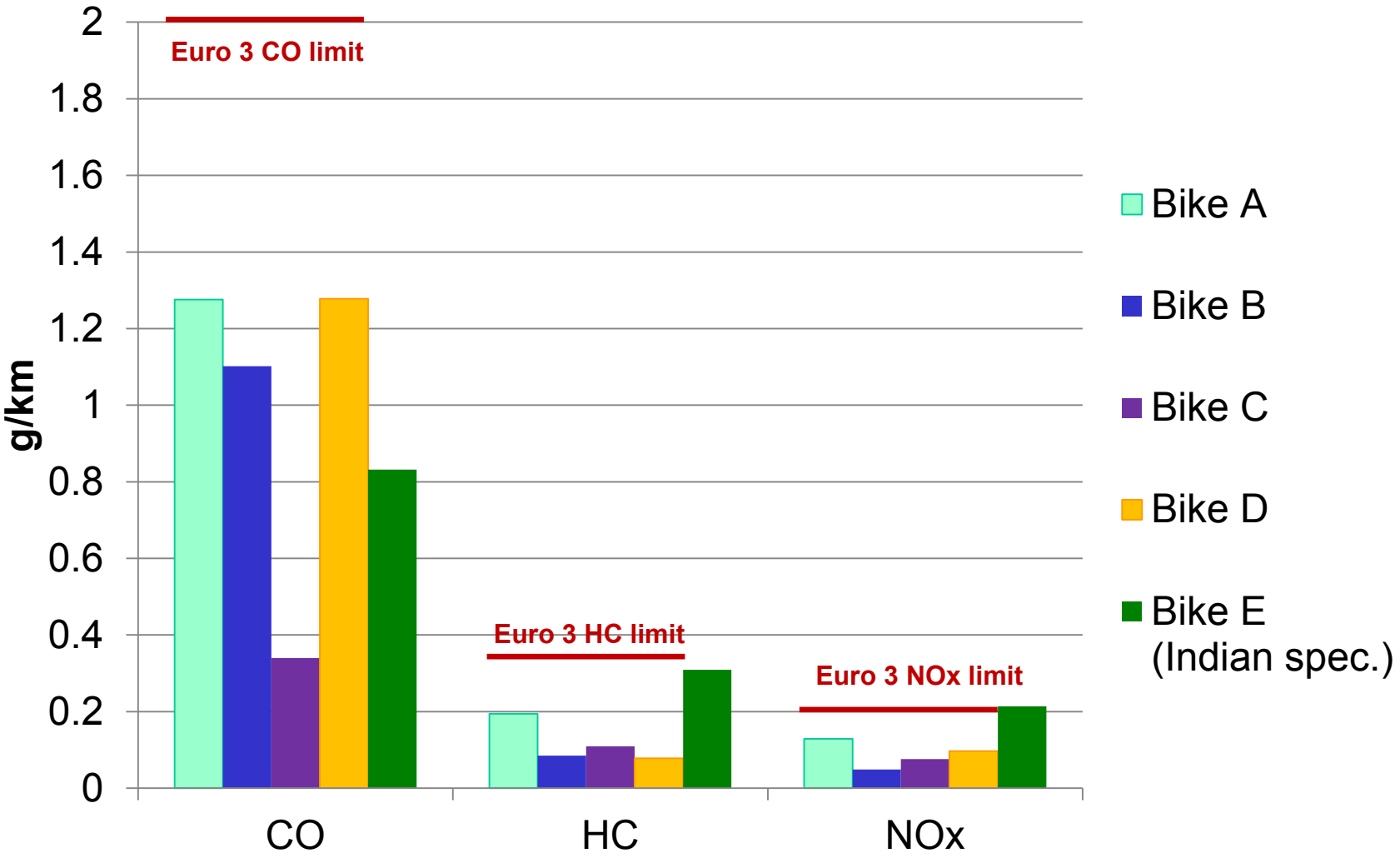
- Particulate mass measured using PTFE coated glass fibre filter.
- 1 test conducted with additional glass fibre filter for chemical analysis.
- Particle numbers sampled from CVS using as in light-duty and heavy-duty PMP using thermal dilution for removal of volatiles and CPC for particle counting.
- Performed according to latest draft of ECE Reg.83 except:
  a) CVS dilution tunnel for motorcycles does not have HEPA filter
  Typical background levels 10-20/cm^3 (cf. light-duty levels <2/cm^3)
  Motorcycle CVS and transfer tube purged of particles and low volatility HC by high temperature operation (150 km/h) of a motorcycle prior to testing.
  b) Mopeds system is 'open' CVS where there is no separate dilution air intake (to avoid depression affecting secondary air system PM and PN background were checked and found to be negligible compared to emissions levels.



Test motorcycles

Bike	Engine	EFI	Open/ Closed Loop Control	SAI	Catalyst	Spec.	WMTC Class	km at test	
A	800cc V4	y	Closed	y	y	Euro 3	3.2	8000	
B	800cc in line 2-cyl.	y	Closed	n	y	Euro 3	3.2	1000	
C	1300cc in line 4-cyl.	y	Closed	y	y	Euro 3	3.2	1000	
D	500cc 1-cyl.	y	Closed	y	y	Euro 3	3.2	1000	
E	149cc 1-cyl.	n	N/A	y	y	Indian spec.	2.1	1000	

