Swedish In-Service Testing Program

On Emissions from Passenger Cars and Light-Duty Trucks

Report for the Swedish Transport Agency

by Kristina Willner
Gareth Taylor
AVL

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Content

AVL MTC AB

Address: Armaturvägen 1
P.O. Box 223
SE-136 23 Haninge
Sweden

Tel: +46 8 500 656 00
Fax: +46 8 500 283 28
e-mail: SE_info@avl.com
Web: http://www.avl.com/

List of Abbreviations

CADC	Common Artemis Driving Cycle
CI	Compression Ignited
CO	Carbon monoxide
CO_2	Carbon dioxide
CPC	Condensation Particle Counter
CVS	Constant Volume Sampler; exhaust emission sampling system
DF	Dilution Factor
DPF	Diesel Particulate Filter
E85	Fuel containing 85% ethanol and 15% petrol
EC	European Community
EUDC	Extra Urban Driving Cycle; Part 2 of the New European Driving Cycle
EURO 1	Type approval test according to Directive 91/441/EEC (& 93/59/EEC)
EURO 2	Type approval test according to Directive 94/12/EEC
EURO 3	Type approval test according to Directive 98/69/EC (& 96/69/EC)
EURO 4	Type approval test according to Directive 98/69/EC, stricter requirements (incl. lower limit values in driving cycle, -7°C test) (& 2002/80/EC)
EURO 5 & 6	Type approval test according to Directive 715/2007/EC
FC	Fuel consumption
HBEFA	Handbook on Emission Factors for Road Transport
HC	Hydro Carbon
JRC	Joint Research Centre
M1	Vehicles and a total vehicle mass of up to 2,500kg
M5 / M6	5-speed / 6-speed manual gearbox
N1	Vehicles for transportation of goods and a total vehicle mass of up to 3,500kg
NEDC	New European Driving Cycle according to Directive 98/69/EC
NO_X	Nitrogen Oxides
OBD	On-Board Diagnosis
PEMS	Portable Emission Measurement System
PM	Particulate Mass
PMP	Particulate Measurement Programme
PN	Particulate Number
SHED	Sealed Housing for Evaporative Emissions Determination
SI	Spark Ignited
STA	Swedish Transport Agency
UDC	Urban Driving Cycle; Part 1 of the New European Driving Cycle

Summary

Considerable air pollution is caused by emissions from motor vehicles on the road. In-Service Testing has become an important tool in an overall concept aiming to achieve sustainable reduction of emissions from traffic. Directive 70/220/EEC as amended by 98/69/EC establishes the In-Service Testing as part of the type approval procedure.

AVL MTC AB has on commission by the Swedish Transport Agency carried out the Swedish In-Service Testing Programme for passenger cars and light duty trucks.

In 2011 the In-Service Testing Programme included a total of 70 vehicles, spread over 14 vehicle families. Nine of the vehicle families had spark ignited (SI) engines and five of the vehicle families had compression ignited (CI) engines. Two of the vehicle families with SI-engine were of flex fuel (ethanol) type. Four of the CI-engine vehicle families were equipped with diesel particulate filters (DPF) with active regeneration and one of the CI engine vehicle families were equipped with a diesel particulate filter of open flow type with passive regeneration.

All vehicles were tested on a chassis dynamometer in the respective type approval cycle, the "New European Driving Cycle“ (Type I /NEDC) in accordance with Directive 70/220/EEC and with later amendments. In addition to this, three vehicles in each family except one where tested according to the Common Artemis Driving Cycle (CADC) where the results will be used as input for the emission data base HBEFA (Handbook on Emission Factors for Road Transport).

Emissions of regulated components i.e. carbon monoxide (CO), total hydrocarbons (THC) and oxides of nitrogen (NOx) were measured. Measurement of Particulate Matter (PM) has been conducted both according to the directive 70/220/EEC including latest amendments and to the PMP-protocol which was implemented in the EU from September 1st 2011 and is a part of UNECE reg.83.

Fuel consumption (Fc) was calculated by the carbon balance method.

The on-board diagnosis (OBD) systems were tested using simulated errors on one vehicle in each family.

All vehicles with SI-engines were also tested at idle speed (Type II test) where emissions of CO, HC, CO_2 and λ were measured and crankcase under pressure were verified (Type III test). For two SI-engine vehicles per type were the evaporative emissions (HC, Type IV test) determined and for two SI-engine vehicles per type were the exhaust emissions (HC, CO) at low ambient temperatures (Type VI test, -7°C) measured.

Three vehicles in one vehicle family with CI-engine (four wheel drive) were in addition to the standard testing programme for CI-engine vehicles, also tested with Portable Emission Measurement System (PEMS). Details can be found in Appendix 3.

The reference fuels (diesel and petrol) used were provided by Haltermann. The fuel specifications are according to directive 2002/80/EC and can be found in Appendix 1. The ethanol (E85/E75) used is bought from Preem refinery in Gothenburg.

Six of the vehicles with SI-engine and five of the vehicles with CI-engine exceeded the Euro 4 emission limit during the Type I test. Two of the CI-engine vehicles that failed the Type I test where of the same vehicle type and the cause of the exceeded pollutant was determined to be the same for both vehicles. According to the statistical procedure for In-Service testing defined in Directive 70/220/EEC as amended by 98/69/EC this vehicle type failed the in service testing. In one of the SI-engine vehicle families, three vehicles exceeded the Euro 4 emission limit for different pollutants and therefore more testing is necessary in order to reach a pass-fail decision. The rest of the vehicle types (12) fulfilled the legal requirements for In-Service testing.

During the NEDC test (Type 1), the average deviation from the values supplied by the manufacturer was more than 10 percent for two of the tested vehicle families, regarding fuel consumption and CO_2 emissions.

No emission related problems were detected when measuring exhaust emissions at idle speed during the Type II tests.

For the Type III tests, two out of forty-five vehicles showed crankcase overpressure at different loads.

Seven out of twenty-two vehicles tested exceeded the limit for evaporative emissions during the Type IV test. Six of the failing vehicles were fuelled with petrol and one with ethanol. The average test result for all the tested vehicles was 1.79 g HC per test.

During the exhaust emission test at low ambient temperatures (Type VI test), all tested vehicles complied with HC emission limits according to Directive 70/220/EEC as amended by 98/69/EC. One of the tested vehicles fuelled with ethanol exceeded the HC emission limits valid for petrol fuelled vehicles.

During the tests of the OBD-systems one simulated failure was not detected.

All emission related failures have been reported to the vehicle manufacturers.

Introduction

During the Swedish In-Service Testing Programme, vehicles in service are subjected to a testing procedure similar to the type approval test.

The results of several surveys show that In-Service testing is a useful tool in order to recognize type specific design faults or inadequate service recommendations which cause an inadmissible increase in exhaust emissions after an extended operating period for the motor vehicle. The In-Service testing is intended to enable the manufacturer to rectify the emission relevant defects on vehicles in service and in series production.

Definition of Conformity of in service vehicles:

According to Directive 70/220/EEC as amended by 98/69/EC, Annex I, §7.1.1., the definition of in service vehicles is: "With reference to type approvals granted for emissions, these measures must also be appropriate for confirming the functionality of the emission control devices during the normal useful life of the vehicles under normal conditions of use (conformity of in service vehicles properly maintained and used). For the purpose of this Directive these measures must be checked for a period of up to 5 years of age or 80 000 km, whichever is the sooner."

The objective of the In-Service Testing Programme is to conduct screening tests on a number of vehicle models to verify durability of the emission control concept. The selection of vehicle families is performed by the Swedish Transport Administration (STA) in close collaboration with AVL. The individual vehicles are randomly selected from the Swedish market after agreement with the vehicle owners.

Another objective of the In-Service Testing Programme is to obtain information of emissions from vehicles during real world driving. These data will be used in order to update the European emission model HBEFA. The emission model is used for emission inventories and as input to air pollution estimations.

Implementation of the programme

General information

Within the framework of the In-Service Testing Programme a total of nine vehicle types with SI-engines and five vehicle types with CI-engines were examined with respect to exhaust emissions limited by regulation. Two of the tested vehicle families with SI-engine were of flex fuel type.

The measurements were carried out according to Directive 70/220/EEC and with later amendments. The test cycles used were the New European Driving Cycle (NEDC) and the Common Artemis Driving Cycle (CADC). The different test cycles are shown on page 14 to 18.

During the chassis dynamometer tests, the emissions of Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (NO_X) and Carbon Dioxide (CO_2) were collected in bags in accordance to the regulation and, in addition, the emissions were measured second by second and the integral values were calculated.

For all vehicles tested during the 2011 programme, the particulate measurement has been conducted both according to 70/220/EEC including latest amendments and according to the new procedure in the PMP-protocol, which was implemented in the EU from September 1st 2011 and is a part of UNECE reg.83.

Fuel consumption was determined during the type approval cycle (NEDC) according to Directive 80/1268/EEC. The fuel consumption was calculated from the emissions of the carbon-bearing exhaust components (CO_2, CO and HC) (carbon balance method).

Exhaust emissions at idle speed (CO, HC, CO2 and λ) (Type II test) were measured on all vehicles with SI-engine.

Crankcase pressure (Type III test) has been measured on all vehicles with SI-engine.

On two vehicles in each family with SI-engine were the evaporative emissions (HC, Type IV test) determined.

On two vehicles in each family with SI-engine were the exhaust emissions (HC, CO) at low ambient temperatures (Type VI test) measured.

The on-board diagnosis (OBD) systems were tested with simulated errors on one vehicle in each family.

Three vehicles in one vehicle family with CI-engine were also tested with Portable Emission Measurement System (PEMS).

The car manufacturer and the car importer were invited to participate during the tests. Representatives from respective vehicle manufacturer and/or car importer were during most of the time present to witness the conduction of the tests.

Test programme vehicles

The vehicles in the test programme where selected in collaboration with Swedish Transport Agency and spread across different manufacturers in order to cover all the aspects the STA wish to attain. In all, vehicles from 13 different manufacturers were tested in the programme of 2011.

Table 1 shows the exhaust emission limits valid for the type approval test of passenger cars and light duty vehicles according to Directive 70/220/EEC as amended by 2003/76/EC.

Engine	MK (Limit)	Vehicle class (1)	Reference Mass (RM) [kg]	CO [g/km]	THC [g/km]	NMHC [g/km]	Nox [g/km]	HC+Nox [g/km]	PM [g/km]
Gasoline/ Ethanol	2000 (Euro 3)	M1 ≤ 2500kg	All	2,30	0,20	-	0,15	-	-
		N1 class I	RM ≤ 1305	2,30	0,20	-	0,15	-	-
		N1 Class II	1305 < RM ≤ 1760	4,17	0,25	-	0,18	-	-
		N1 class III	1760 < RM	5,22	0,29	-	0,21	-	-
	2005 (Euro 4)	M1 ≤ 2500kg	All	1,00	0,10	-	0,08	-	-
		N1 class I	RM ≤ 1305	1,00	0,10	-	0,08	-	-
		N1 Class II	1305 < RM ≤ 1760	1,81	0,13	-	0,10	-	-
		N1 class III	1760 < RM	2,27	0,16	-	0,11	-	-
	2009 (Euro 5a)	M1 ≤ 2500kg	All	1,00	0,10	0,068	0,060		0,005
		N1 class I	RM ≤ 1305	1,00	0,10	0,068	0,060		0,005
		N1 Class II	1305 < RM ≤ 1760	1,81	0,13	0,090	0,075		0,005
		N1 class III	1760 < RM	2,27	0,16	0,108	0,082		0,005
Diesel	2000 (Euro 3)	M1 ≤ 2500kg	All	0,64	-	-	0,50	0,56	0,05
		N1 class I	RM ≤ 1306	0,64	-	-	0,50	0,56	0,05
		N1 Class II	1305 < RM ≤ 1760	0,80	-	-	0,65	0,72	0,07
		N1 class III	1760 < RM	0,95	-	-	0,78	0,86	0,10
	2005 (Euro 4)	M1 ≤ 2500kg	All	0,50	-	-	0,25	0,30	0,025
		N1 class I	RM ≤ 1305	0,50	-	-	0,25	0,30	0,025
		N1 Class II	1305 < RM ≤ 1760	0,63	-	-	0,33	0,39	0,040
		N1 class III	1760 < RM	0,74	-	-	0,39	0,46	0,060
	2005PM	M1 ≤ 2500kg	All	0,50	-	-	0,25	0,30	0,005
		N1 class I	RM ≤ 1305	0,50	-	-	0,25	0,30	0,005
		N1 Class II	1305 < RM ≤ 1760	0,63	-	-	0,33	0,39	0,005
		N1 class III	1760 < RM	0,74	-	-	0,39	0,46	0,005
	2009 (Euro 5a)	M1 ≤ 2500kg	All	0,50	-	-	0,180	0,230	0,005
		N1 class I	RM ≤ 1305	0,50	-	-	0,180	0,230	0,005
		N1 Class II	1305 < RM ≤ 1760	0,63		-	0,235	0,295	0,005
		N1 class III	1760 < RM	0,74		-	0,280	0,350	0,005

Table 1 Emission limits for passenger cars and light-duty heavy vehicles
(1) N1 limits are also valid for class M vehicles with maximum mass > 2500kg

Following criteria were used when selecting the individual vehicles.

- same type approval for all vehicles in each family
- kilometre reading between 15,000 km (alternatively at least 6 months in traffic) and 80,000 km
- regular service committed according to the manufacturers' recommendation
- series production vehicle with no modifications performed
- no mechanical damage to components

The vehicle types, which were selected and subjected to testing, can be seen in table 2 and table 3.

Manufacturer	Type	Trade name	Engine type	Engine capacity (cm3)	Power (kW)	Emission approval	Swedish enviroment class	Milage min (km)	Milage max (km)	Registration
TOYOTA	AB1	Aygo	1KR-FE	998	50	EURO4	MK 2005	28281	67030	2007-01-16 to 2007-12-14
PEUGEOT	AB1	307 Bioflex	NFU	1587	80	EURO4	MK 2005	35163	67734	2007-07-25 to 2008-01-08
VW	1T	Touran	BMY	1390	103	EURO4	MK 2005	41276	80764	2006-11-16 to 2008-01-30
RENAULT	Clio III	Clio	D4FH784	1149	74	EURO4	MK 2005	24026	67111	2007-07-05 to 2009-08-19
BMW	320i	320i	N43B20A	1995	125	EURO4	MK 2005	42186	64585	2008-01-08 to 2009-08-27
VOLKSWAGEN	1K	Golf Multifuel	CCS	1595	75	EURO4	MK 2005	35604	71067	2007-11-30 to 2008-02-15
SKODA	1Z	Oktavia	CCSA	1595	75	EURO4	MK 2005	43198	66724	2008-08-14 to 2009-06-01
SUZUKI	MZ	Swift	M13A	1328	67	EURO4	MK 2005	36856	74201	2007-01-17 to 2007-06-27
FIAT	312	500	1,2 EVO	1242	51	EURO4	MK 2005	31976	68052	2008-04-29 to 2008-09-30

Table 2 Test programme vehicles, spark ignited engines

Manufacturer	Type	Trade name	Engine type	Engine capacity (cm3)	Power (kW)	Emission approval	Swedish enviroment class	Milage min (km)	Milage max (km)	Registration
HYUNDAI	FD	I30	D4FB (66/84kW)	1582	84	EURO4	MK 2005	48539	65166	2007-06-18 to 2008-05-22
OPEL	1T	Corsa	BMY	1248	55	EURO4	MK 2005PM	38279	67484	2007-11-30 to 2008-06-30
AUDI	8PAEHD	A3	BLS 1,9 D	1896	77	EURO4	MK 2005PM	63953	79777	2007-10-11 to 2007-12-20
FORD	QXBA	Mondeo	2,0 DURATORQ	1997	103	EURO4	MK 2005PM	36967	85329	2007-05-31 to 2008-03-10
SUBARU (*)	C4B20D8	Legacy	EE20	1998	110	EURO4	MK 2005	39139	70675	2008-03-21 to 2009-01-06

Table 3 Test programme vehicles, compression ignited engines

(*) In addition to chassis dynamometer testing, three of the Subaru Legacys were also tested on-road with a Portable Emission Measurement System - PEMS. Test results are presented in Appendix 3

Actual test programme

Within the framework of the programme, 14 vehicle types were tested. The investigations were implemented with reference to Directive 70/220/EEC and later amendments. In order to obtain a reliable assessment if type-specific defects are present on a vehicle type, five vehicles of each selected vehicle type were measured with respect to exhaust emissions.

In table 4 the tests for type approval of passenger cars and light duty vehicles are illustrated.

Test	Description	Positive ignition vehicles	Compression ignition vehciles
Type I	tailpipe after colds start	yes	yes
Type II	carbon monoxide emissions at idling speed	yes	-
Type III	emission of crankcase gases	yes	-
Type IV	evaporative emissions	yes	-
Type V	durability of anti-pollution control device	yes	yes
Type VI	low ambient temperature tailpipe emissions after a cold start	yes	-
OBD	on board diagnosis	yes	yes

Table 4 Application of tests for type approval

Prior to testing, the service record manual of each vehicle was reviewed in order to make sure specified maintenance interval had been observed and that the vehicle was in proper condition.

The vehicles were checked regarding the tightness of the exhaust system, catalytic function, oil and oil filter, fuel filter, air filter and sparkplugs. OBD information was read to ensure that no emission relevant fault codes were detected. Before the vehicles were tested on the chassis dynamometer the vehicles were refuelled with reference fuel (see Appendix 1 for more details regarding relevant fuels).

Before the test, all test vehicles were subjected to a pre-conditioning drive in order to obtain similar start conditions before the actual test. For Type I tests, all vehicles with SI-engines where driven 1xNEDC and the vehicles with CI-engine where driven 3xNEDC Part Two (Extra Urban Cycle), all according to the Directive 70/220/EEC as amended by 2003/76/EC. After the pre-conditioning, the vehicles were left in the soak area between 6 and 36 hours, at an ambient temperature between 20 °C and 30 °C,

Type approval inertia weight and coast down values were supplied by the manufacturer. No deterioration factor was used for evaluating the Type I test results.

Type II tests were performed on vehicles with SI-engine directly when the vehicles arrived to AVL MTC. Type III tests were performed on vehicles with SI-engines immediately after the Type I test. The OBD check was performed at the end of the test procedure to make sure that the simulation of emission relevant failures would not affect the results of the other tests.

Table 5 displays which tests being performed on SI-engine vehicles and CI-engine vehicles.

Actions	Spark ignited	Compression ignited
Re-fuel with reference fuel	5 vehicles per car family	5 vehicles per car family
CADC – ARTEMIS	3 vehicles per car family	3 vehicles per car family
Pre-conditioning of vehicle	5 vehicles per car family (1xNEDC)	5 vehicles per car family (3xNEDC – Part Two)
Type I test	5 vehicles per car family	5 vehicles per car family
Type II test	5 vehicles per car family	N/A
Type III test	5 vehicles per car family	N/A
Type IV test	2 vehicles per car family	N/A
Type VI test	2 vehicles per car family (1xNEDC Part one)	N/A
OBD check	1 vehicles per car family	1 vehicle per car family

Table 5 Test programme

Figure 1 illustrates the programme conducted at AVL MTC.