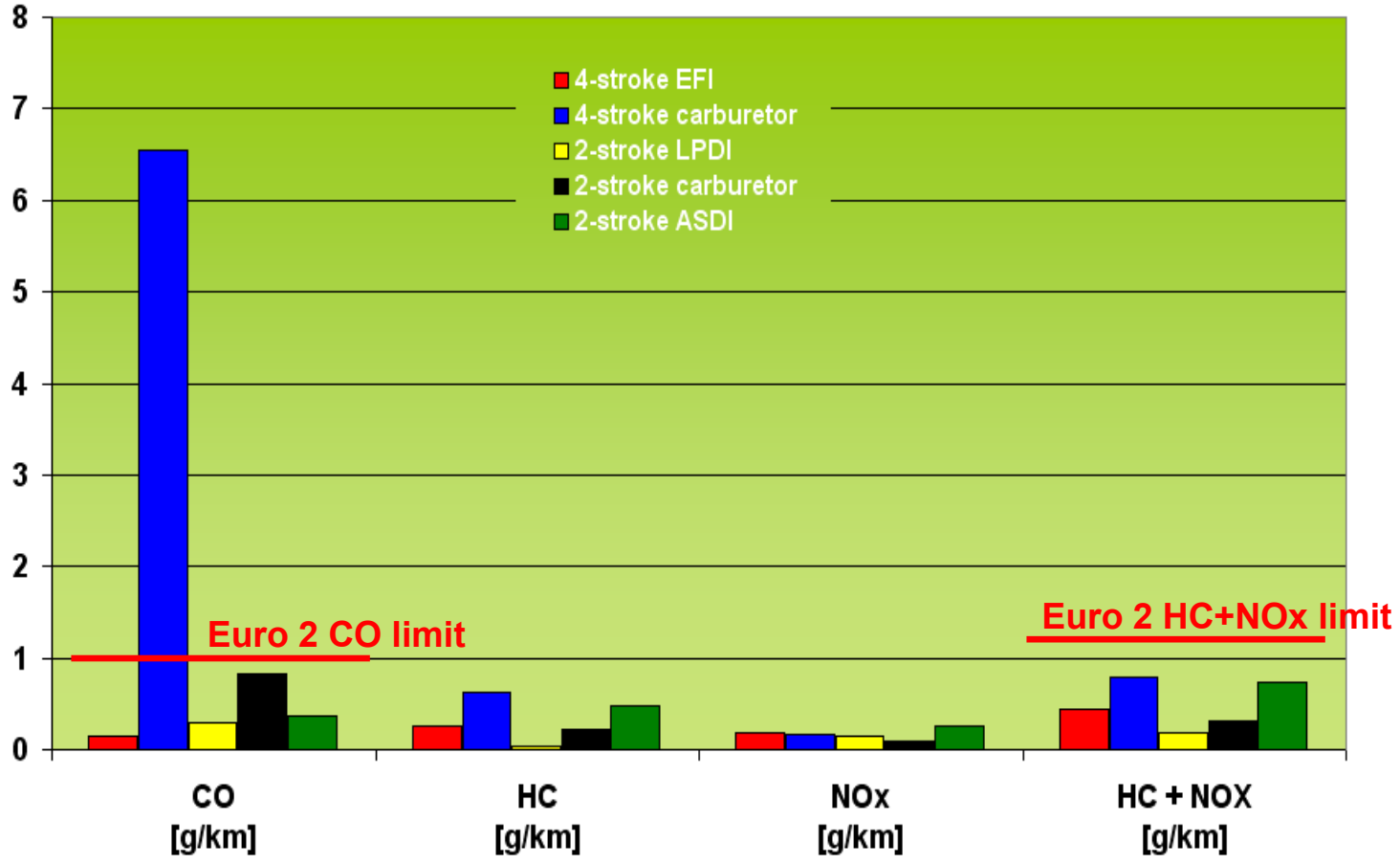
Motorcycle emissions results – Reg.40 cycle



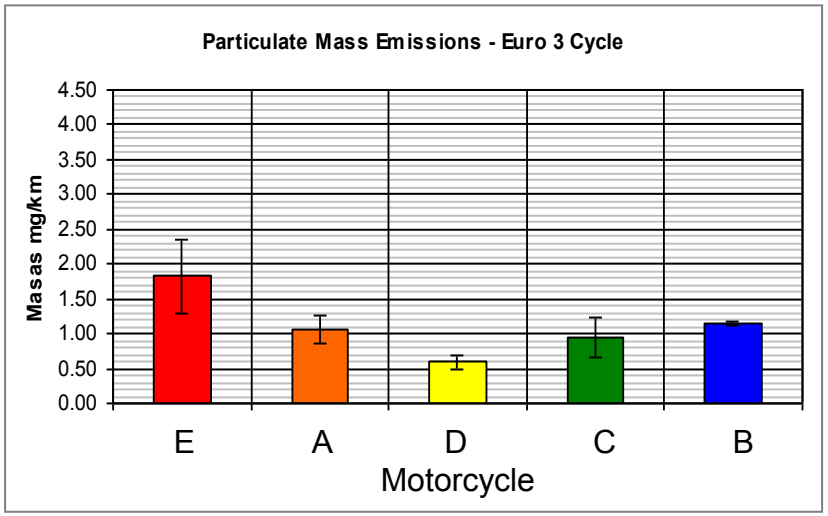
Test mopeds

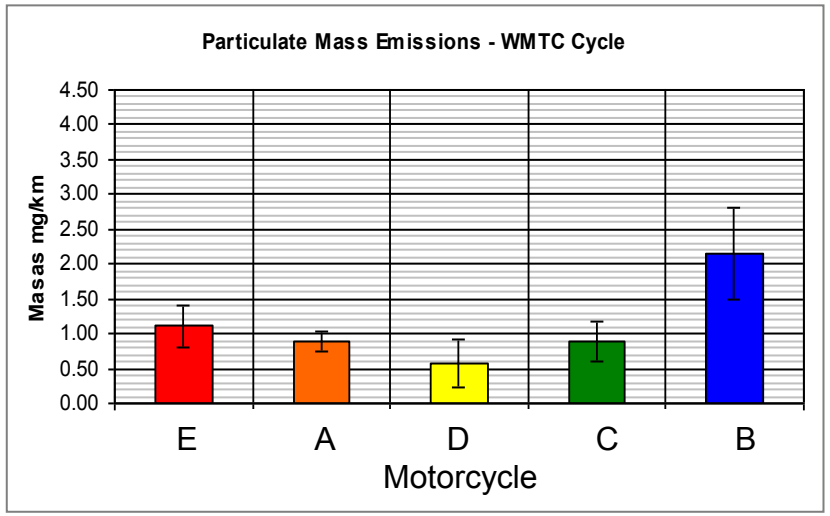
Vehicle	Specifications		Mixture preparation	Exhaust system	Max. velocity	Emission standard
4-stroke EFI	4-stroke / 4-valve SOHC		EFI with λ-sensor	3-way catalyst	44 km/h restricted by leaning	EURO 2 ECE R47
	Power [kW] / [rpm] :	3 / 7500				
	Cooling :	liquid				
	Reference mass [kg] :	85				
4-stroke carburetor	4-stroke / 2-valve SOHC		carburettor (constant depression)	1 catalyst secondary air	48 km/h restricted by ignition retarding	EURO 2 ECE R47
	Power [kW] / [rpm] :	2.88 / 8500				
	Cooling :	fan				
	Reference mass [kg] :	111				
TUG 2-stroke LPDI	2-stroke		Low Pressure Direct Injection	1 catalyst	47 km/h restricted by leaning	Designed for EURO 3 ECE R47
	Power [kW] / [rpm] :	3.7 / 7200				
	Cooling :	liquid				
	Reference mass [kg] :	95				
2-stroke carburetor	2-stroke		carburettor (slider)	1 catalyst secondary air	>50 km/h unrestricted. Throttle closed at 50km/h for these tests	Designed for EURO 3 ECE R40
	Power [kW] / [rpm] :	2.3 / 6250				
	Cooling :	fan				
	Reference mass [kg] :	103				
2-stroke ASDI	2-stroke		Air Supported Direct Injection	1 catalyst	42 km/h restricted by leaning	EURO 2 ECE R47
	Power [kW] / [rpm] :	4 / 7750				
	Cooling :	liquid				
	Reference mass [kg] :	108				

Mopeds emissions results – hot start (current) Reg. 47 cycle



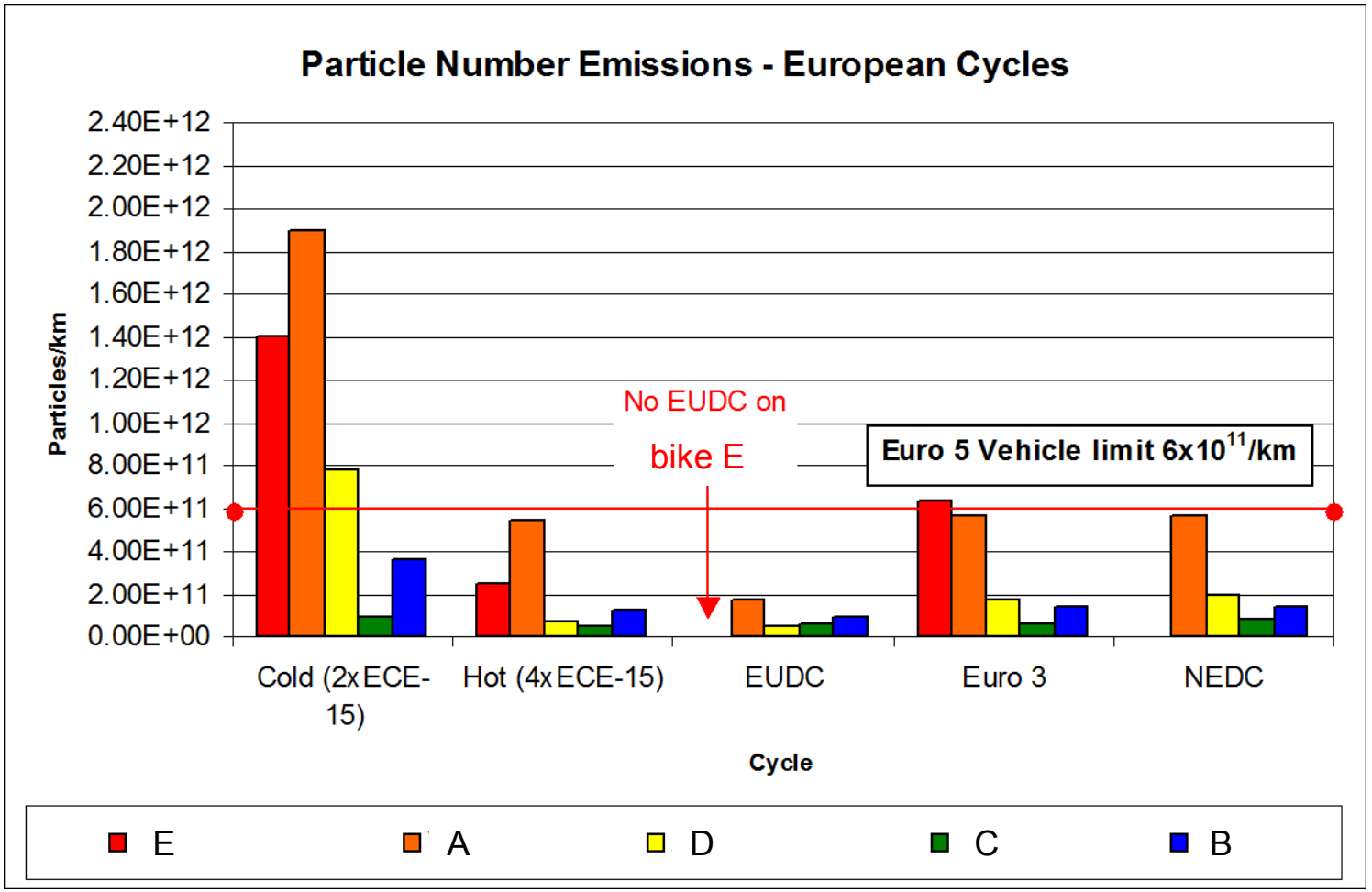
Motorcycle PM results





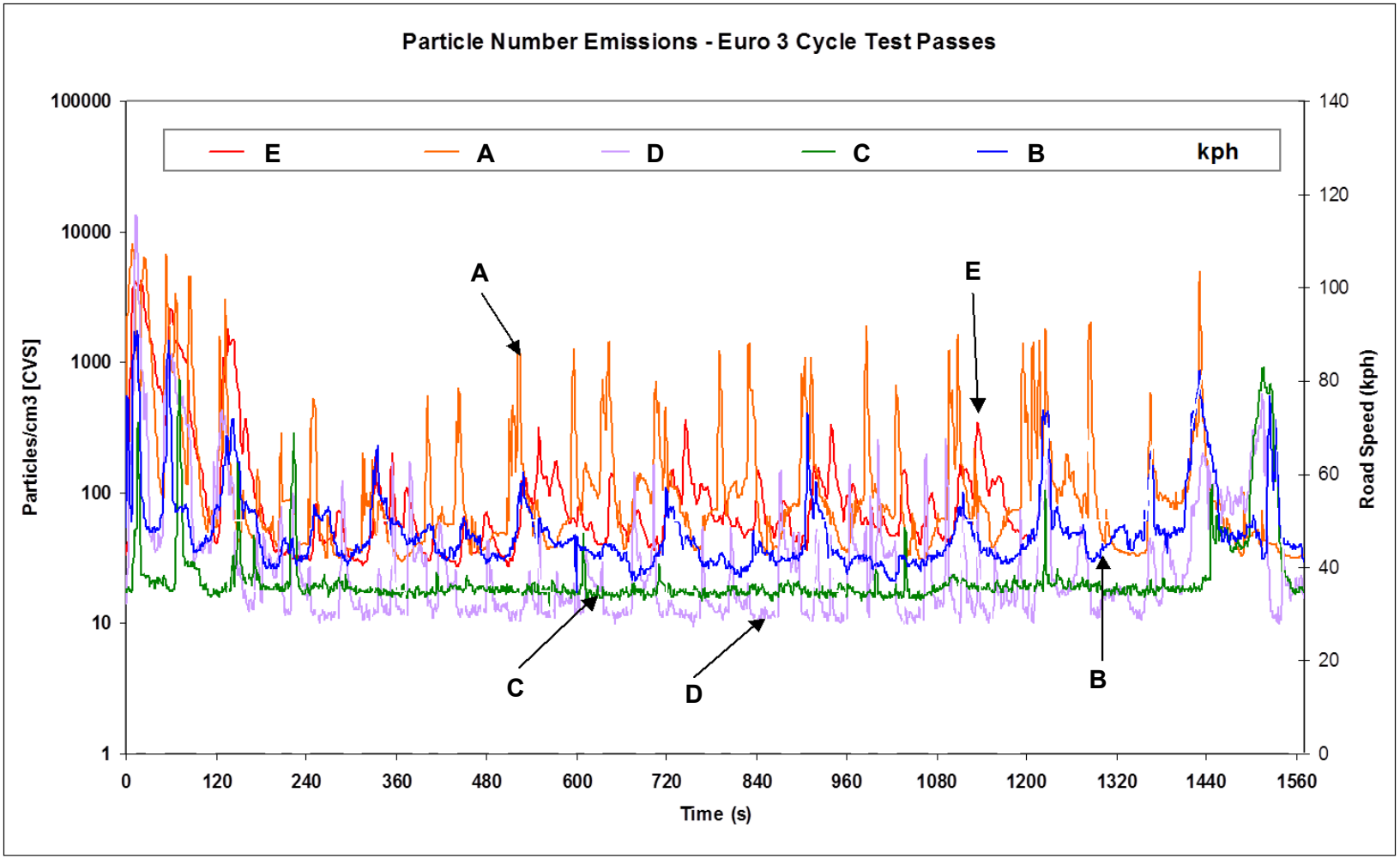
- Generally similar mass levels were attained from all motorcycles on both WMTC and Euro 3 cycles.
- Mass emissions always <2.5mg/km.
- Emissions levels are all well below the 4.5 mg/km level required for the 3rd step of the Commission proposal (Euro 6).