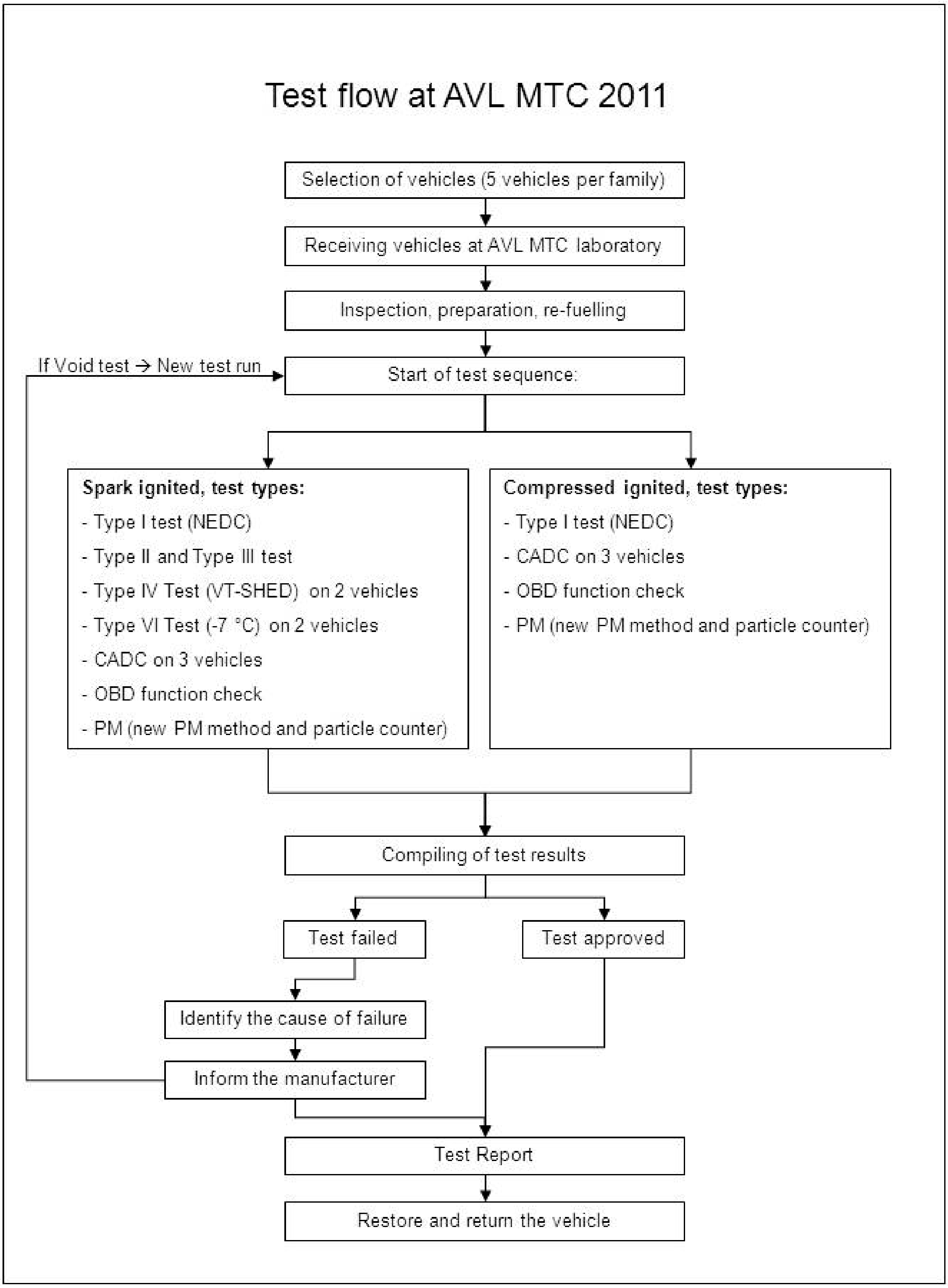

Figure 1 Illustration of the work flow for the In-Service Testing Programme at AVL MTC 2011

Test Fuels

According to Directive 70/220/EEC and later amendments, reference fuels shall be used when performing Type 1 and Type VI tests. During the test programme different batches of reference fuels were used.

For more detailed information regarding fuel compositions see Appendix 1

Test Cycles

New European Driving Cycle (NEDC)

The NEDC is the test cycle used for emission certification type approval of light duty vehicles.

The first 780 s includes four identical cycles, representing the Urban Driving Cycle (UDC). This part may be further divided into two parts of 390 s each (C_1+2 as UDC1 and C_3+4 as UDC2) in order to compare vehicle emissions from a cold engine and exhaust system with those from the engine and exhaust system at a proper operating temperature. The period from 780 s to the cycle end at 1180 s represents the higher speed part of the cycle, the Extra Urban Driving Cycle (EUDC).

Figure 2 shows the breakdown of the Type I test (NEDC).

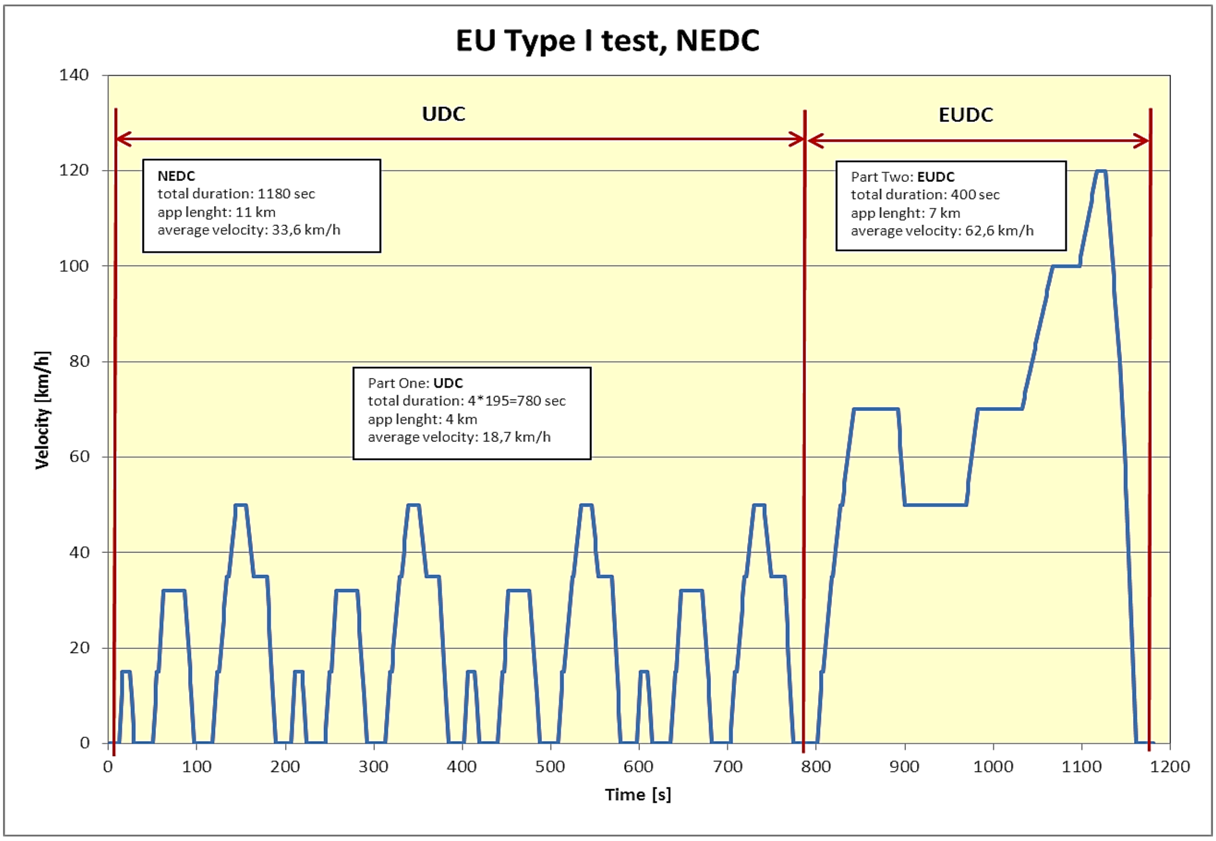

Figure 2 EU TYPE I Test - NEDC - New European Driving Cycle

Common Artemis Driving Cycle (CADC)

The objective of the In-Service Testing Programme is also to give input to the update of the European emission model HBEFA. The driving cycles “Common Artemis Driving Cycle” (CADC) were developed from real world driving patterns in order to gain better knowledge about emissions in real traffic. The emission model is used for emission inventories and as input to air pollution estimations.

For the programme of 2011, four different measurement cycles were used to cover the specified CADC-range. They are shown in figures 3 to 6.

Emissions are measured second by second on-line from 0s to the end of the test cycle. The bag samples were taken between the green and the red line, shown in figures 3 to 6.

The CADC consists of four sub cycles:
- Artemis urban cold cycle, duration 993 seconds, cold start
- Artemis urban cycle, duration 993 seconds, warm start
- Artemis road cycle, duration 1082 seconds, warm start
- Artemis motorway cycle, duration 1068 seconds, warm start

For the urban, road and motorway cycles; all test vehicles are subjected to a pre-conditioning drive to obtain similar start conditions before the actual test. The vehicles are driven 10 minutes at 80 km/h on their individual dynamometer setting.

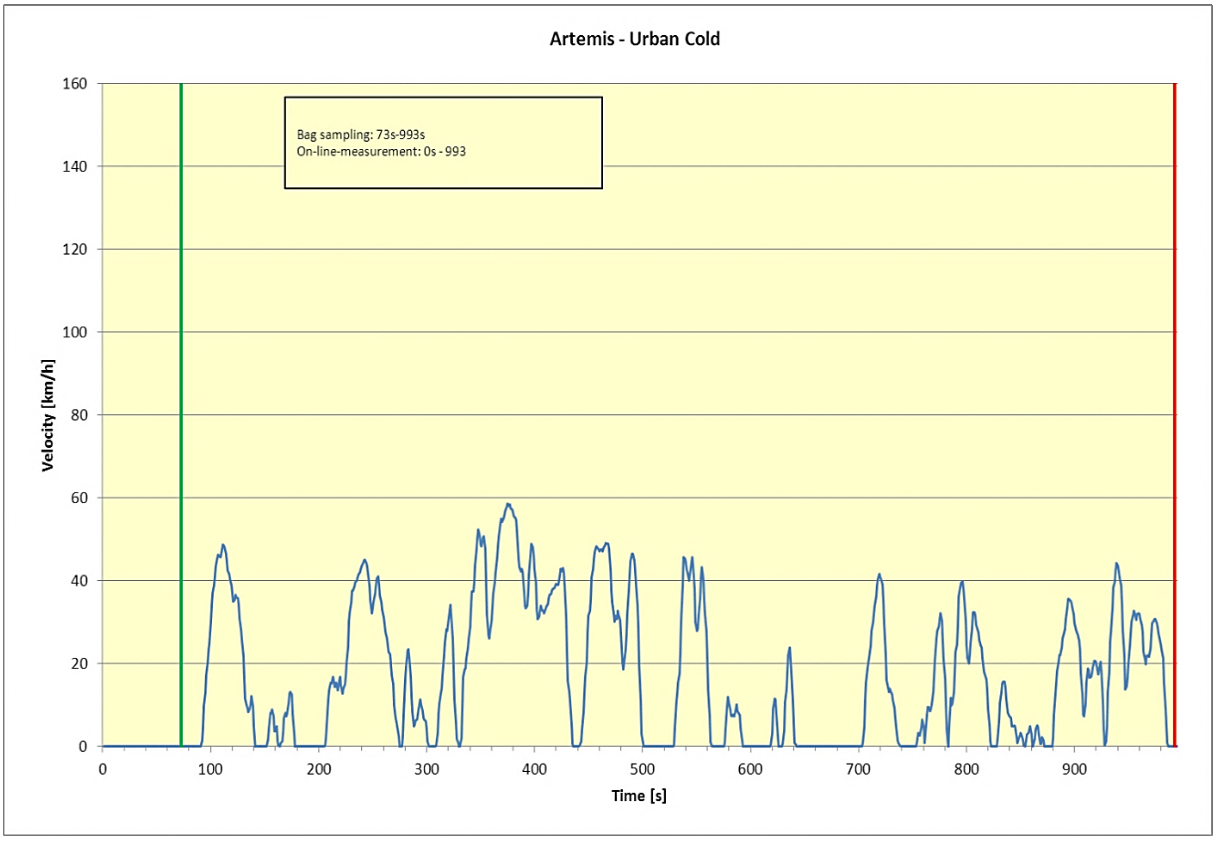

Figure 3 ARTEMIS – Urban Cold Cycle (without pre-conditioning)

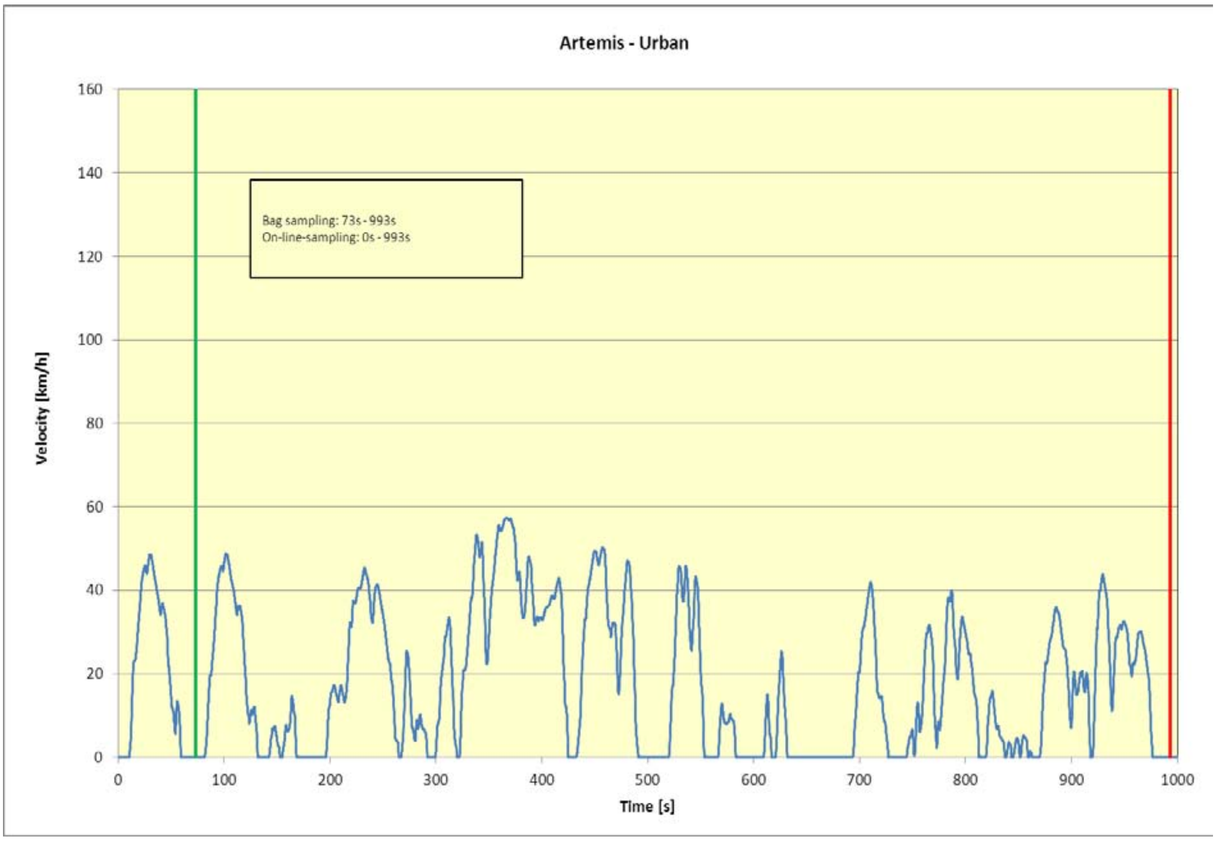

Figure 4 ARTEMIS – Urban Cycle

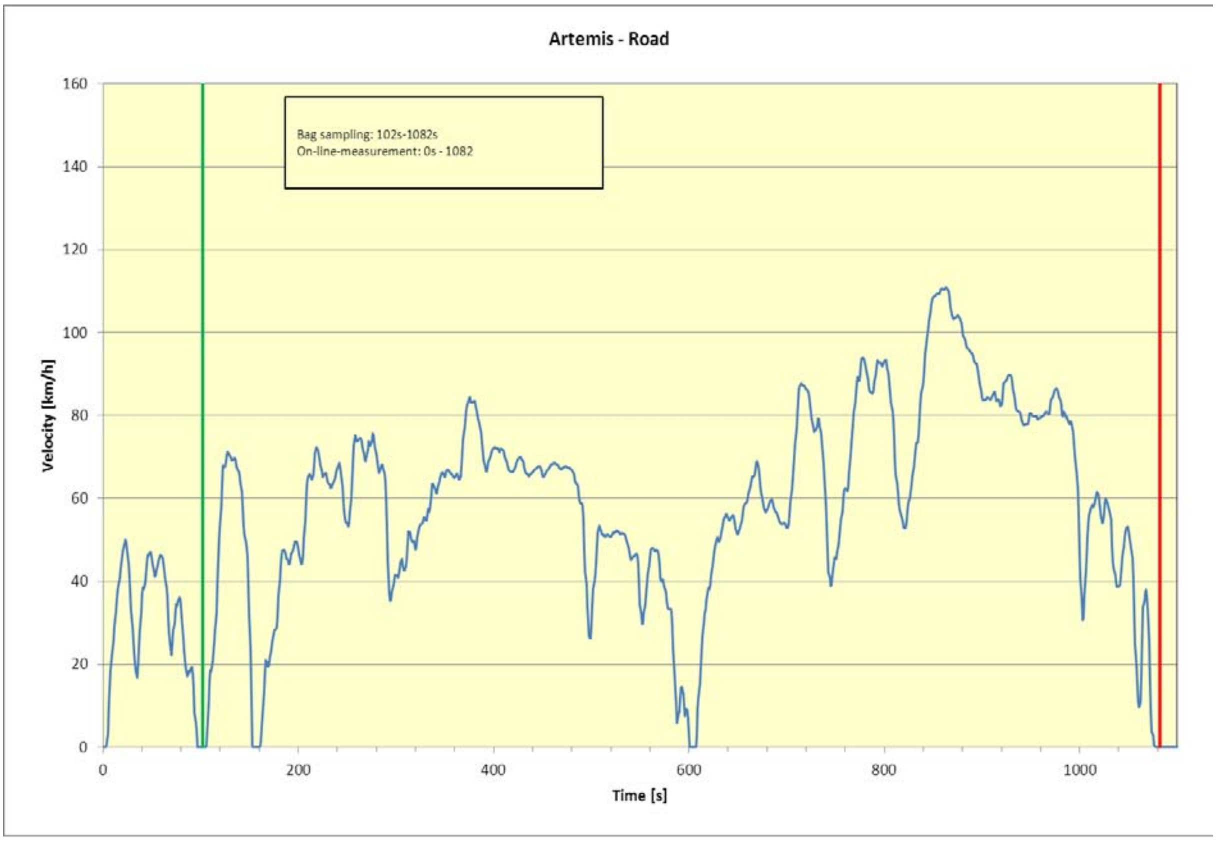

Figure 5 ARTEMIS – Road Cycle

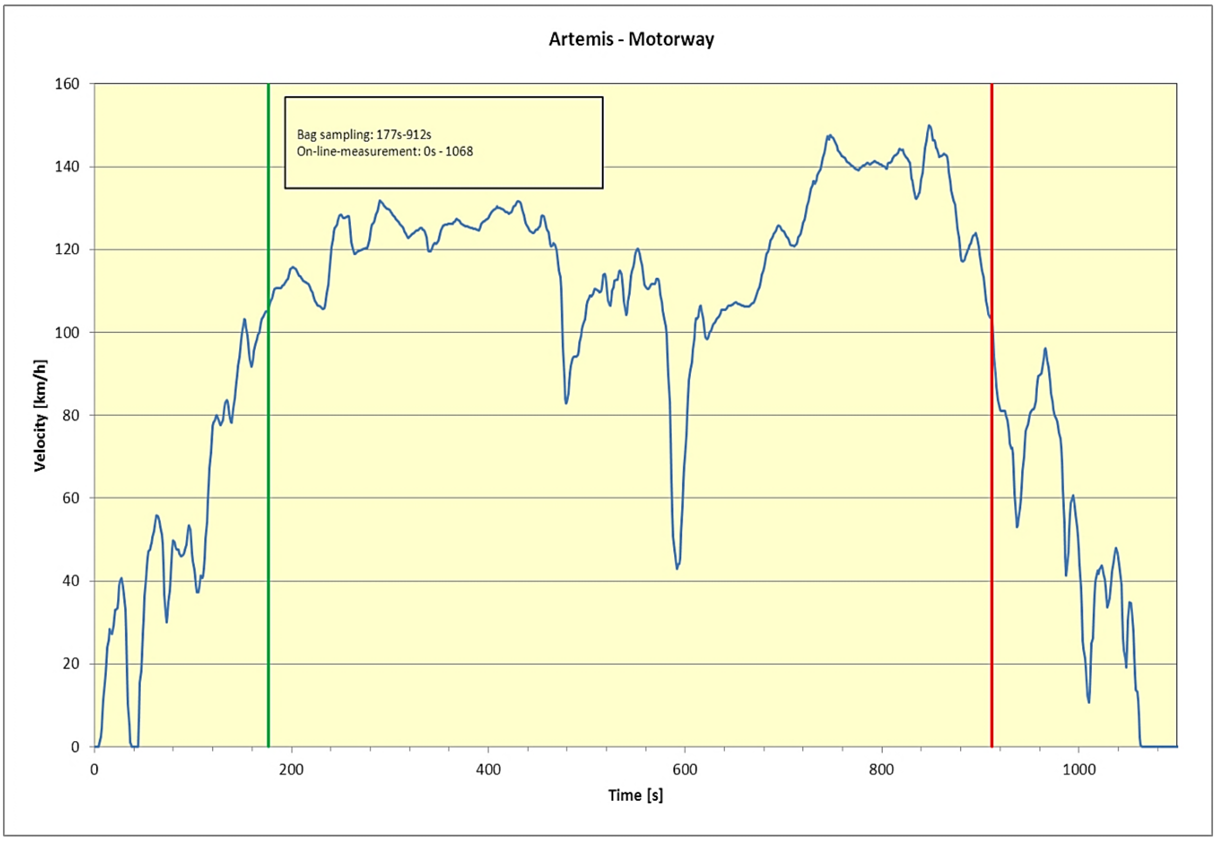

Figure 6 ARTEMIS – Motorway Cycle

Type VI test (-7 C)

The Type VI test is used in order to verify the average low ambient temperature Carbon Monoxide (CO) and Hydrocarbon (HC) tailpipe emissions after a cold start.