Particle number emissions
ECE Reg.40 cycle

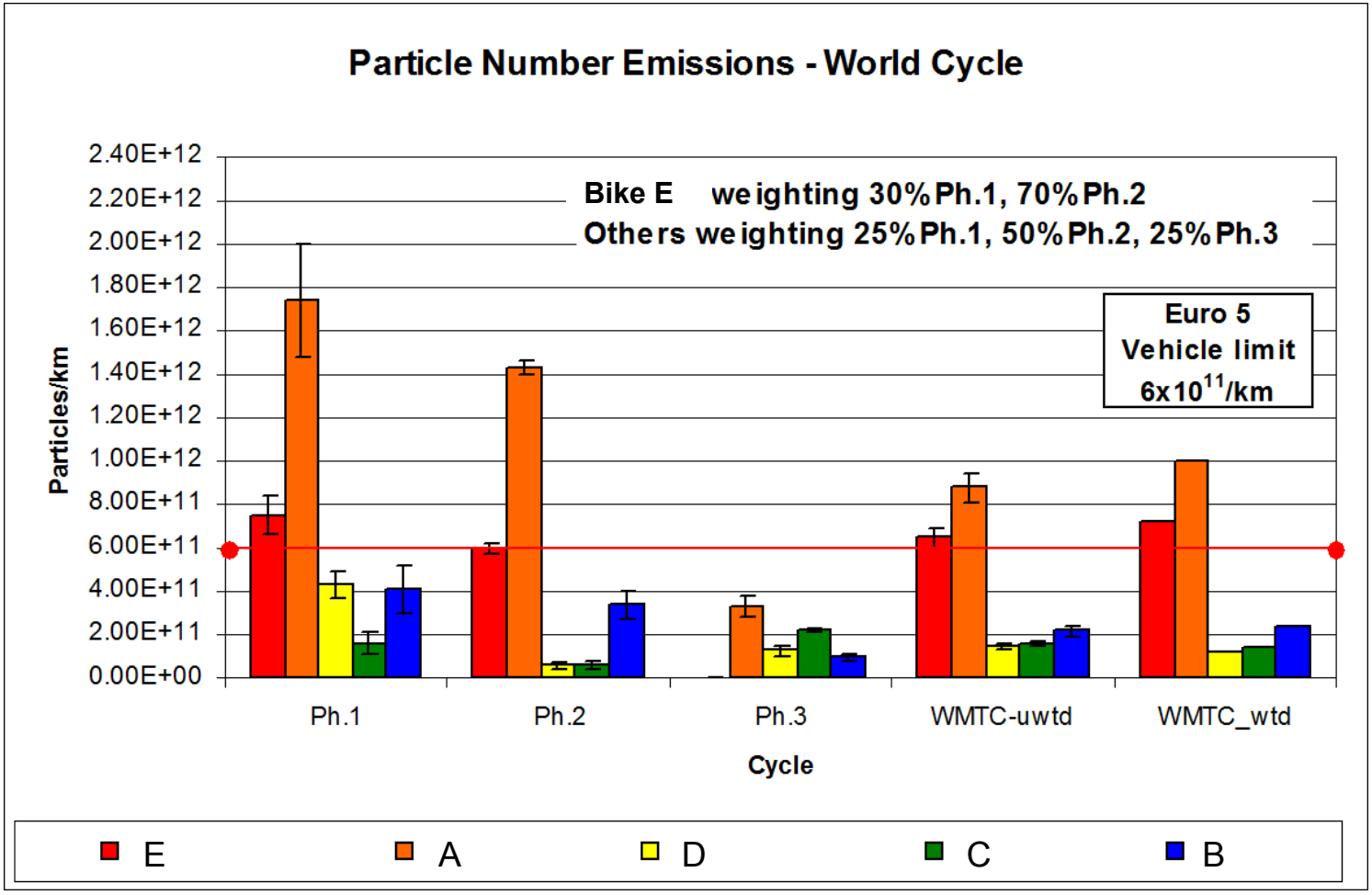


NEDC emissions from motorcycles calculated from cold start average (first two ECE-15 elements of the Euro 3 test), twice the average of the next 4 ECE-15 units and from the EUDC cycle average

Motorcycle continuous particle emissions traces - Reg. 40 cycle

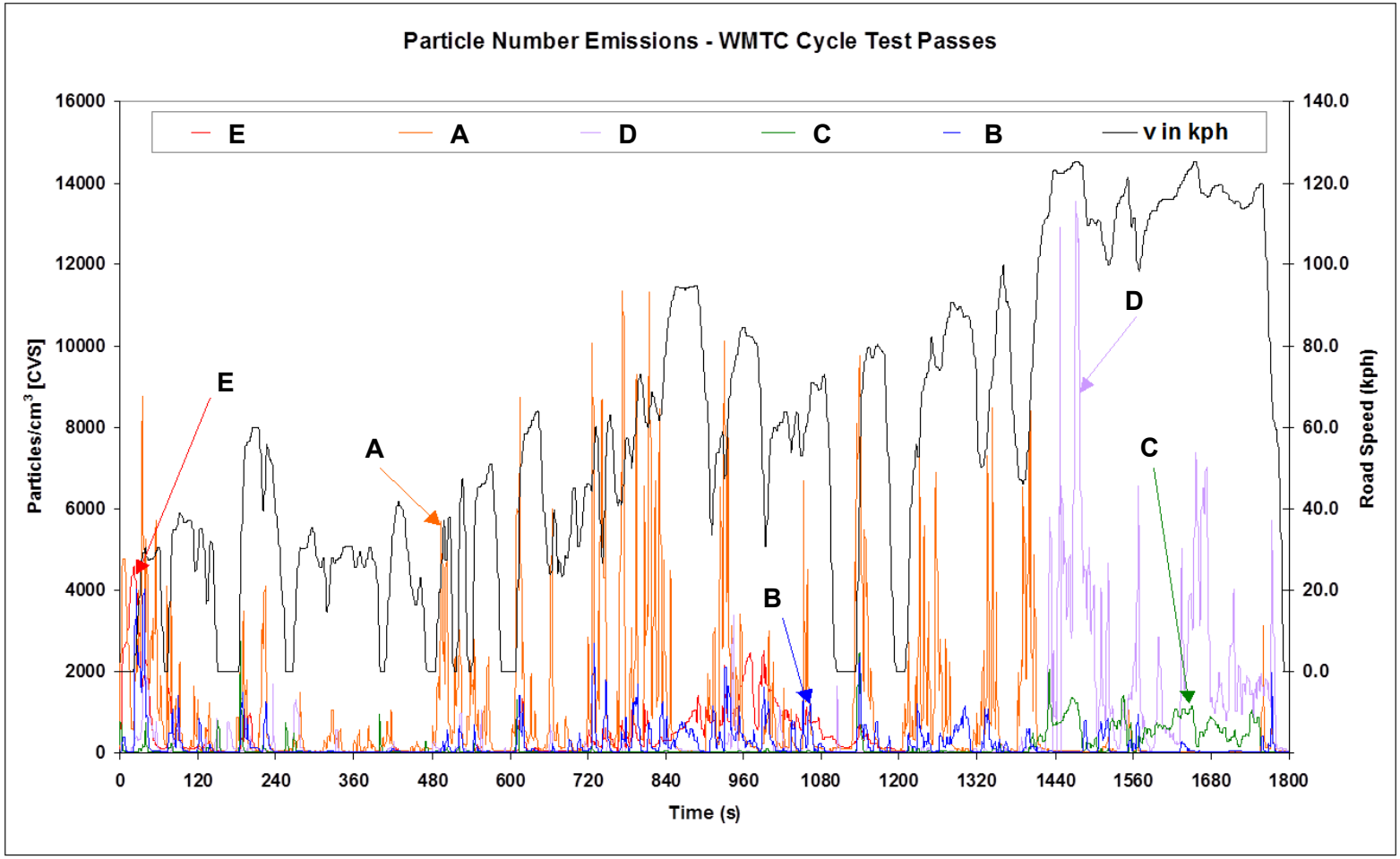


Motorcycle particle number emissions WMTC

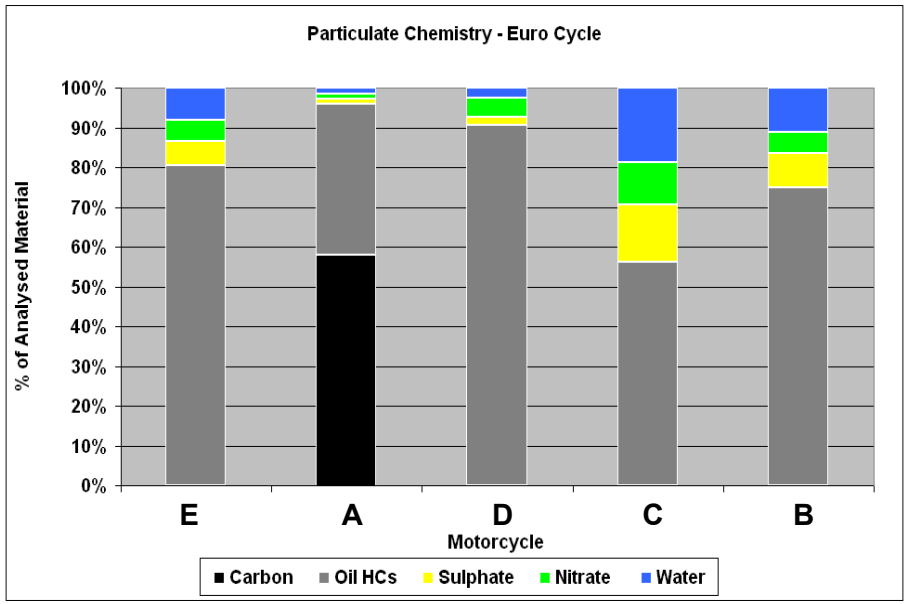


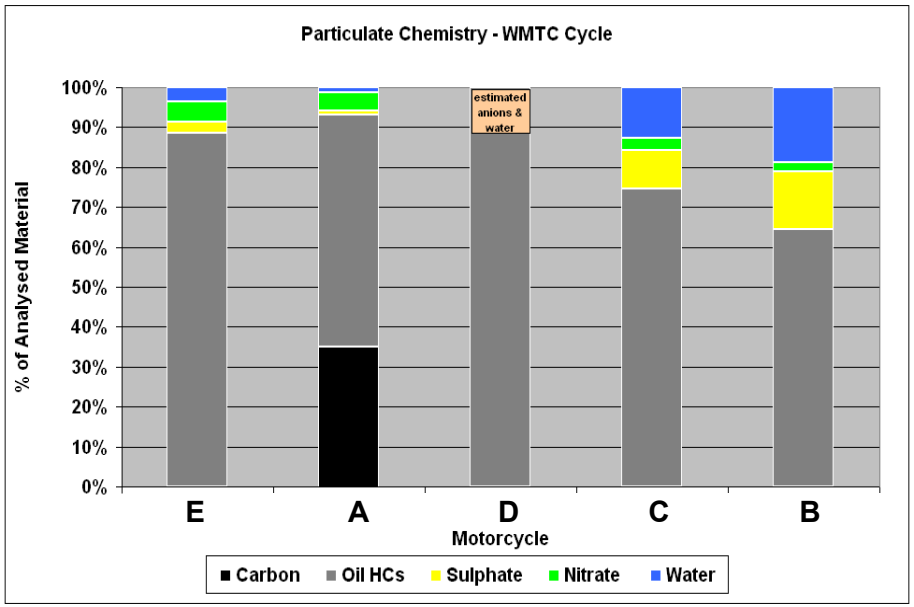
As for the ECE cycle, highest results are generally on the cold start.
All except bike D gave somewhat higher results on the WMTC

Motorcycle continuous particle emissions traces - WMTC



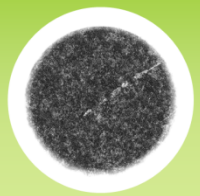
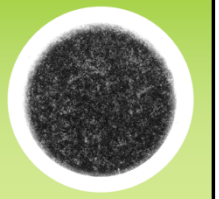
Chemical Analyses of Motorcycle PM filters