The test cycle is a modified Type I test (NEDC) were only part one is being evaluated (UDC) (see figure 7).

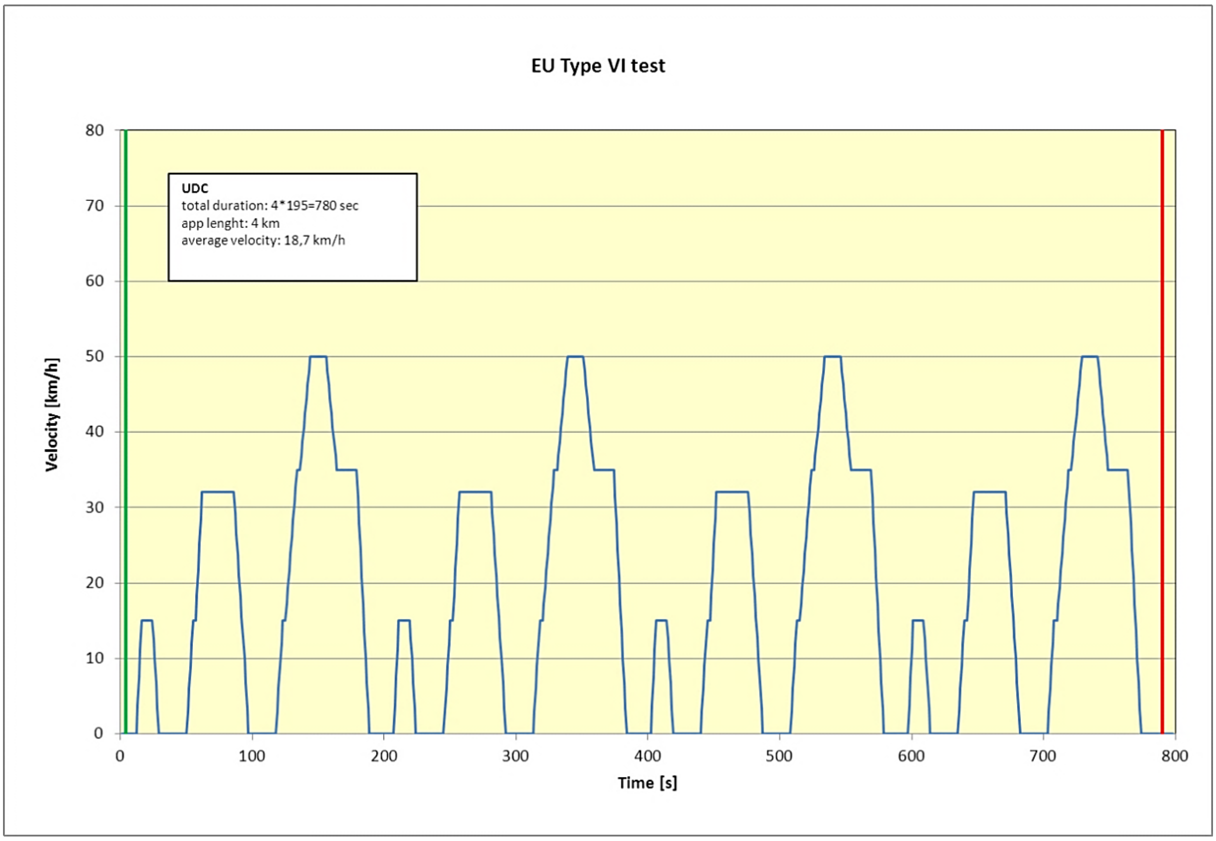

Figure 7 Type VI test cycle

Results

Emissions from Type I Test

The following section show the average results of the exhaust emissions from Type I testing. More detailed information from each family is shown in the test reports previously sent to each manufacturer and to the STA.

In Table 6 the average NEDC results are presented in relevant categories. One of the tested vehicle types with CI-engine failed to comply with the directive due to high emissions of NO_X.

Category	Emission level	CO [g/km]	HC [g/km]	NOx [g/km]	HC+NOx [g/km]	CO_2 [g/km]	Fc [L/100km]	PM-PMP [g/km]	PN [#]
Spark Ignition	Euro4	0,36	0,06	0,02	0,07	114,40	4,81	0,0017	3,55E+11
	Euro4	0,75	0,06	0,03	0,10	183,00	7,72	0,0026	2,83E+12
	Euro4	0,32	0,05	0,02	0,06	146,00	6,13	0,0006	2,66E+11
	Euro4	0,42	0,06	0,03	0,09	175,60	7,37	0,0032	6,57E+12
	Euro4	0,32	0,03	0,04	0,07	176,80	7,42	0,0003	7,57E+11
	Euro4	0,22	0,03	0,02	0,05	129,80	5,45	0,0004	3,77E+11
	Euro4	0,40	0,04	0,01	0,06	144,00	6,04	0,0003	1,70E+11
	Euro4	0,74	0,08	0,05	0,13	181,40	7,65	0,0009	1,90E+12
	Euro4	0,30	0,04	0,05	0,09	175,20	7,36	0,0003	4,36E+11
E85(1)	Euro4	0,70	0,07	0,07	0,14	178,20	11,10	0,0007	1,26E+12
	Euro4	0,37	0,09	0,04	0,13	169,38	10,54	0,0004	1,31E+11
Limit	Euro4	**1,0**	**0,10**	**0,08**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Compression Ignition	MK 2005PM	0,20	0,02	0,22	0,24	145,80	5,53	0,0001	5,38E+10
	MK 2005PM	0,44	0,04	0,21	0,24	121,60	4,63	0,0001	5,47E+09
	MK 2005PM	0,21	0,03	0,21	0,24	129,20	4,89	0,0002	5,13E+09
	MK 2005PM	0,15	0,01	0,34	0,35	156,60	5,93	0,0003	5,13E+10
	Euro4	0,23	0,02	0,21	0,23	156,40	5,93	0,0232	4,48E+13
Limit	Euro4	**0,5**	**N/A**	**0,25**	**0,30**	**N/A**	**N/A**	**0,025**	**N/A**
Limit	MK 2005PM	**0,5**	**N/A**	**0,25**	**0,30**	**N/A**	**N/A**	**0,005**	**N/A**

Table 6 Average exhausts emissions during Type I test (NEDC)

(1) E85 vehicles are type approved as a petrol vehicle and follow the Euro 4 emission regulations

The figures 7 to 12 gives examples of average CO, HC and NO_X emissions from Type I tests from vehicles with SI-engines and CI-engines. As can be seen in the figures most of the emissions occur at cold start and in the beginning of the test cycles. Regarding the CI-engine vehicles, emissions of NO_X show a significant increase on the highway part of the NEDC-cycle.