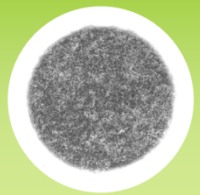
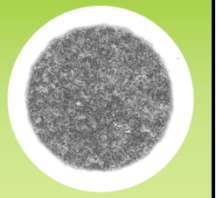


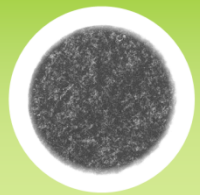
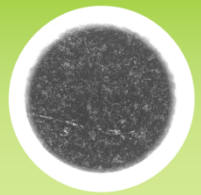
- Elemental carbon is only present at trace levels (similar to blank) in PM from most bikes
- Oil HC is major contributor (sometimes >80% of total)
  May be a contributor to solid particle numbers

Particulate mass - mopeds

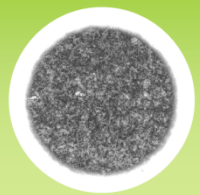
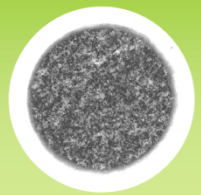
ECE R47	Pallflex EMFAB 4000 lpm sampling 012	Pallflex EMFAB 4000 lpm sampling 018
4-stroke EFI		
	0,315 [mg]	0,471 [mg]
	2,235 [mg/km]	3,398 [mg/km]

ECE R47	Pallflex EMFAB 4000 lpm sampling 040	Pallflex EMFAB 4000 lpm sampling 042
2-stroke LPDI		
	1,241 [mg]	0,677 [mg]
	8,472 [mg/km]	4,783 [mg/km]

ECE R47	Pallflex EMFAB 4000 lpm sampling 016	Pallflex EMFAB 4000 lpm sampling 023
4-stroke carburetor		
	0,723 [mg]	0,722 [mg]
	5,042 [mg/km]	4,933 [mg/km]

ECE R47	Pallflex EMFAB 4000 lpm sampling 015	Pallflex EMFAB 4000 lpm sampling 021
2-stroke carburetor		
	2,105 [mg]	1,935 [mg]
	13,500 [mg/km]	12,172 [mg/km]

Note: Mopeds were tested over the cold-start Reg.47 test to be used for Euro 3 (i.e. 8 x ECE cycle).
PM and PN emissions were measured over this complete cycle.

ECE R47	Pallflex EMFAB 4000 lpm sampling 034	Pallflex EMFAB 4000 lpm sampling 036
2-stroke ASDI		
	0,978 [mg]	1,562 [mg]
	7,450 [mg/km]	11,212 [mg/km]

Particulate Mass & Particle Number - mopeds

	PM	PN (to PMP)
Euro 3 cycle (8 x ECE) , unweighted	mg/km	particles/km
4-stroke EFI	2.52	3.84×10^{12}
4-stroke carburettor	5.05	1.98×10^{13}
2-stroke LPDI	6.68	2.35×10^{13}
2-stroke carburettor	12.39	2.78×10^{14}
2-stroke ASDI	10.04	1.09×10^{14}

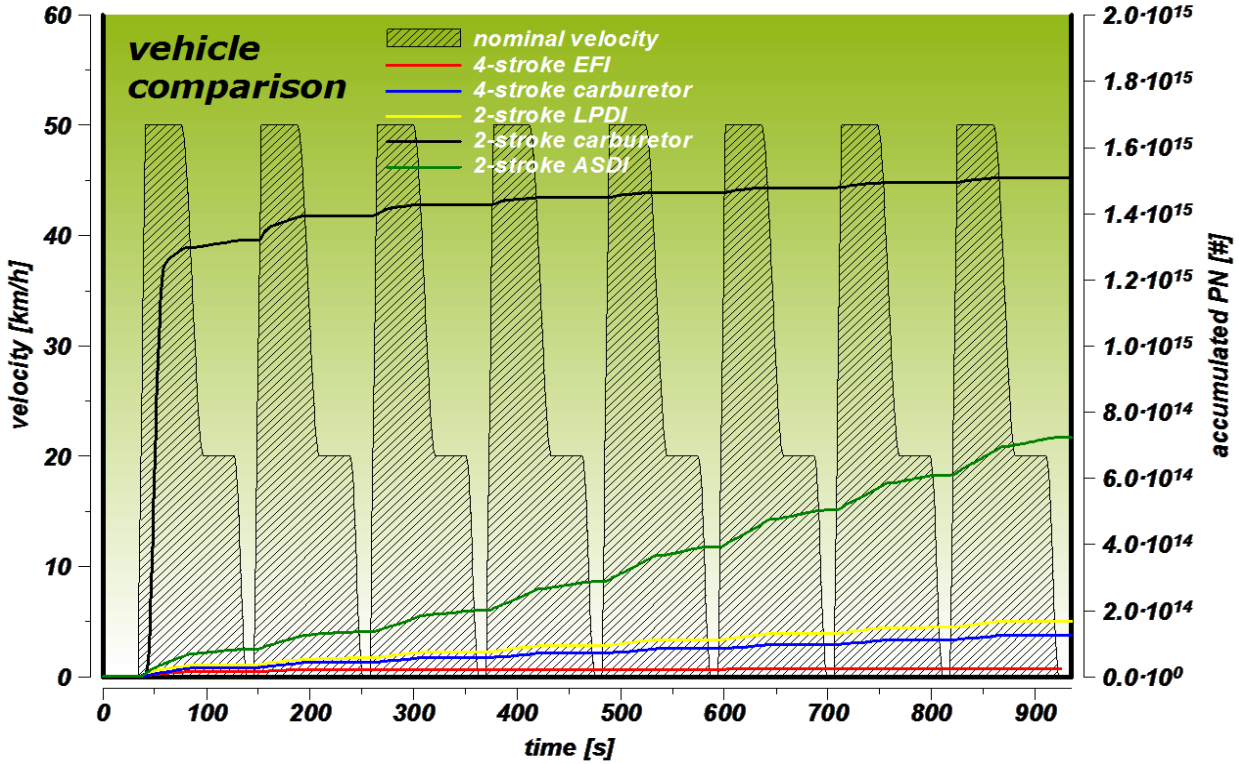
- Only the 4-stroke EFI would meet the PM limit of 4.5 mg/km proposed for the Euro 5 stage.
- Solid Particle number emissions measured by PMP-based method range from 3.84×10^{12}/km to 2.78×10^{14}/km - levels similar to diesel cars without DPFs.