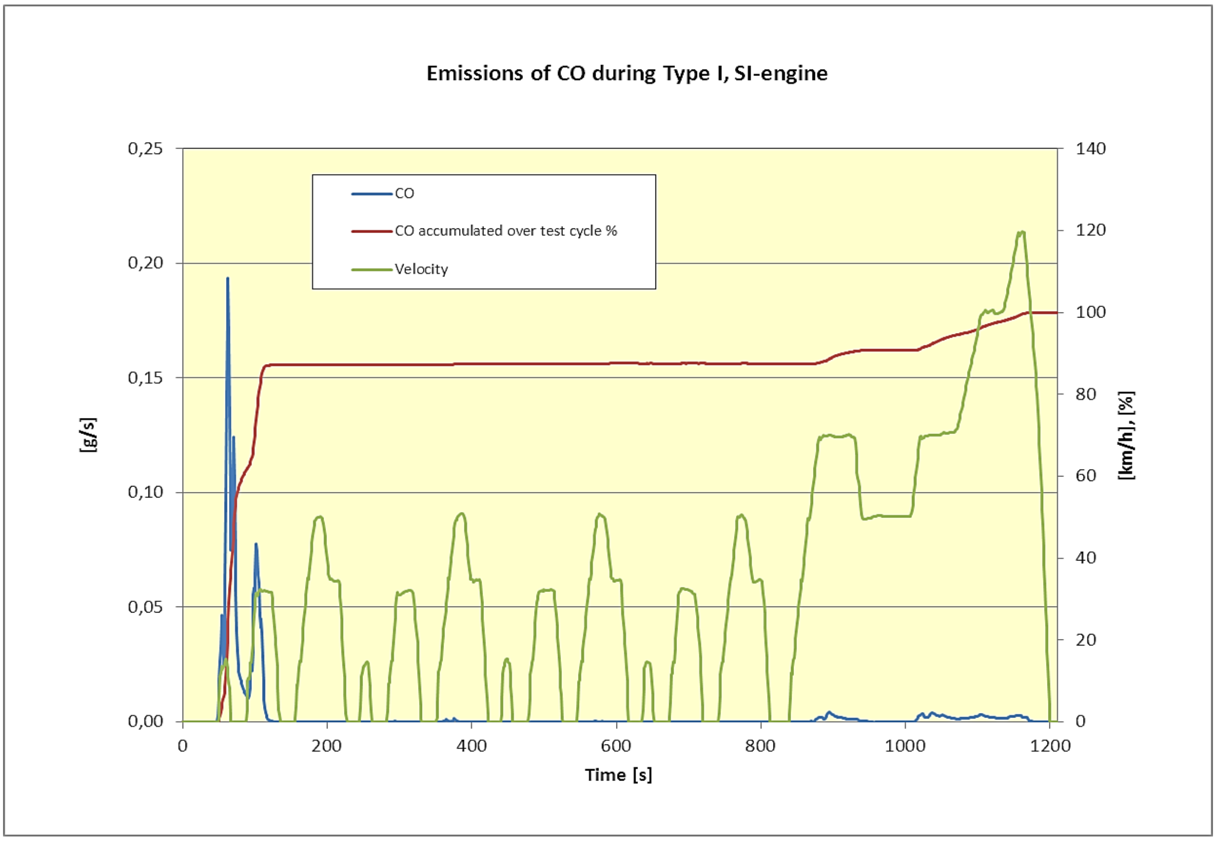

Figure 8 Average CO emitted by a SI-engine vehicle during Type I test

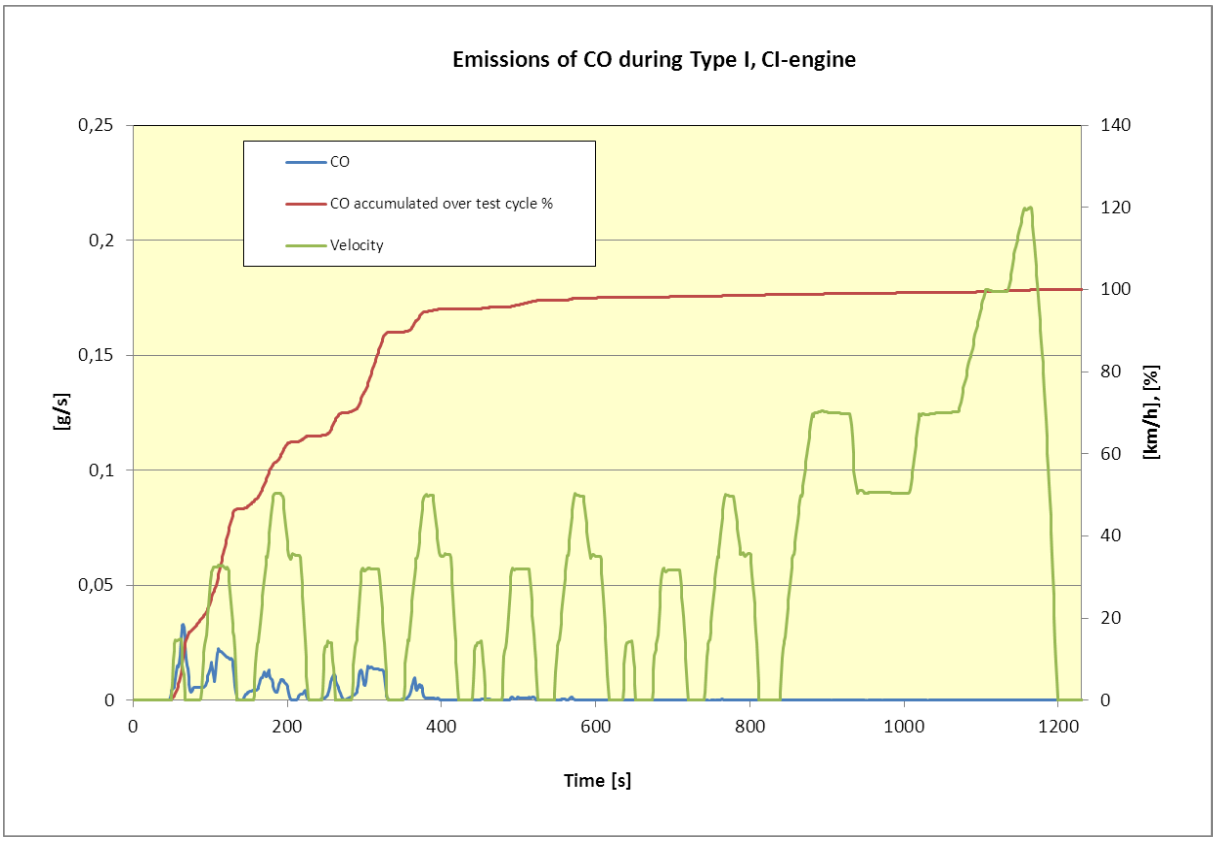

Figure 9 Average CO emitted by a CI-engine vehicle during Type I test

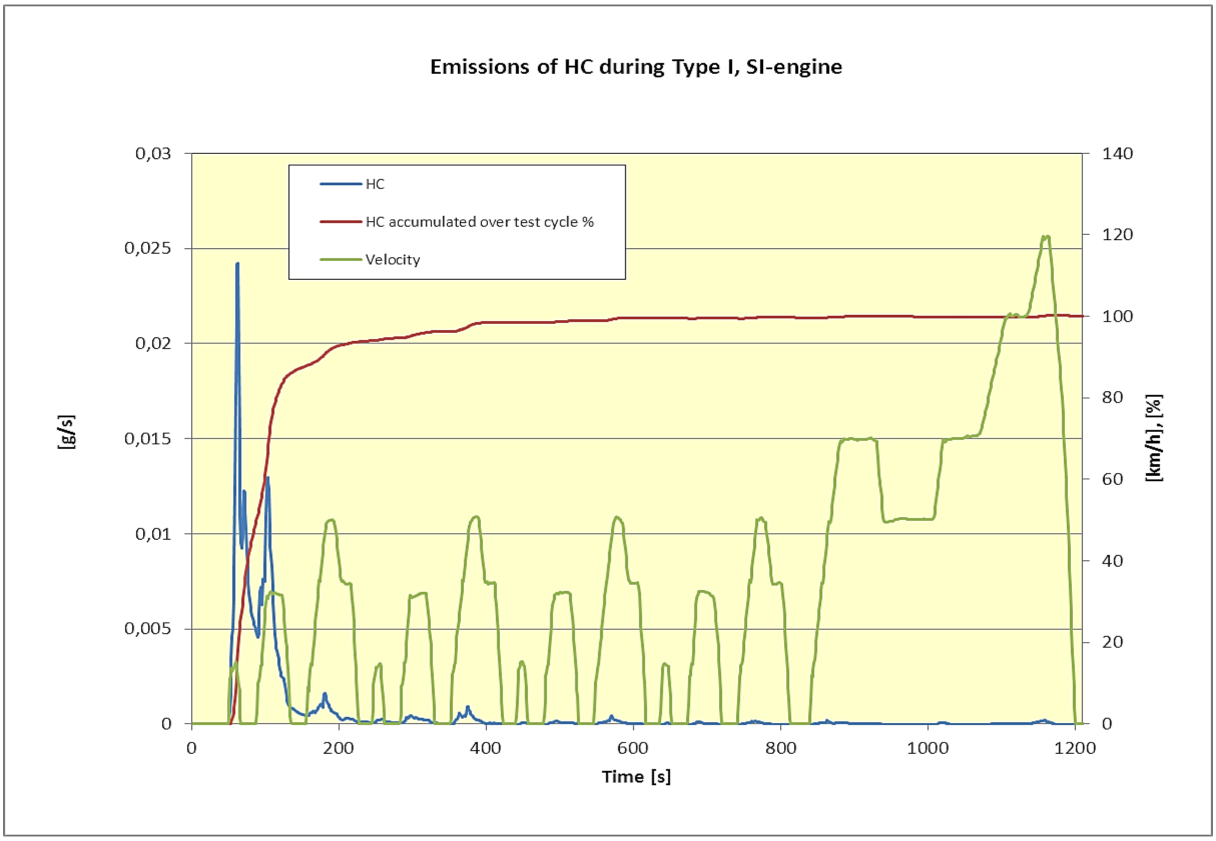

Figure 10 Average HC emitted by a SI-engine vehicle during Type I test

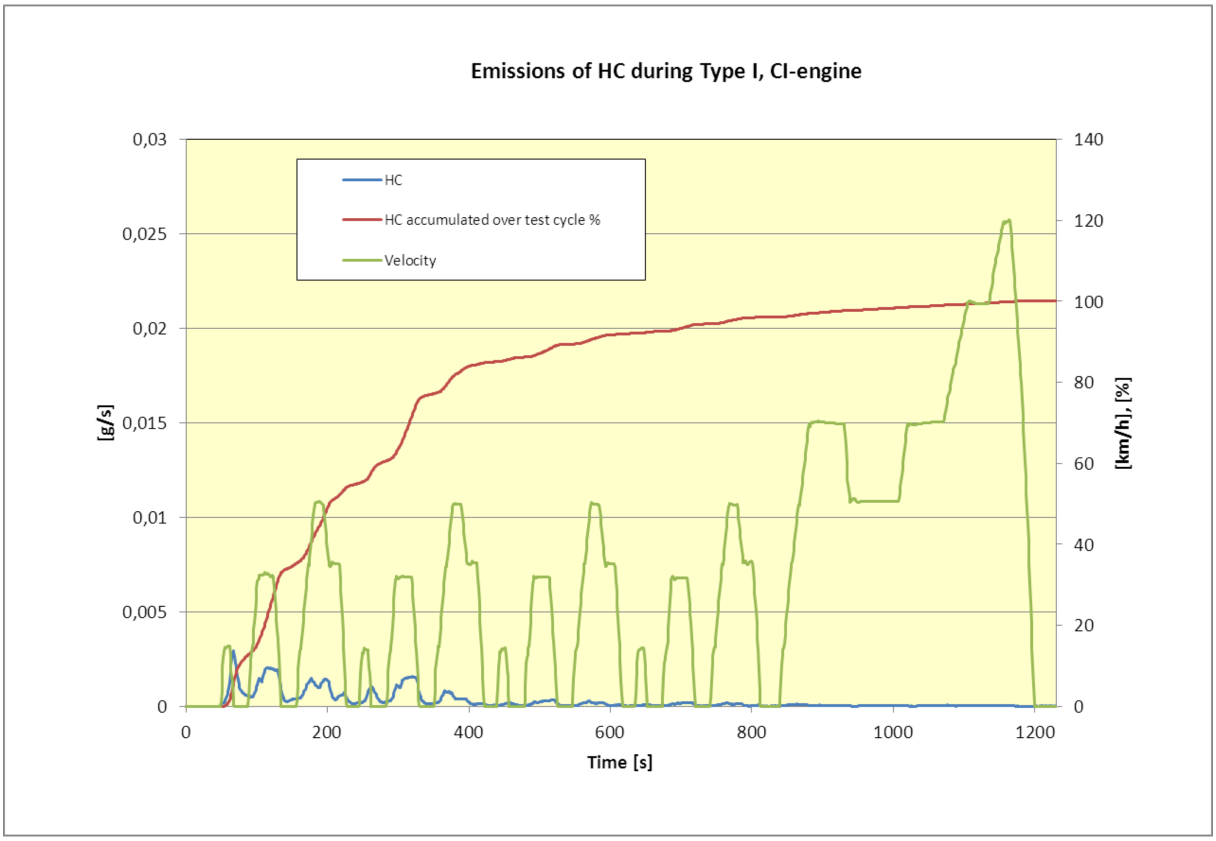

Figure 11 Average HC emitted by a CI-engine vehicle during Type I test

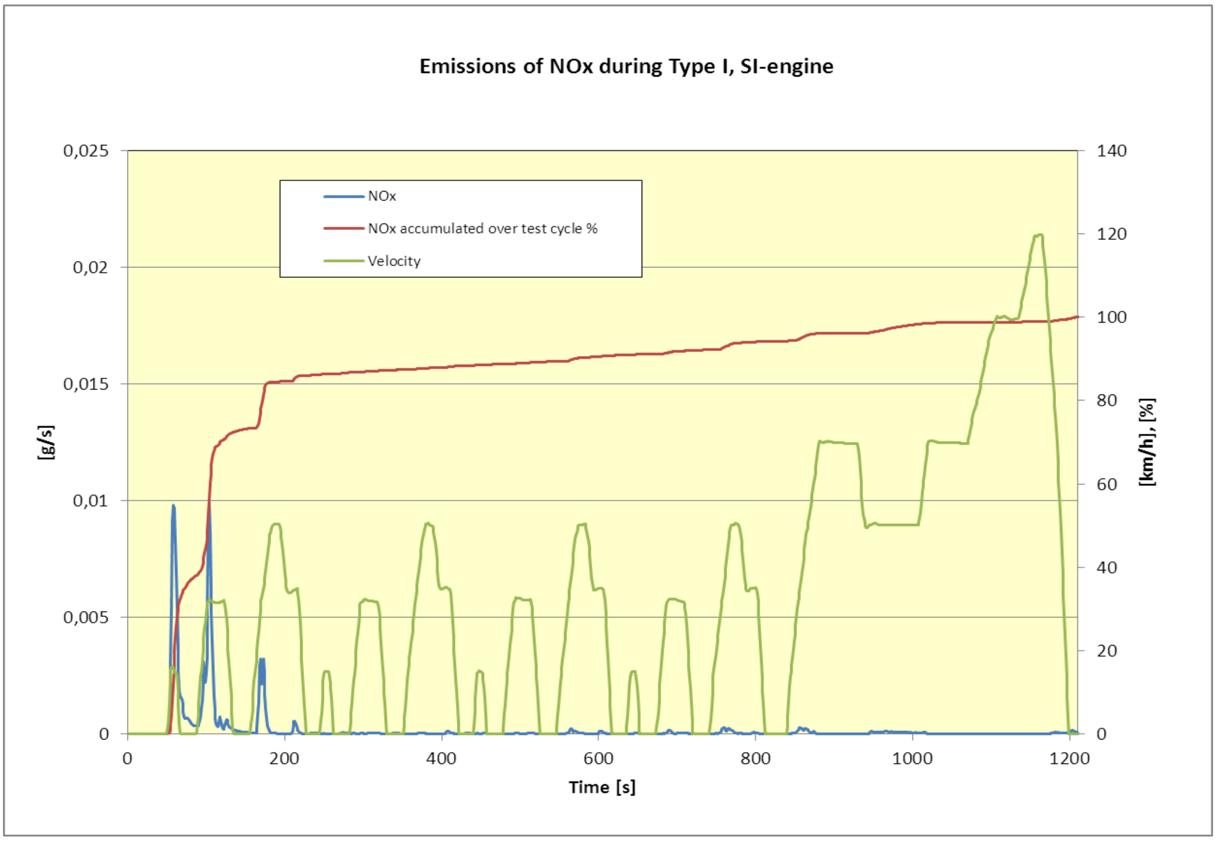

Figure 12 Average NOX emitted by a SI-engine vehicle during Type I test

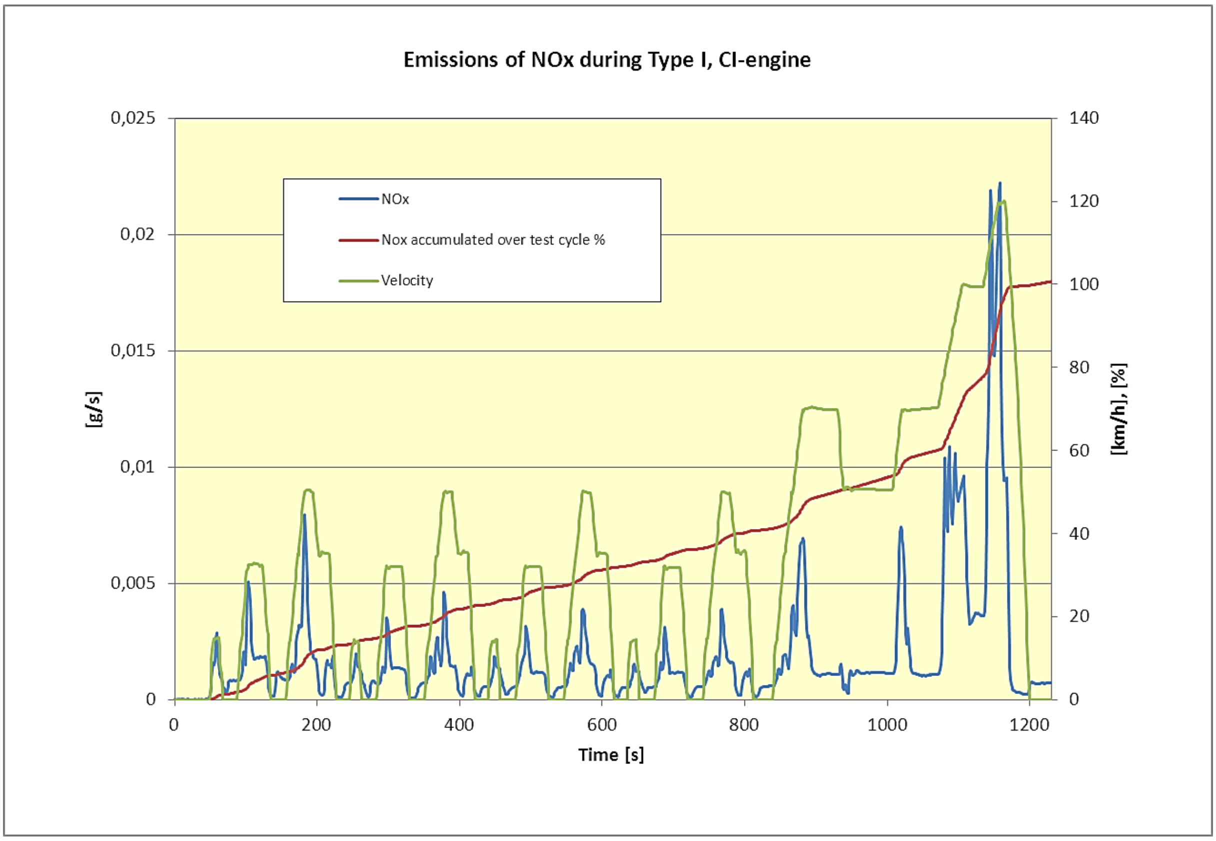

Figure 13 Average NOX emitted by a CI-engine vehicle during Type I test

Figure 13 shows the CO and HC emissions during Type I test of SI-engine vehicles. Two of the SI-engine vehicles, driven on petrol, exceeded the Euro 4 emission limit. One of the E85 fuelled vehicles exceeded the Euro 4 emission limit.

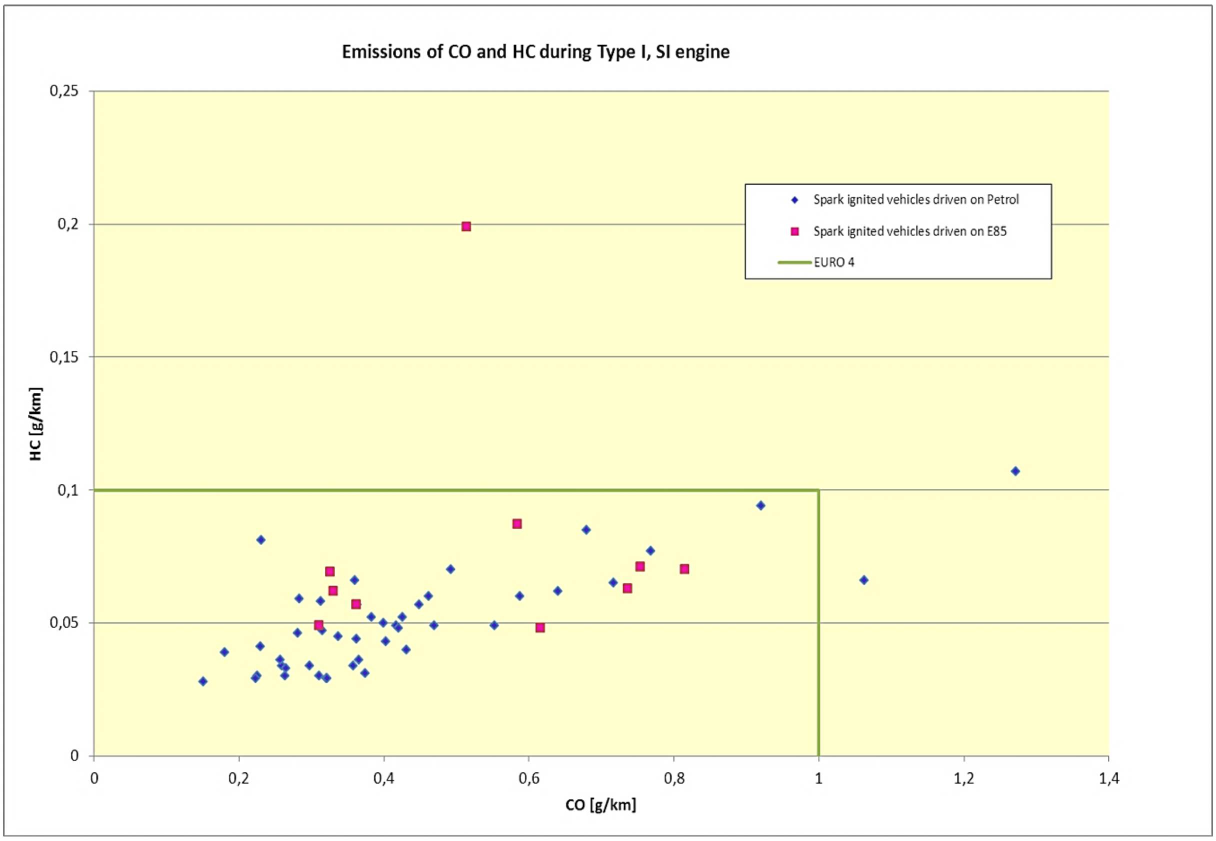

Figure 14 CO and HC emissions of vehicles with SI-engine during Type I test

Figure 14 shows the NO_X and HC emissions during Type I test of SI-engine vehicles. Three of the SI-engine vehicles, driven on petrol, and two of the SI-engine vehicles driven on E85, exceeded the Euro 4 emission limit.

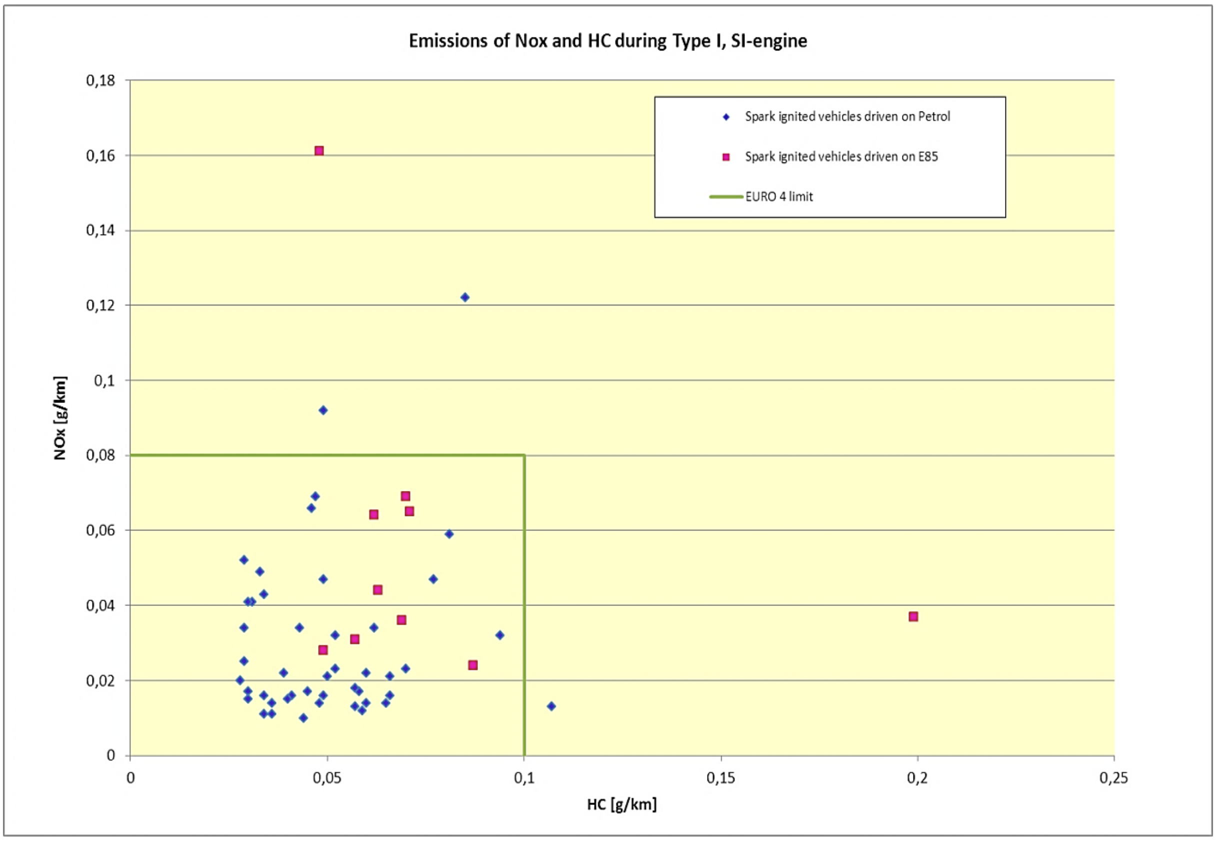

Figure 15 NOX and HC emissions of vehicles with SI-engine during Type I test

Figure 15 shows the CO and NO_X emissions during Type I test of CI-engine vehicles. As can be seen four of the vehicles exceeded the Euro 4 emission limit.

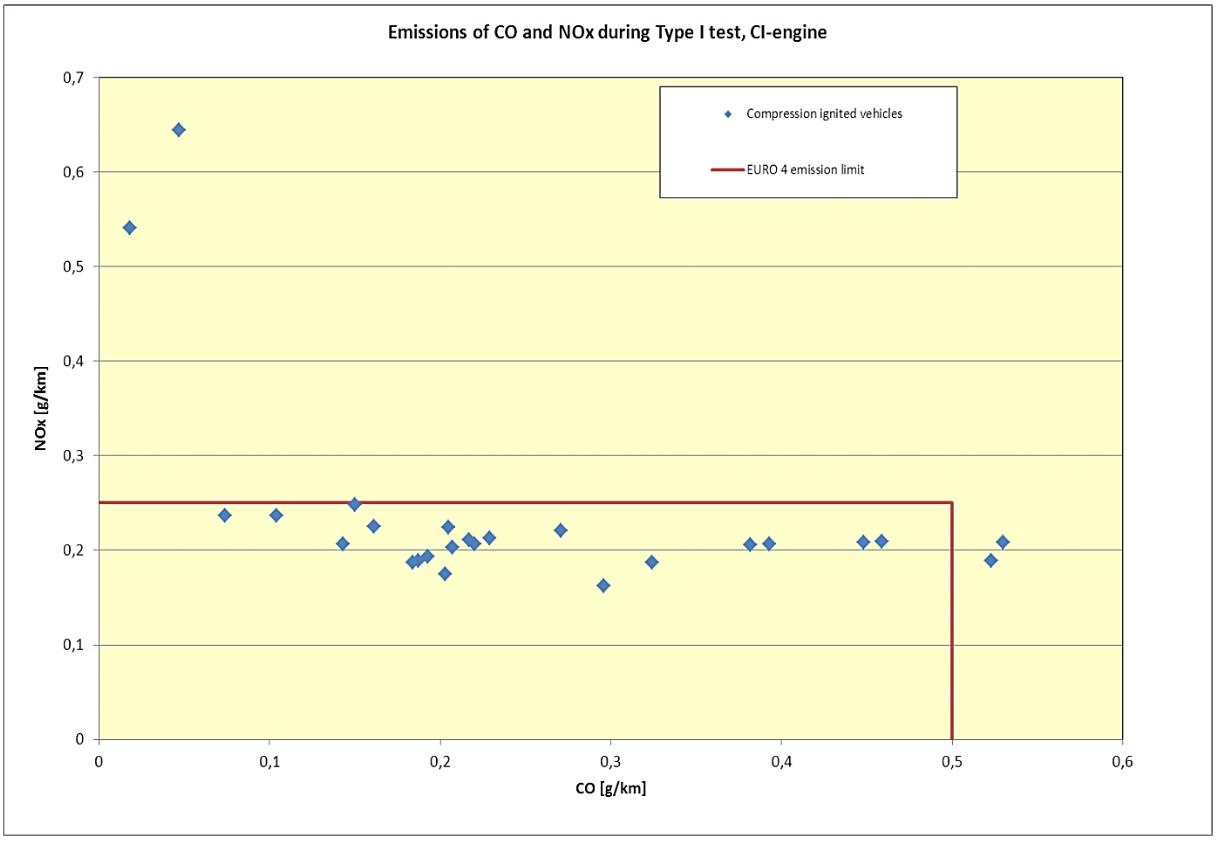

Figure 16 CO and NOx emissions from Euro 4 vehicles with CI-engine during Type I test

PM and NO_X emissions during Type I test of CI-engine vehicles. As can be seen three of the vehicles exceeded the Euro 4 emission limit.

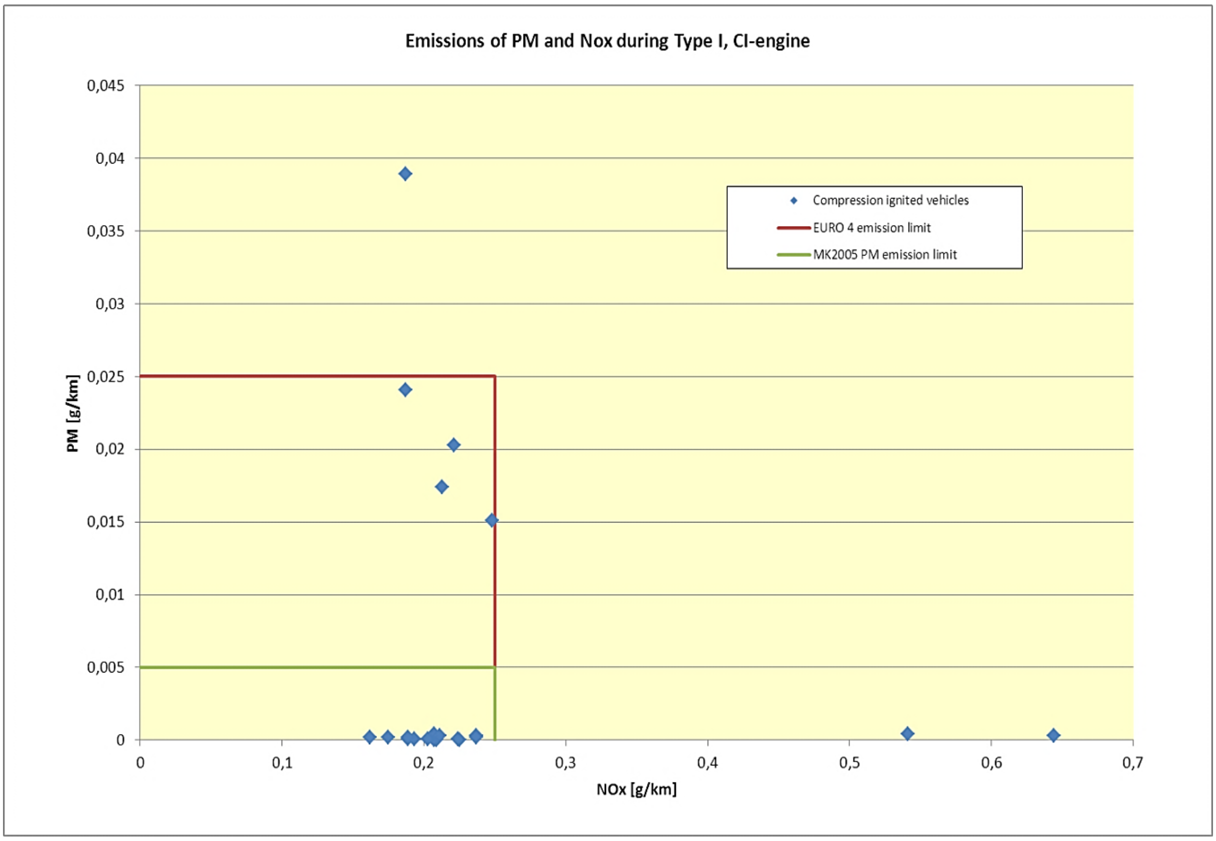

Figure 17 PM and NOx emissions from Euro 4 vehicles with CI-engine during Type I test

Carbon Dioxide emissions Vs. Fuel consumption

According to Directive 80/1268/EEC, the member states are not permitted to refuse grant of the EC type approval or conformity of production for a vehicle type for reasons which are related to emissions of carbon dioxide and/or fuel consumption. These values are a part of the type approval but no limit values. The CO_2 and consumption declarations are for consumer information and in many EU countries used as a basis for vehicle related taxes.