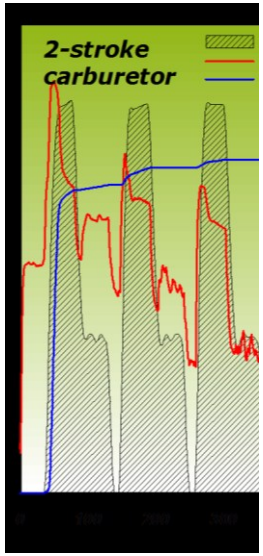
Particle Numbers - mopeds

Moped	ECE R47 Cycle (#/km)	WMTC (#/km)
4-stroke EFI	3.84×10^{12}	3.19×10^{12}
4-stroke carburettor	1.98×10^{13}	1.74×10^{13}
2-stroke LPDI	2.35×10^{13}	1.55×10^{13}
2-stroke carburettor	2.78×10^{14}	1.10×10^{14}
2-stroke ASDI	1.09×10^{14}	7.67×10^{13}

- Solid Particle number emissions over the WMTC are similar to those for the Reg. 47 cycle.

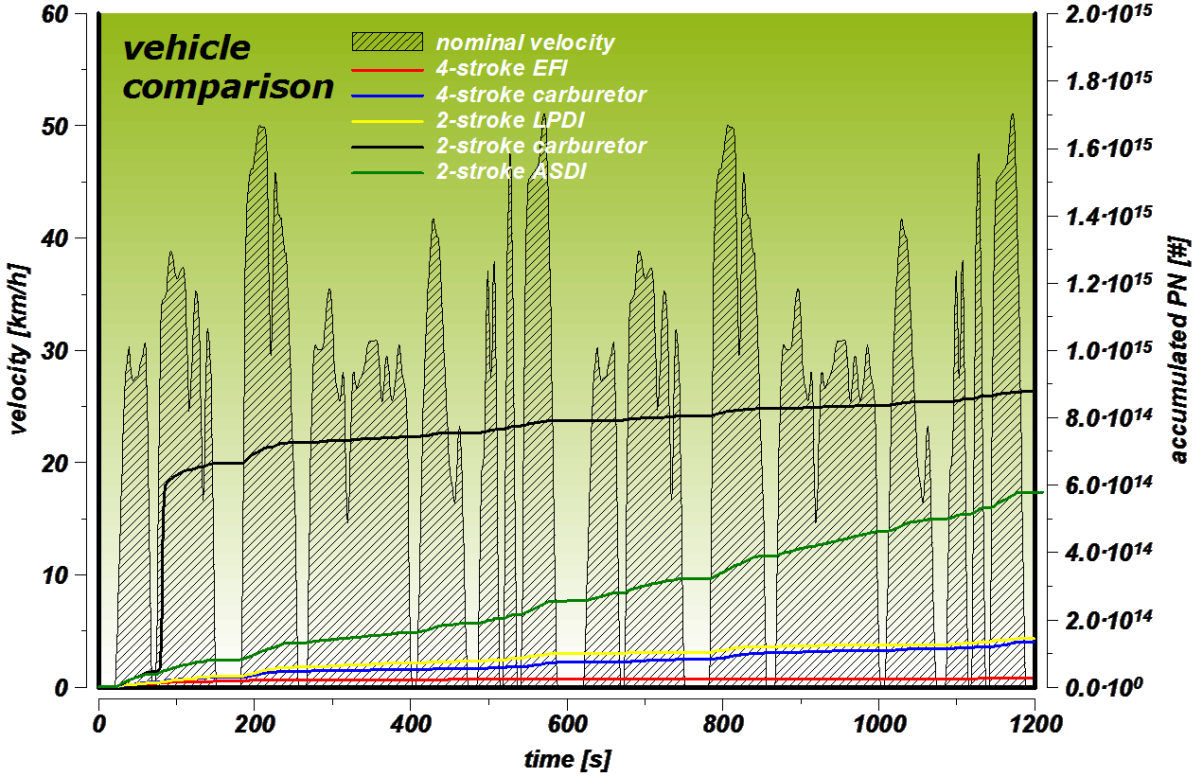
Examples of Moped continuous particle emissions traces - Reg. 47 cycle

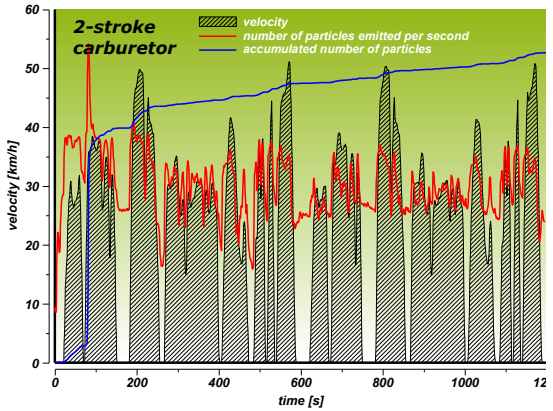




- The overall pattern of PN emissions was generally similar for the two 4-stroke mopeds, the 2-stroke LPDI and the 2-stroke ASDI, with gradual rate of increase (at different rates) throughout the test.
- The 2-stroke carburettor moped shows a substantial number of particles at the start of the test, with a gradual increase thereafter.