The CO_2 emissions are measured in the "New European Driving Cycle" (Type I test). The fuel consumption is calculated using the measured CO_2 emissions and the other carbon containing emissions (CO and HC). Measurement in accordance with Directive 80/1268/EEC is carried out using reference fuel.

The test vehicle must be presented in good mechanical condition. It must be run-in and must have an odometer reading between 3,000 and 15,000 km.

In figure 17 the measured fuel consumption (incl. max and min values) is compared to the fuel consumption given by the manufacturers.

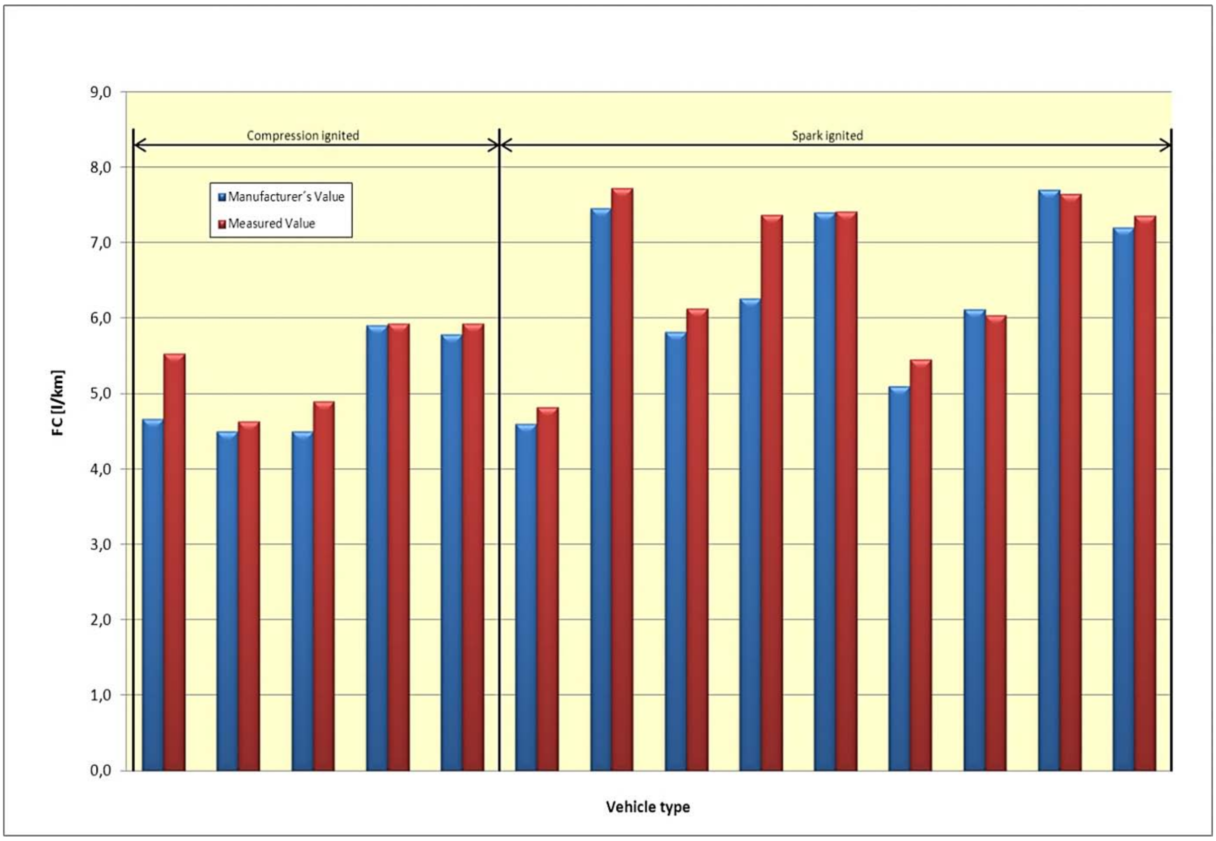

Figure 18 Average fuel consumption during Type I test for different vehicle types

Figure 18 shows the FC deviation between measured and manufacturer values. Twelve of the tested families showed higher FC compared to the manufacturers' values. Two vehicle types showed lower FC compared to the manufacturers' values.

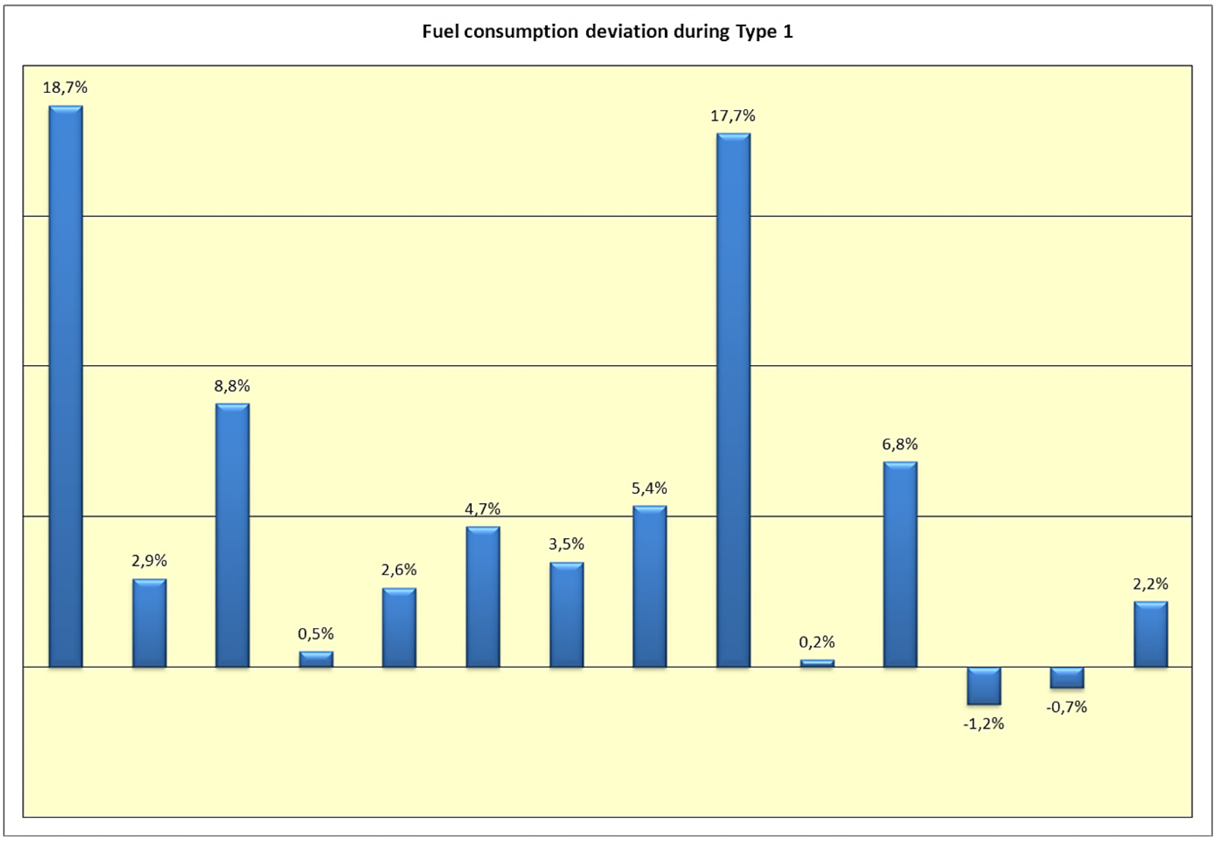

Figure 19 Relative deviation of the FC towards the manufacturer's values during Type I test for different vehicles types

Figure 19 shows the measured CO_2 emissions compared to the CO_2 emissions given by the manufacturers.

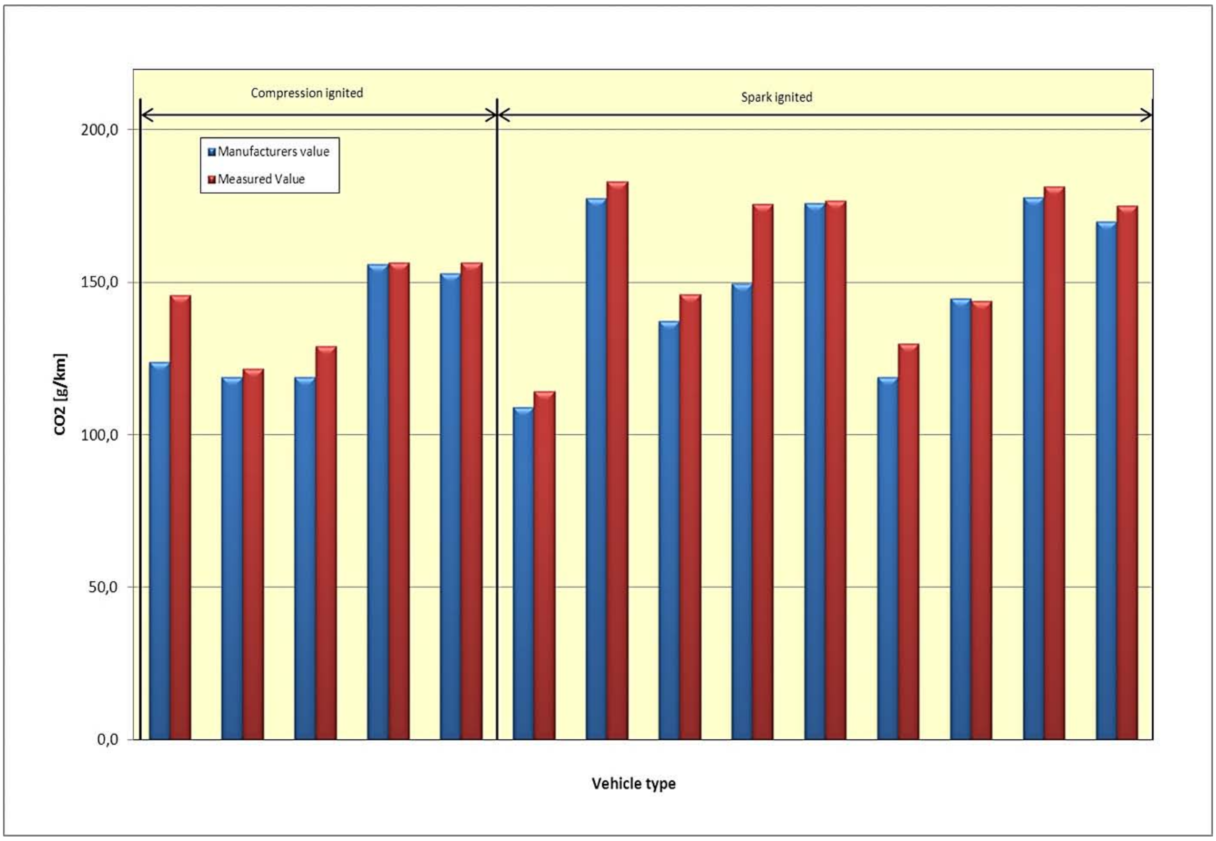

Figure 20 Average CO2 emissions during Type I test for different vehicle types

Figure 20 shows the CO_2 deviation between measured values and manufacturer values. Thirteen of the tested families showed higher CO_2 emissions compared to the manufacturers' values. One vehicle type showed lower CO_2 emissions compared to the manufacturers' values.

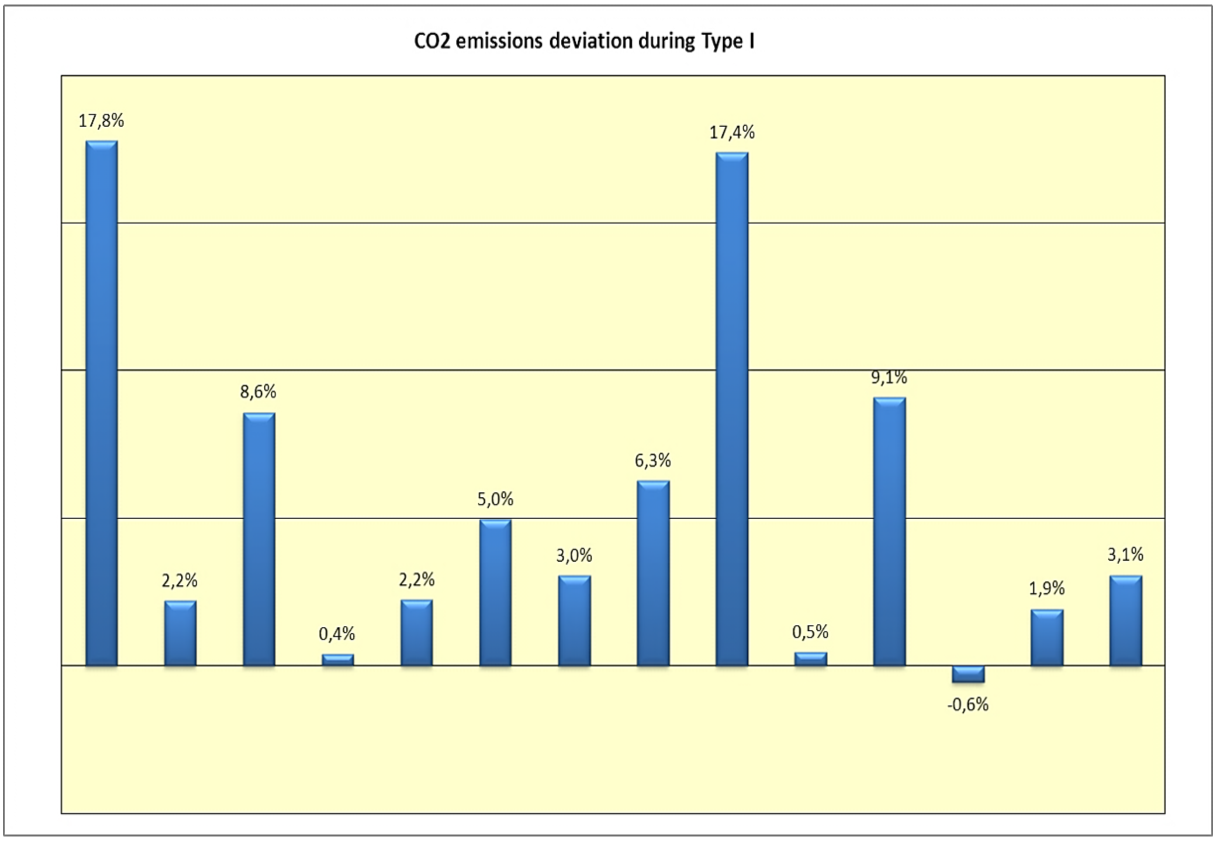

Figure 21 Relative deviation of the CO_2 emissions towards the manufacturer's values during Type I test for different vehicles types

Idle Test (Type II test)

During the Type II test, the ambient temperature must be between 20 and 30 °C. The exhaust emissions are measured at idle speed and at approximately 2,500 rpm.

None of the tested vehicles with SI-engine had emission related problems meaning that all vehicles complied within the limits of the directive. The results are displayed in Table 7.

The Type II test is not relevant for vehicles with a CI-engine.

	Idle			
	CO [%vol.]	HC [ppm]	CO2 [%vol.]	λ
Gasoline average	0,0	6,8	14,1	1,1
Limit	3,5	-	-	-
	High Idle (2.500 rpm)			
	CO [%vol.]	HC [ppm]	CO2 [%vol.]	λ
Gasoline average	0,0	4,9	15,2	1,1
Limit	-	-	-	-
	Idle			
	CO [%vol.]	HC [ppm]	CO2 [%vol.]	λ
E85 average	0,0	11,0	14,6	1,0
Limit	3,5	-	-	-
	High Idle (2.500 rpm)			
	CO [%vol.]	HC [ppm]	CO2 [%vol.]	λ
E85 average	0,0	11,0	14,6	1,0
Limit	-	-	-	-

Table 7 Exhausts emissions during Type II test (Idle test)

Crankcase Ventilation (Type III test)

Exhaust gases passing by the piston rings may cause environmental pollution. Vehicles with SI-engines are therefore equipped with crankcase ventilation systems.

The crankcase gases are routed to the intake manifold and then combusted in the engine. The crankcase ventilation system is tested by measuring the pressure within the system. The pressure measured in the crankcase may not exceed the atmospheric pressure at different load conditions.

Two out of forty-five vehicles showed crankcase overpressure at different loads. The two vehicles were of the same vehicle type.

Measuring the crankcase pressure is not relevant for vehicles with CI-engines.

Evaporative Emissions (Type IV test)

When the fuel system of a vehicle is exposed to heat, the vapour pressure in the fuel system increase and some of the vapour may escape through joints, seams and through the material itself. If these vapours escape into the environment they may cause considerable pollution. To avoid this, modern vehicles with SI-engine are equipped with systems for retaining such fuel vapours. Measuring the evaporative emissions is due to the diesel fuel's less volatile characteristics not relevant for vehicles with CI-engines.

For the measurement of evaporative emissions, a VT-SHED (Variable Temperature Sealed Housing for Evaporative Determination) is used. The determination of evaporative emissions according to Directive 70/220/EEC, is performed in two separate tests;

- Hot soak loss determination: The test vehicle is placed in the VT-SHED (stable temperature of 20-30ºC) for one hour directly after having finished a NEDC (=warm vehicle) in order to determine the emissions evaporated from the car short after engine stop.

- Diurnal loss determination: the cool (~20ºC) test vehicle is placed in the VT-SHED for 24 hours. The vehicle is exposed to an ambient temperature cycle which simulates the temperature profile of a summer day, and the hydrocarbons released are then measured. In this way, hydrocarbon emissions due to permeation and micro-leaks in the whole fuel-bearing system are considered.

Prior to the tests, a preparation sequence is being performed according to figure 21.

The sum of the two test results represents the total evaporative emission test result of the tested vehicle.

Directive 70/220/EEC and its last amendment, Annex I, paragraph 5.3.4.2. say "When tested in accordance with Annex VI, evaporative emissions shall be less than 2 g/test."

During the In-Service Testing Programme of 2011, measurement of evaporative emissions was carried out on two vehicles per type with SI-engine. Prior to testing where items with possible impact on the test results, such as perfumes, rugs, bottles etc. removed from the car in order to avoid influence on the test results. Vehicles carrying for example a plastic fuel container on board were not tested due to risk for hydrocarbon contamination.

Figure 22 illustrates the Type IV test flow.

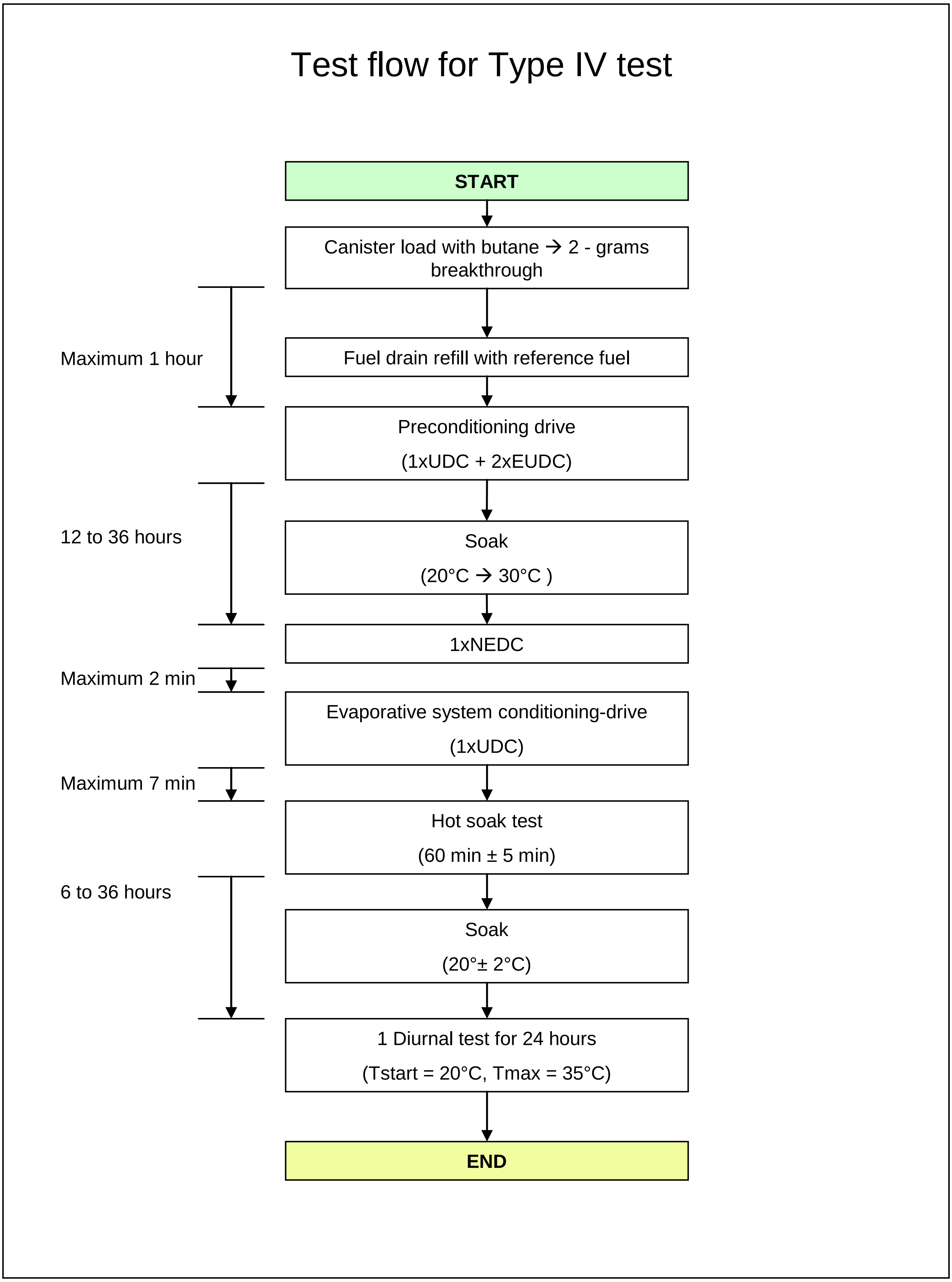

Figure 22 Type IV test procedure

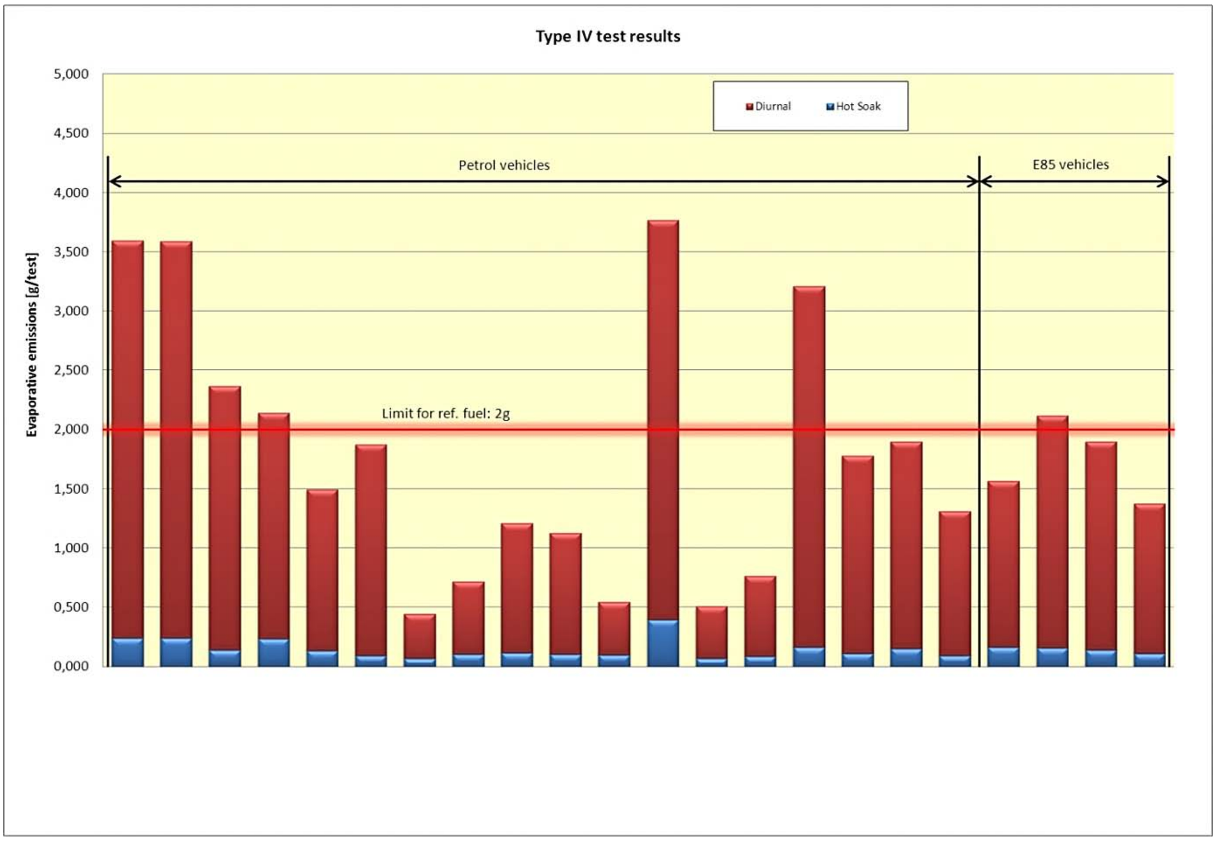

Figure 23 Results from Type IV test

For the 2011 In-Service Testing Programme, petrol and E85 were used as fuel for SI-engine vehicles. In total, 22 measurements were made. The result is summarised in figure 22 and table 8 shows the average of all tested vehicles.

The average result of all tested vehicles was 1,79 g HC/test. Based on the directive, six of the petrol vehicles and one ethanol fuelled vehicle failed to comply with the Euro 4 limits.

Note that vehicle no 15-18 (tested on petrol) are the same as vehicle no 19-22 (tested on ethanol (E85)).

	Evaporative emissions [g HC]		
Vehicle No.	**Hot Soak**	**Diurnal**	**Total**
1	0,24	3,36	3,60
2	0,24	3,35	3,59
3	0,14	2,23	2,37
4	0,24	1,91	2,14
5	0,14	1,36	1,50
6	0,09	1,78	1,87
7	0,07	0,37	0,44
8	0,11	0,61	0,72
9	0,12	1,09	1,21
10	0,10	1,03	1,13
11	0,10	0,44	0,54
12	0,40	3,37	3,77
13	0,07	0,44	0,76
14	0,09	0,68	0,76
15	0,17	3,05	3,21
16	0,11	1,67	1,78
17	0,15	1,74	1,84
18	0,10	1,22	1,31
19	0,17	1,40	1,56
20	0,16	1,96	2,12
21	0,14	1,76	1,90
22	0,11	1,26	1,37
	Average		
	0,15	**1,64**	**1,79**
	Limit		
	—	—	**2,00**

Table 8 Type IV Average evaporative emissions

Figure 23 and 24 shows the difference between vehicles that failed respectively passed the Type IV test.

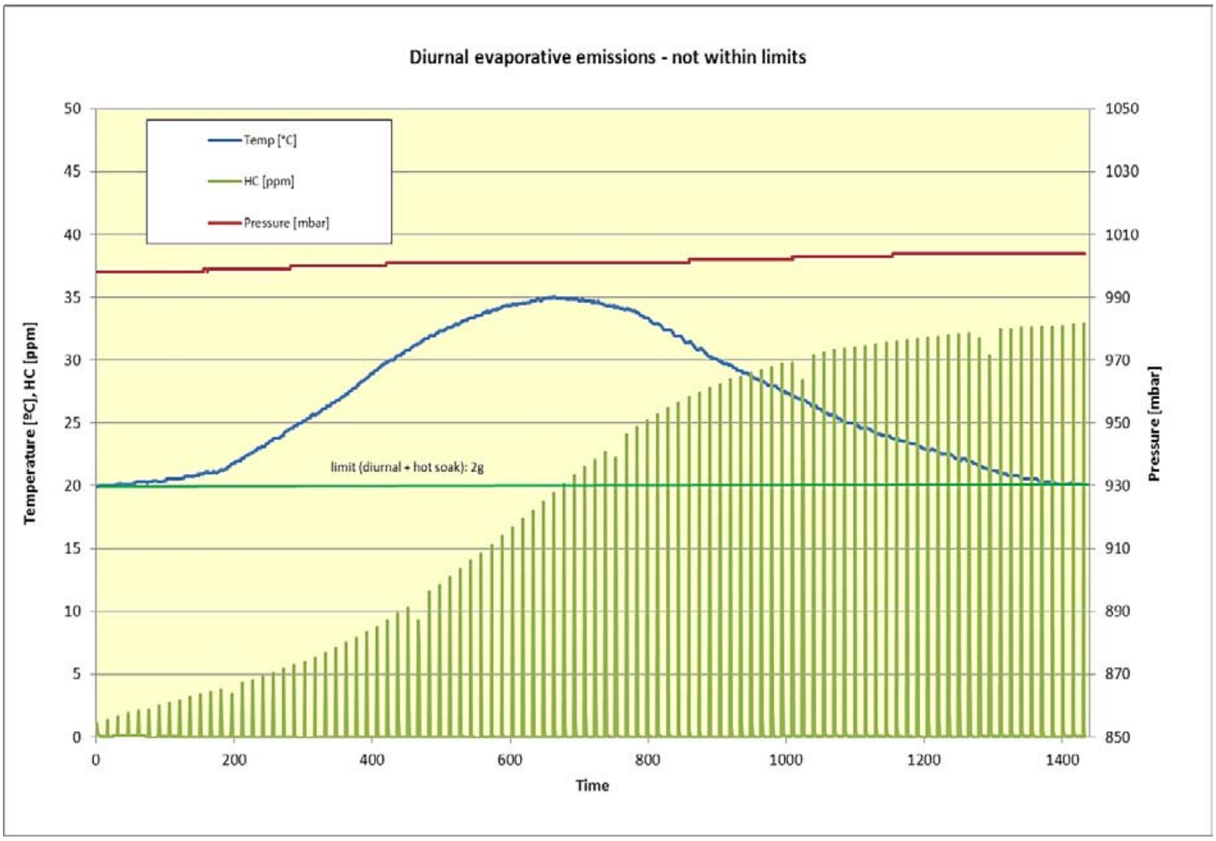

Figure 24 Type IV test - vehicle not within limits

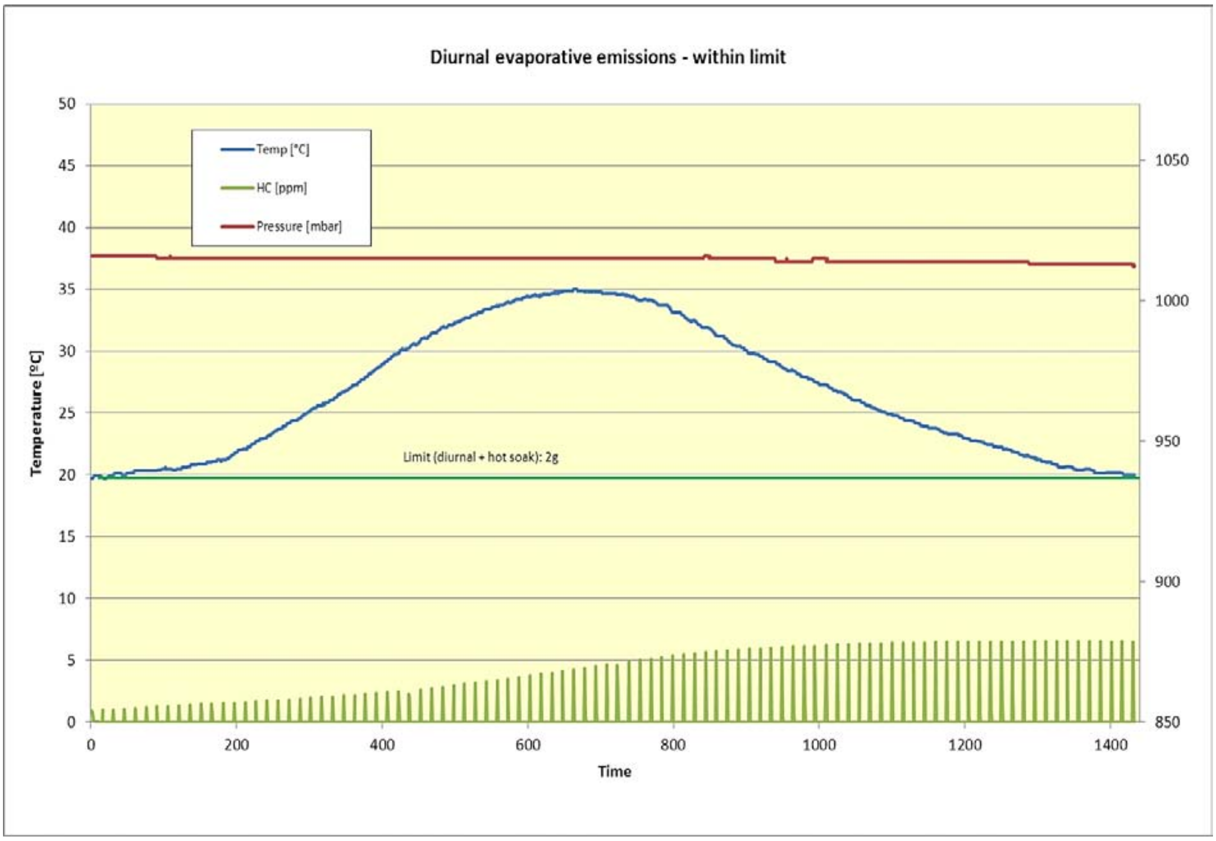

Figure 25 Type IV test – vehicle within limits

Exhaust emissions at low ambient temperatures (Type VI test, - 7°C)

According to Directive 70/220/EEC as amended by 2003/76/EC shall a Type VI emission test be carried out at low ambient temperature (-7 C°). The purpose of the Type VI test is to measure cold start emissions. Emissions of CO and HC are limited by the directive.

In the 2011 In Service Testing Programme two vehicles per family with SI-engine were tested.

Table 9 and figure 26 show a comparison between the Type I and Type VI test for the UDC cycle. Average emissions from E85-fuelled vehicles are also included within table 9 and figure 26.

Vehicles with SI-engine		**Exhaust emissions**			
Test	**Cycle**	**CO [g/km]**	**HC [g/km]**	**NOx [g/km]**	**CO_2 [g/km]**
Type I	UDC Petrol	0,99	0,13	0,048	211
	UDC E85	1,27	0,20	0,061	235
Type VI	UDC Petrol	5,21	0,87	0,136	243
	UDC E75(1)	6,73	1,77	0,186	251
Limit VI	**UDC Petrol**	**15**	**1,8**		

Table 9 Average exhaust emissions during Type VI and Type I of vehicles with SI-engine, tested at – 7°C

(1) In order to facilitate engine start at low temperatures, ethanol fuel sold in winter time (and used for low ambient temperature tests) contains only 75% ethanol compared to 85% in the summer, i.e. E75.

Figure 26 show a comparison between the average exhausts emissions (CO, HC, NO_X and CO_2) from different fuels during Type VI (- 7°C) and Type I test (+24°C).

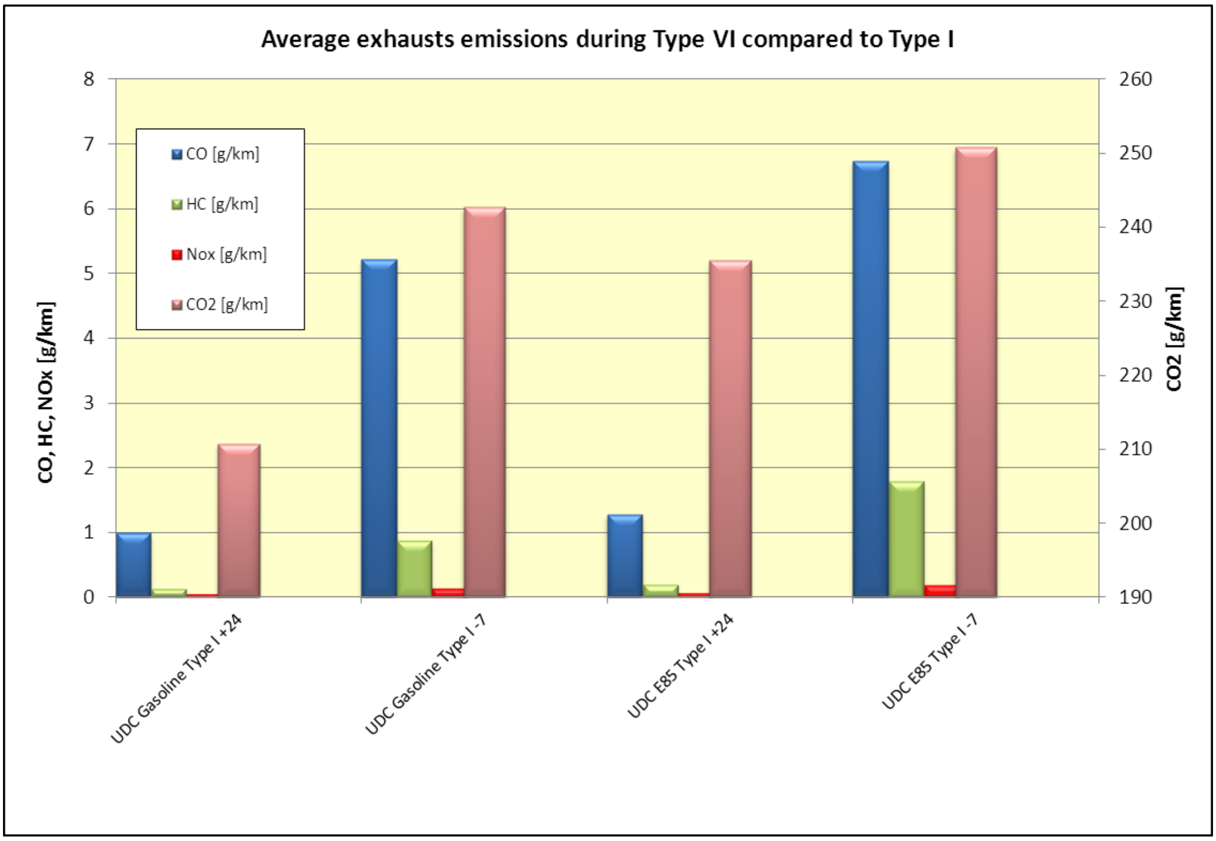

Figure 26 Compilation of average exhausts emissions at low ambient temperatures during Type VI compared to Type I test

In figure 27 the average UDC fuel consumption is shown for the Type I test compared with the Type VI test.