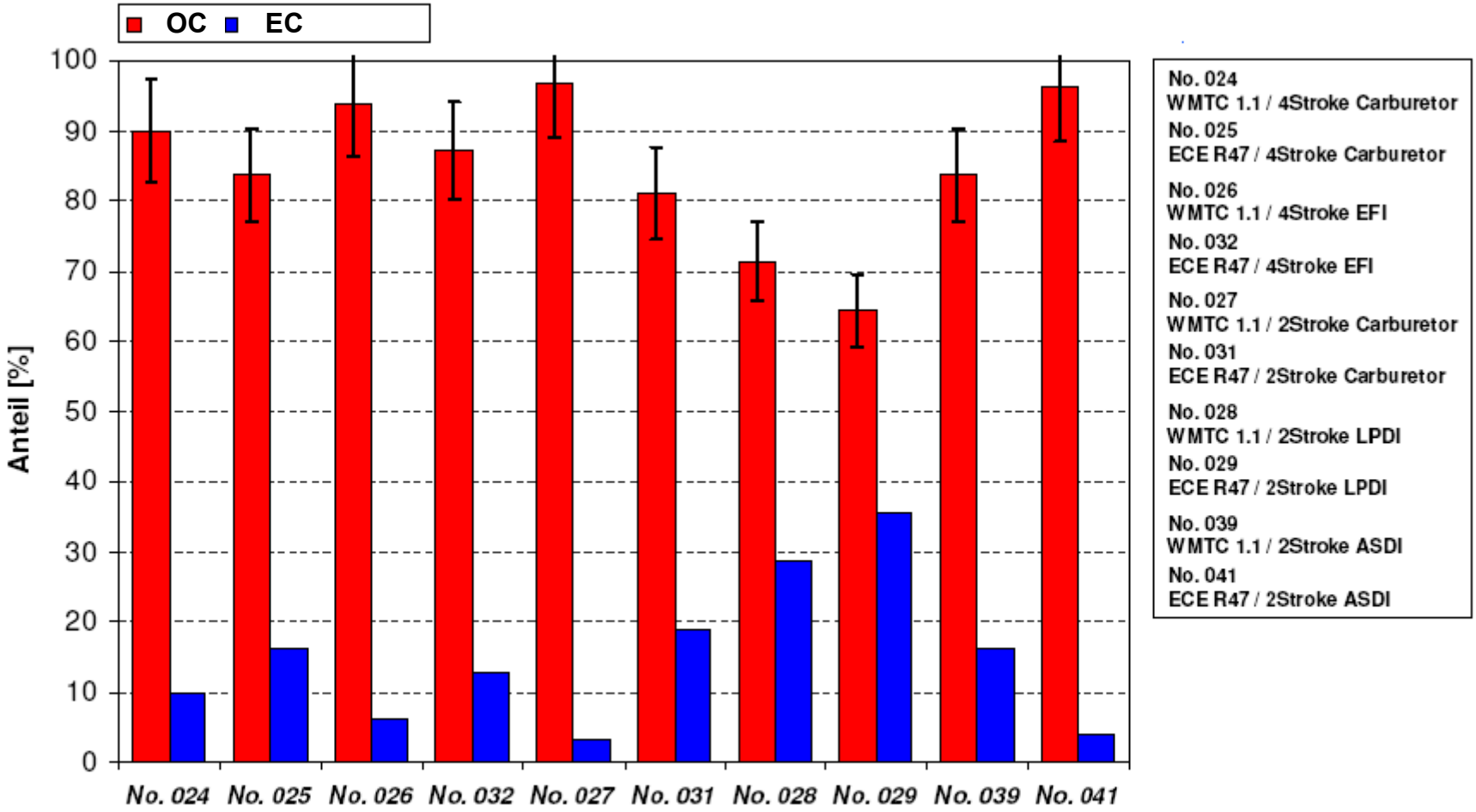
Examples of Moped continuous particle emissions traces - WMTC





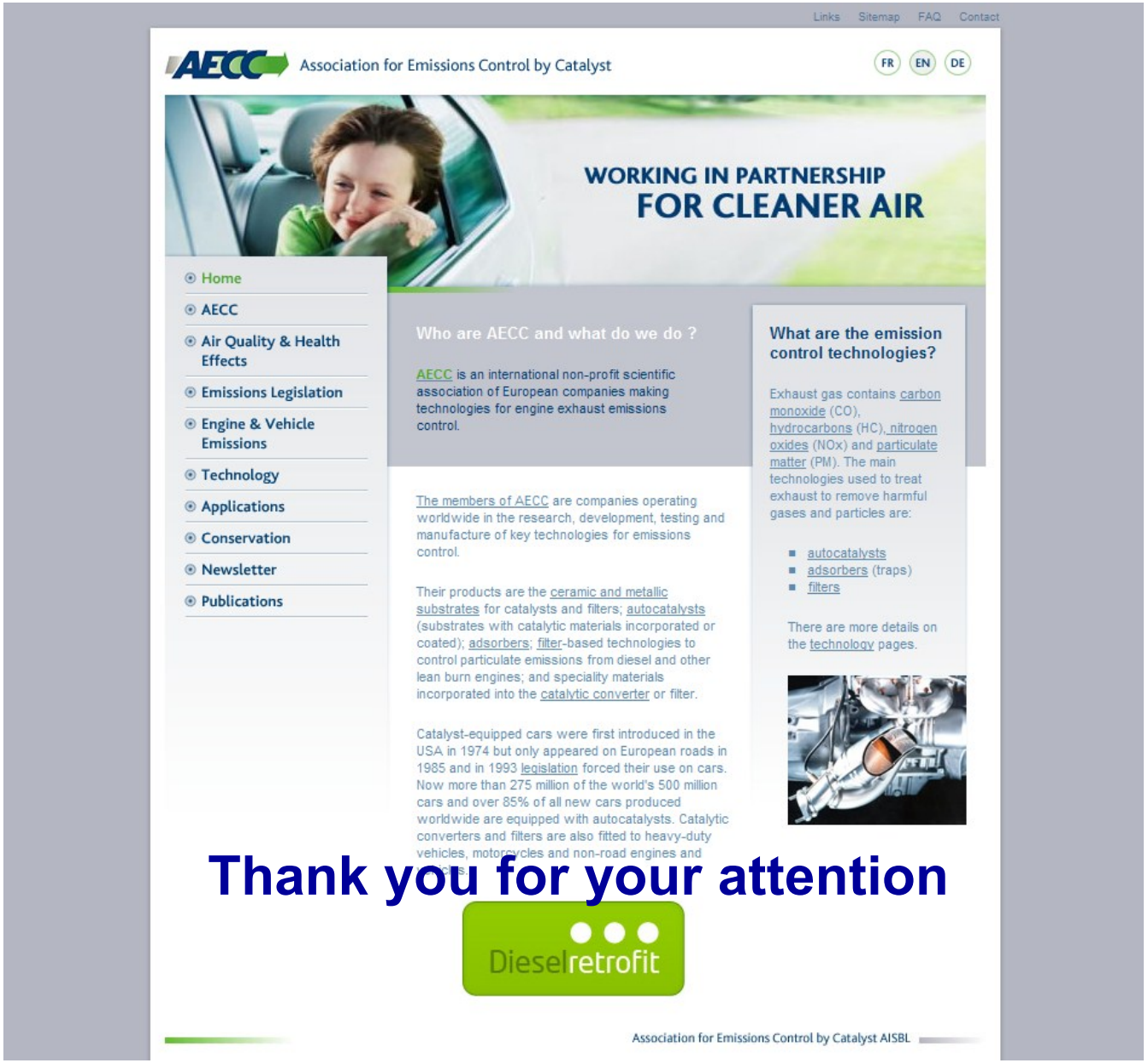
- The overall pattern of PN emissions is similar to that for the ECE reg. 47 cycle. Again the -stroke carburettor moped shows a substantial number of particles near the start of the test, with a gradual increase thereafter.

Mopeds - Elemental and Organic Carbon



Particulates / particles conclusions

- The motorcycles tested would all have met the 4.5 mg/km limit proposed for the final stage of the L-category emissions Regulation.
- On the Euro 3 cycle the motorcycles tested would also have met Euro 5 PM and PN limits for diesel cars.
- For mopeds only the 4-stroke EFI machine would have met the proposed limit for the L-category Euro 5 step.
- For mopeds solid (PMP) particle number emissions are at a similar level to diesel cars without DPF.
- Particle numbers are highest with cold start enrichment.
- For both motorcycles and mopeds EC/OC analysis shows very little Elemental Carbon (i.e. mostly organic). This is despite the high numbers of PMP particles for the mopeds.



Thank you for your attention

Dieselretrofit