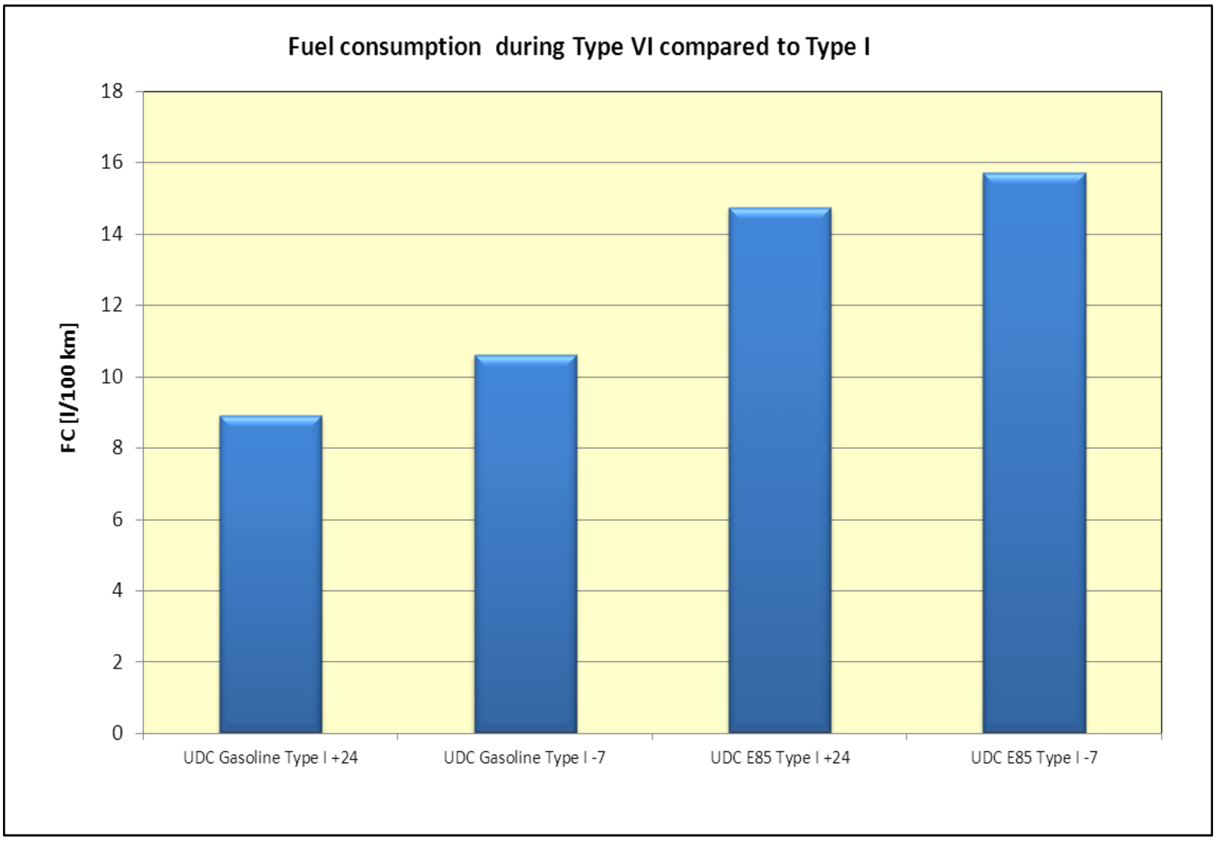

Figure 27 Average fuel consumption at low ambient temperatures during Type VI compared to Type I test

Figure 28 shows the average CO and HC emissions during Type IV (- 7°C) test of SI-engine vehicles driven on petrol and E85. One of the SI-engine vehicles, driven on ethanol, exceeded the Euro 4 emission limit valid for petrol fuelled vehicles.

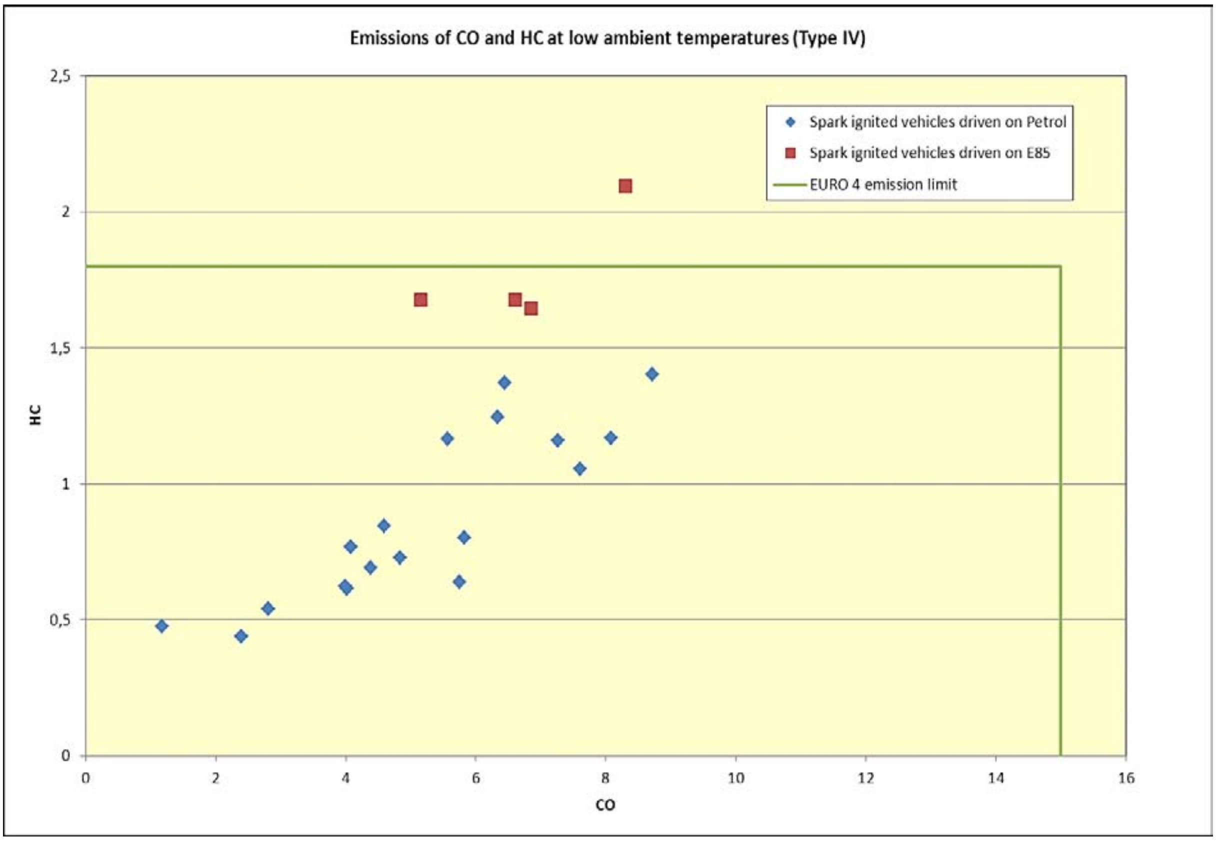

Figure 28 CO and HC emissions at low ambient temperatures (Type IV (- 7°C))

Figure 29 shows the HC emissions during Type I compared with Type VI (- 7°C) test of SI-engine vehicles.

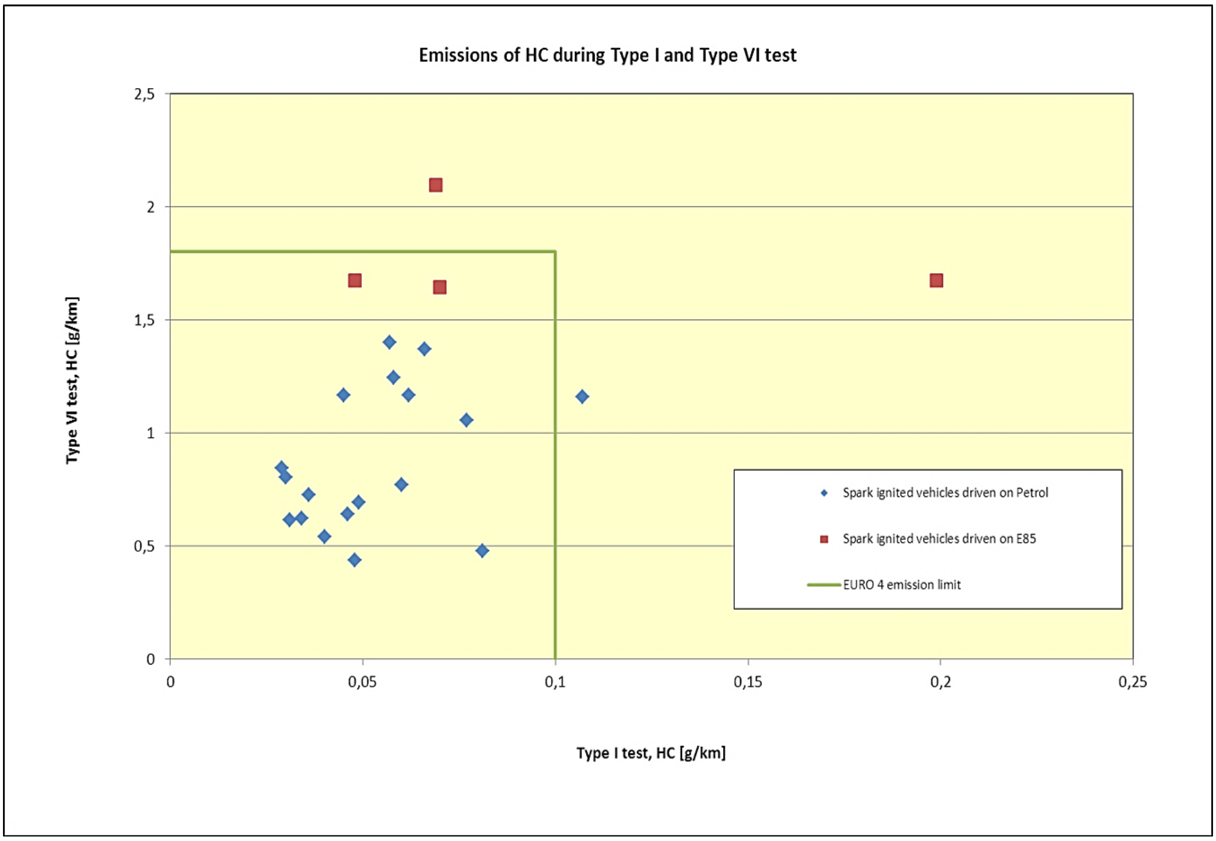

Figure 29 HC emissions during Type I and Type VI test (- 7°C)

Exhaust Emissions during Common Artemis Driving Cycle (CADC)

More detailed information regarding the CADC and some examples and comparisons between a SI-engine and a CI-engine vehicle, regarding CO, HC and NO_X emissions during the different CADC sub cycles can be seen in Appendix 2.

Table 10 show the average emission test results from all different vehicle types who have performed the CADC cycles and also Type I test (NEDC).

PM-PMP = according to the new procedure in the PMP-protocol (EURO 5).
PM2 = according to 70/220/EEC including latest amendments (EURO 4).

	Driving Cycle		CO [g/km]	HC [g/km]	NOx [g/km]	PM-PMP [g/km]	PN [#/km]	PM2 [g/km]
Petrol Euro 4	NEDC	Average	0,426	0,050	0,030	0,0011	1,52E+12	0,0012
		Std.dev.	0,107	0,012	0,014	0,0009	8,37E+11	0,0009
	ARTEMIS Urban Cold	Average	1,754	0,194	0,144	0,0039	5,49E+12	0,0039
		Std.dev.	0,153	0,009	0,016	0,0005	6,26E+11	0,0005
	ARTEMIS Urban	Average	0,286	0,009	0,083	0,0018	3,97E+12	0,0018
		Std.dev.	0,057	0,002	0,013	0,0003	6,40E+11	0,0004
	ARTEMIS Road	Average	0,325	0,005	0,067	0,0016	2,78E+12	0,0013
		Std.dev.	0,089	0,001	0,010	0,0002	4,02E+11	0,0002
	ARTEMIS Motorway	Average	2,072	0,015	0,088	0,0030	4,68E+12	0,0033
		Std.dev.	0,326	0,004	0,044	0,0006	9,98E+11	0,0006
Diesel Euro 4	NEDC	Average	0,247	0,024	0,238	0,0048	8,99E+12	0,0049
		Std.dev.	0,088	0,010	0,058	0,0020	1,20E+12	0,0023
	ARTEMIS Urban Cold	Average	0,721	0,028	0,610	0,0300	1,90E+13	0,0343
		Std.dev.	0,111	0,010	0,055	0,0041	1,25E+12	0,0341
	ARTEMIS Urban	Average	0,213	0,001	0,731	0,0222	2,29E+13	0,0244
		Std.dev.	0,028	0,002	0,043	0,0026	4,42E+11	0,0033
	ARTEMIS Road	Average	0,067	0,003	0,431	0,0127	1,71E+13	0,0151
		Std.dev.	0,019	0,001	0,008	0,0007	1,88E+11	0,0010
	ARTEMIS Motorway	Average	0,014	0,000	0,748	0,0099	1,50E+13	0,0109
		Std.dev.	0,002	0,000	0,063	0,0005	5,35E+11	0,0006
E85 Euro 4	NEDC	Average	0,535	0,078	0,056	0,0005	6,93E+11	0,0006
		Std.dev.	0,090	0,039	0,033	0,0003	4,56E+11	0,0004
	ARTEMIS Urban Cold	Average	2,365	0,211	0,083	0,0010	2,67E+12	0,0012
		Std.dev.	0,221	0,006	0,011	0,0001	2,59E+11	0,0001
	ARTEMIS Urban	Average	0,470	0,019	0,065	0,0011	1,75E+12	0,0012
		Std.dev.	0,043	0,002	0,007	0,0001	5,65E+10	0,0001
	ARTEMIS Road	Average	0,289	0,007	0,071	0,0010	1,83E+12	0,0010
		Std.dev.	0,025	0,001	0,013	0,0001	1,32E+11	0,0000
	ARTEMIS Motorway	Average	0,956	0,019	0,136	0,0016	2,33E+12	0,0019
		Std.dev.	0,116	0,003	0,027	0,0001	3,95E+11	0,0001

Table 10 Average exhausts emissions from different vehicle types during Type I test (NEDC) and Common Artemis Driving Cycle

Figures 30 to 34 shows the average CO, HC, NO_X, PM emissions and FC during CADC for all tested vehicles compared to the average NEDC results.

For vehicles with SI-engine most of the CO is emitted during the UDC-phase (1st part of the NEDC-cycle) and in the ARTEMIS Urban Cold cycle (see fig 30).

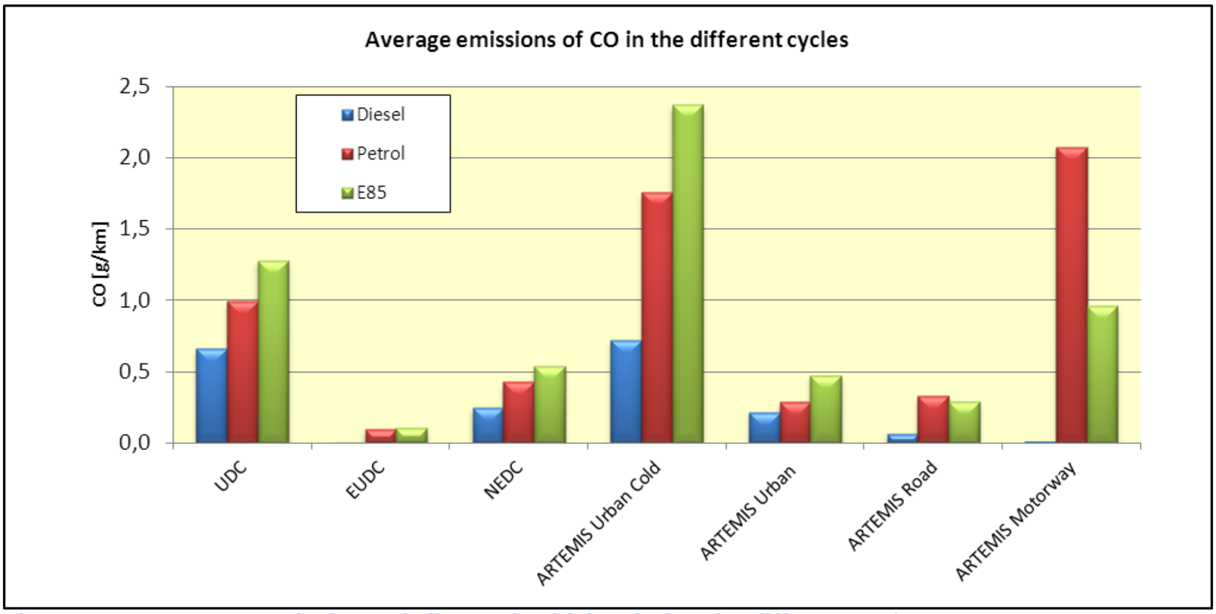

Figure 30 Average CO emissions of all tested vehicles during the different cycles

Figure 31 show the HC emissions from the different cycles.

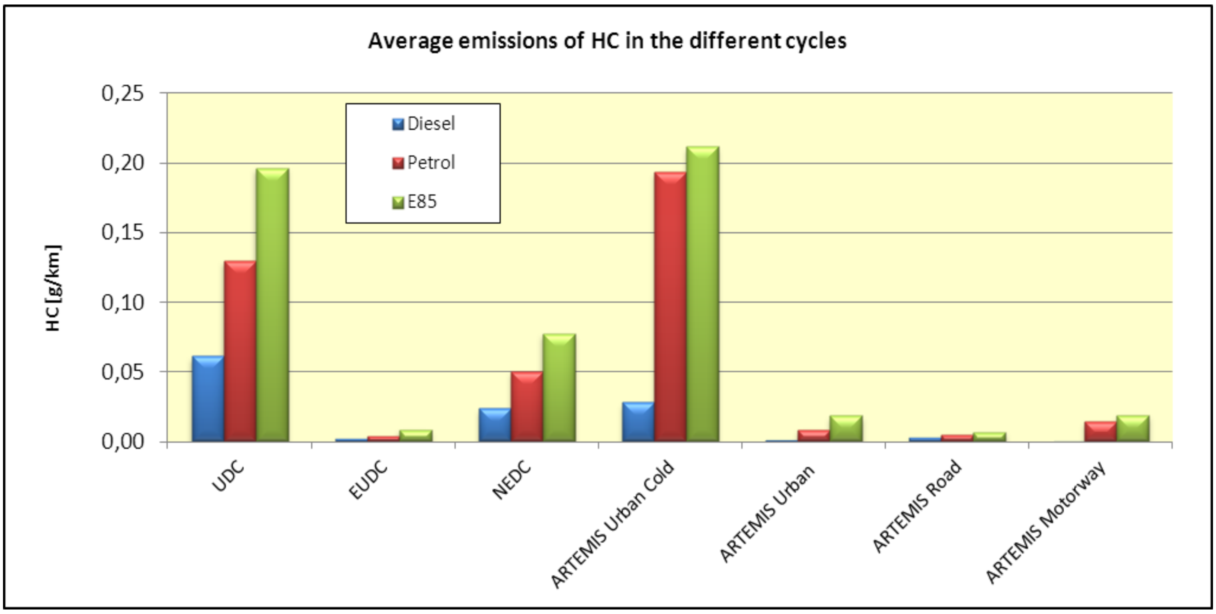

Figure 31 Average HC emissions of all tested vehicles during the different cycles

In figure 32 the CI-engine vehicles shows significant higher NO_X emissions than the SI-engine vehicles. Euro 4 legislation allows three times more NO_X emissions for CI-engine vehicles compared SI-engine vehicles.

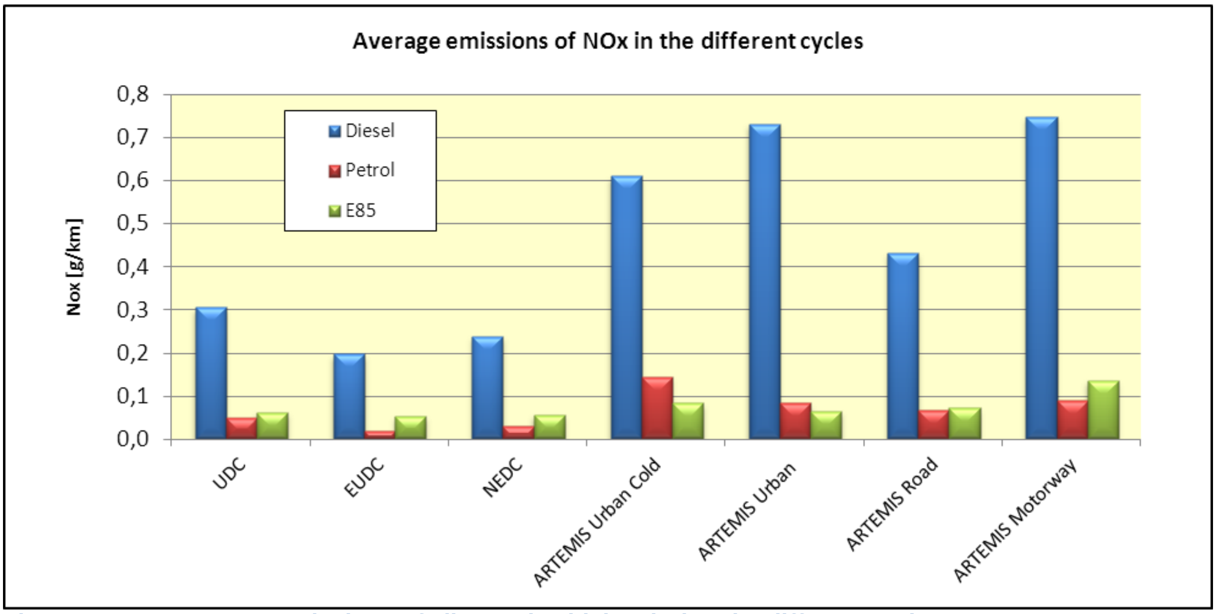

Figure 32 Average NOX emissions of all tested vehicles during the different cycles

Figure 33 shows the average fuel consumption for all tested vehicles. When looking at the different vehicle types it is difficult to draw conclusions due to the different weight classes and also the different energy content of the different fuels.

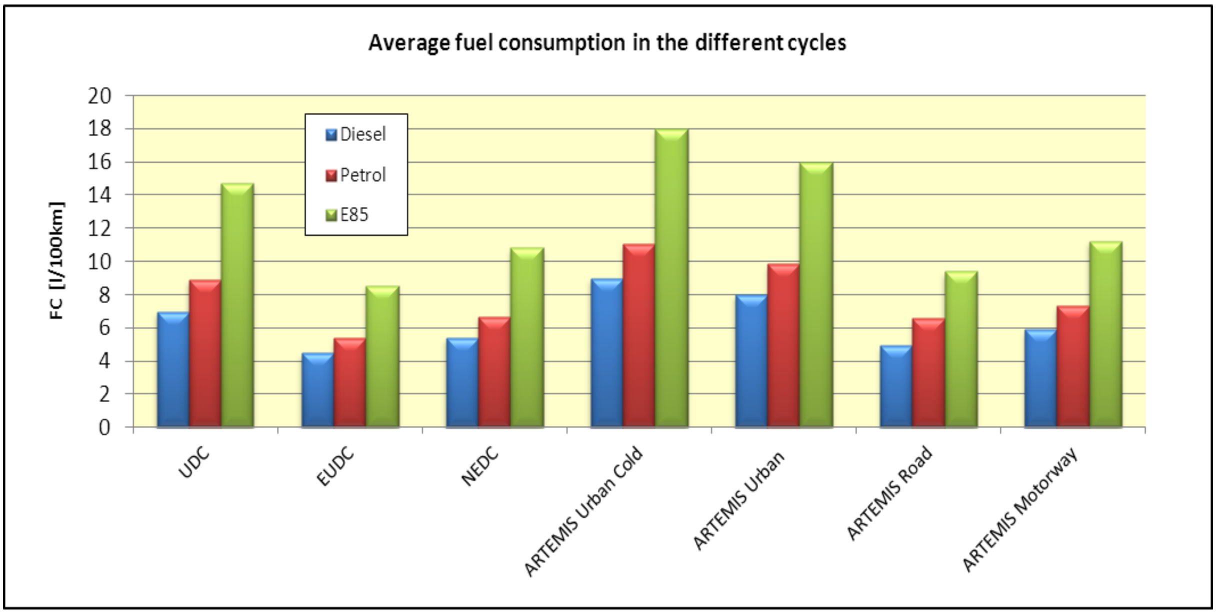

Figure 33 Average FC of all tested vehicles during the different cycles

Figure 34 Note that the PM level during Type I test tends to be higher for SI-engine vehicles compared to the CI-engine vehicles with DPF.

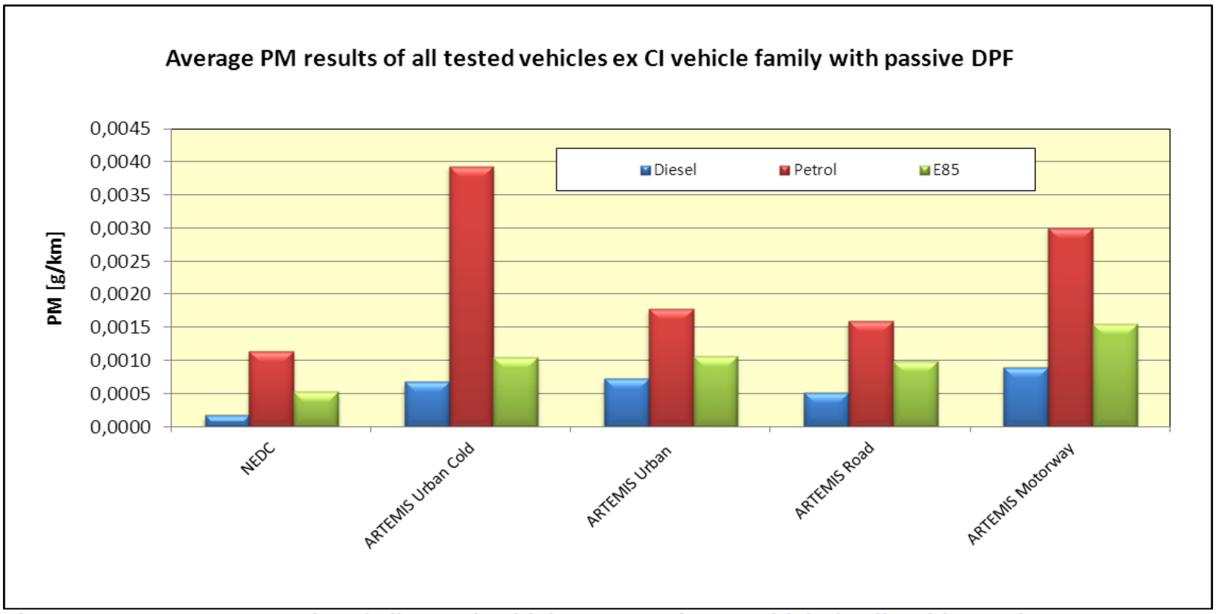

Figure 34 Average PM results of all tested vehicles except the CI vehicle family with passive DPF

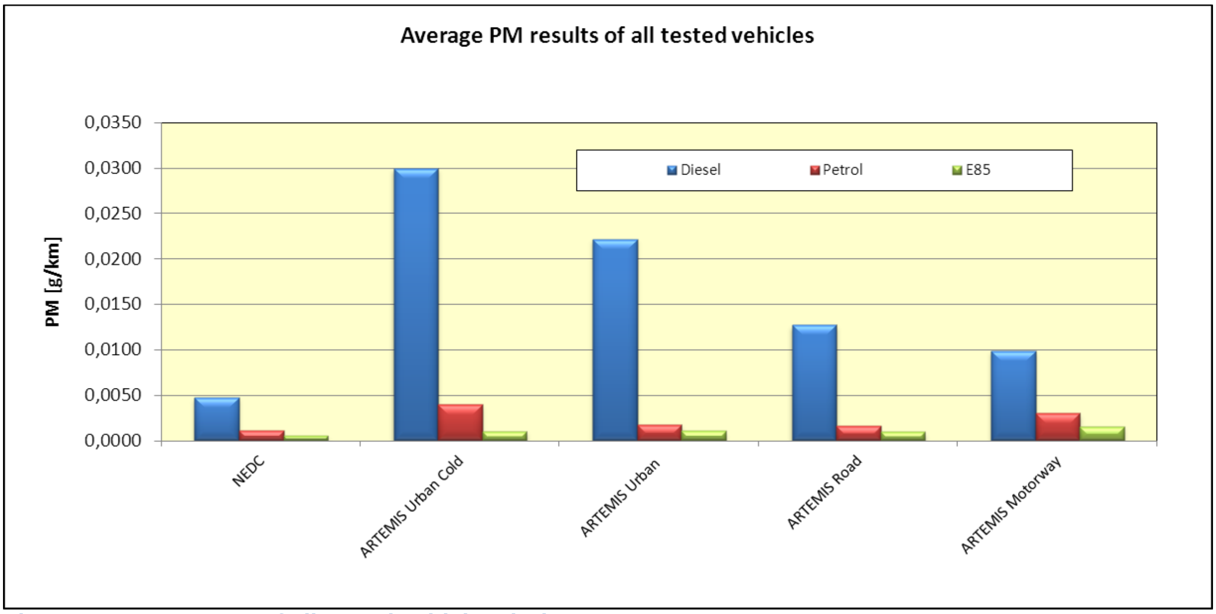

Figure 35 Average PM of all tested vehicles during CADC

Particulate measurement according to PMP - protocol

Particle Measurement Programme (PMP) was initiated by a Working Group of the UN-ECE.

The objective of the PMP programme was to develop new particle measurement technologies in order to complement or replace the existing filter-based PM measurement method, with special consideration given to measuring particle emissions at very low levels. In the PMP programme, it was decided to measure only solid particles, since these are anticipated to have the most adverse health effects.

For all the vehicles tested during the 2011 programme, the particulate measurement has been conducted according to 70/220/EEC including latest amendments (EURO 4) as well as with the new procedure in the PMP-protocol, which was implemented in the EU from September 1st, 2011 and is a part of UNECE reg.83.

The sampling system and analysing equipment are based on full flow dilution systems, i.e. the total exhaust is diluted using the CVS (Constant Volume Sampling) concept. The sampling system fulfils the requirements of the Directive 70/220/EEC including latest amendments.

Differences between PM and PMP can be seen in table 11.

PM according to 70/220/EEC including latest amendments	PM according to PMP protocol
HEPA Filter with 99.97% efficiency for dilution air	HEPA Filter with 99.97% efficiency for dilution air
Probe with china hat	Probe without china hat combined with cyclone
Temperature at filter pads max 52°C	Temperature at filter pads max 52°C
TA60 filterpads with 96,4% efficiency: one filter + backup filter per phase	TX40 filterpads with 99,9% efficiency: one filter without backup filter for both phases

Table 11 PM determination according to 70/220/EEC including latest amendments and to PMP protocol

Within the PMP protocol there are also requirements for particle number measurement.

The Euro 5b limit for Particulate Matter (PM-PMP) is 4,5 mg/km and the Particle Number (PN) limit is $6{,}00*10^{11}$. The regulation has been effective from September 1st, 2011 for the type-approval on new types of vehicles and will be effective from January 1st, 2013 for all new vehicles sold, registered or put into service in the European Community.

Table 12 shows the average PM and PN for all tested vehicles during the programme.

PN and PM-PMP = according to the new procedure in the PMP-protocol implemented in the EU from September 1st, 2011 and part of the UNECE reg.83 (EURO 5).

PM = according to 70/220/EEC including latest amendments (EURO 4).

		NEDC	ARTEMIS Urban Cold	ARTEMIS Urban	ARTEMIS Road	ARTEMIS Motorway
Petrol Euro 4	PM - PMP [mg/km]	1,1	3,9	1,8	1,6	3,0
	PM [mg/km]	1,2	3,9	1,8	1,3	3,3
	PN [#/km]	1,5E+12	5,5E+12	4,0E+12	2,8E+12	4,7E+12
Diesel Euro 4	PM - PMP [mg/km]	4,8	30,0	22,2	12,7	9,9
	PM [mg/km]	4,9	34,3	24,4	15,1	10,9
	PN [#/km]	9,0E+12	1,9E+13	2,3E+13	1,7E+13	1,5E+13
Euro 4 E85	PM - PMP [mg/km]	0,5	1,0	1,1	1,0	1,6
	PM [mg/km]	0,6	1,2	1,2	1,0	1,9
	PN [#/km]	6,9E+11	2,7E+12	1,7E+12	1,8E+12	2,3E+12

Table 12 Average particle mass and particle number.

Figure 36 shows the difference, for all tested vehicles types (except the CI-engine vehicle family equipped with a passive DPF), between Particulate Matter measured with PM-PMP (EURO 5) compared to Particulate Matter measured with PM (EURO 4) during Type 1 test (NEDC).

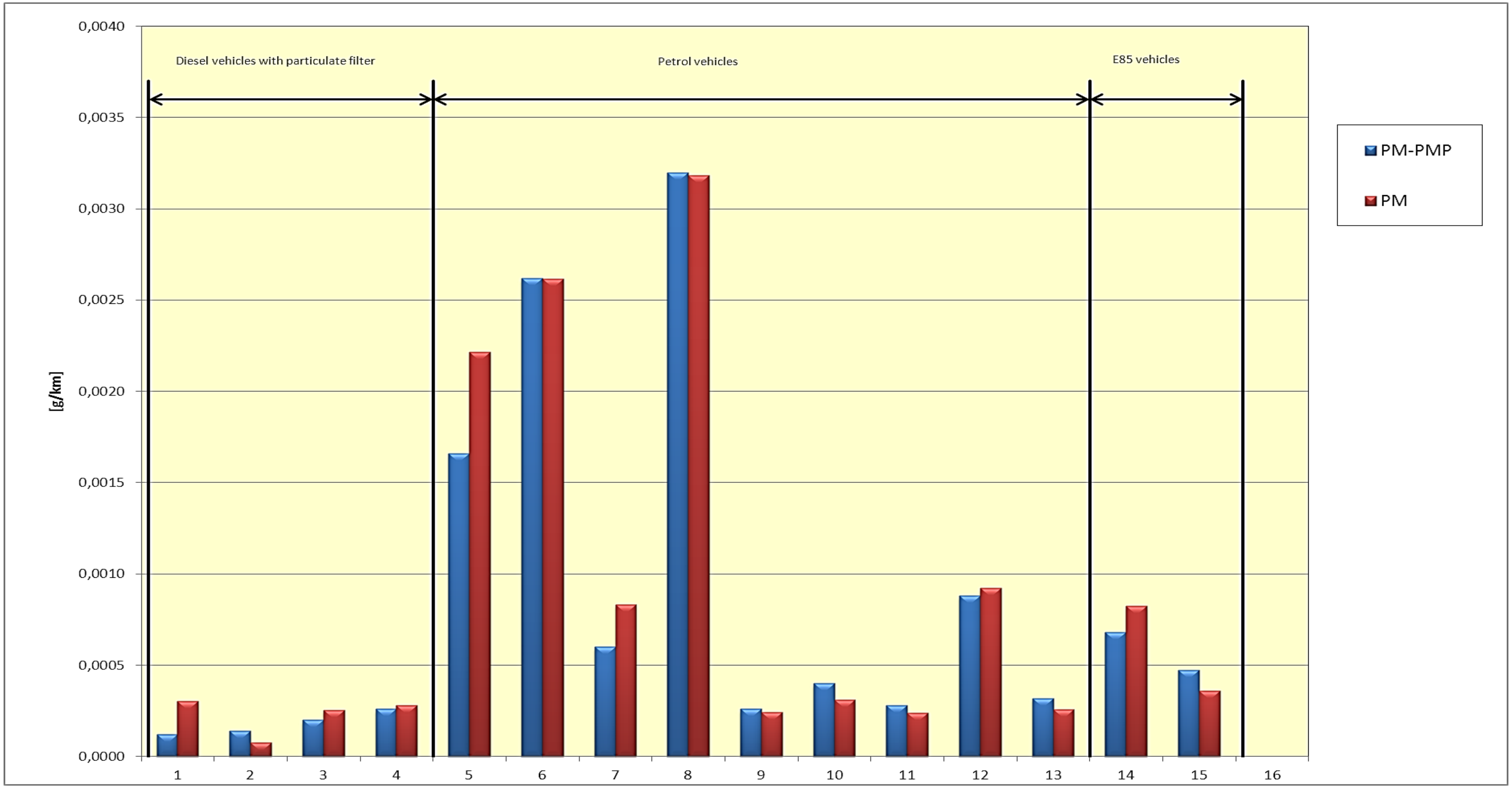

Figure 36 Difference between Particulate Matter (PM-PMP vs. PM) for all tested vehicles types during Type I test (NEDC)

Figure 37 shows the average PN# for each tested vehicle family during Type I test.

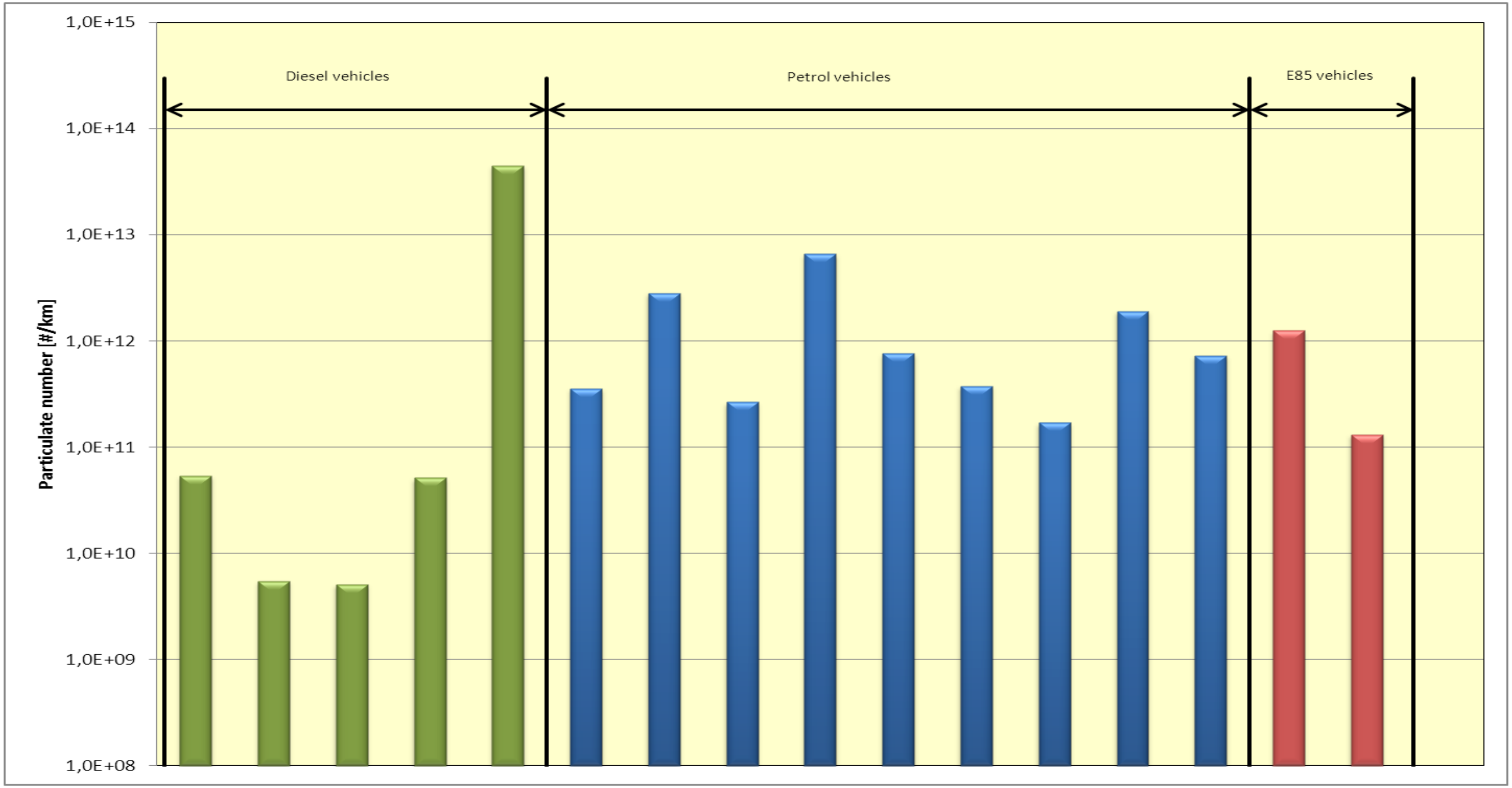

Figure 37 Particle number results for all tested vehicles types during Type I test (NEDC)

Figure 38 and figure 39 show the difference in PN# between a SI-engine vehicle and a CI-engine vehicle, running the Type I test. Note: different scales.

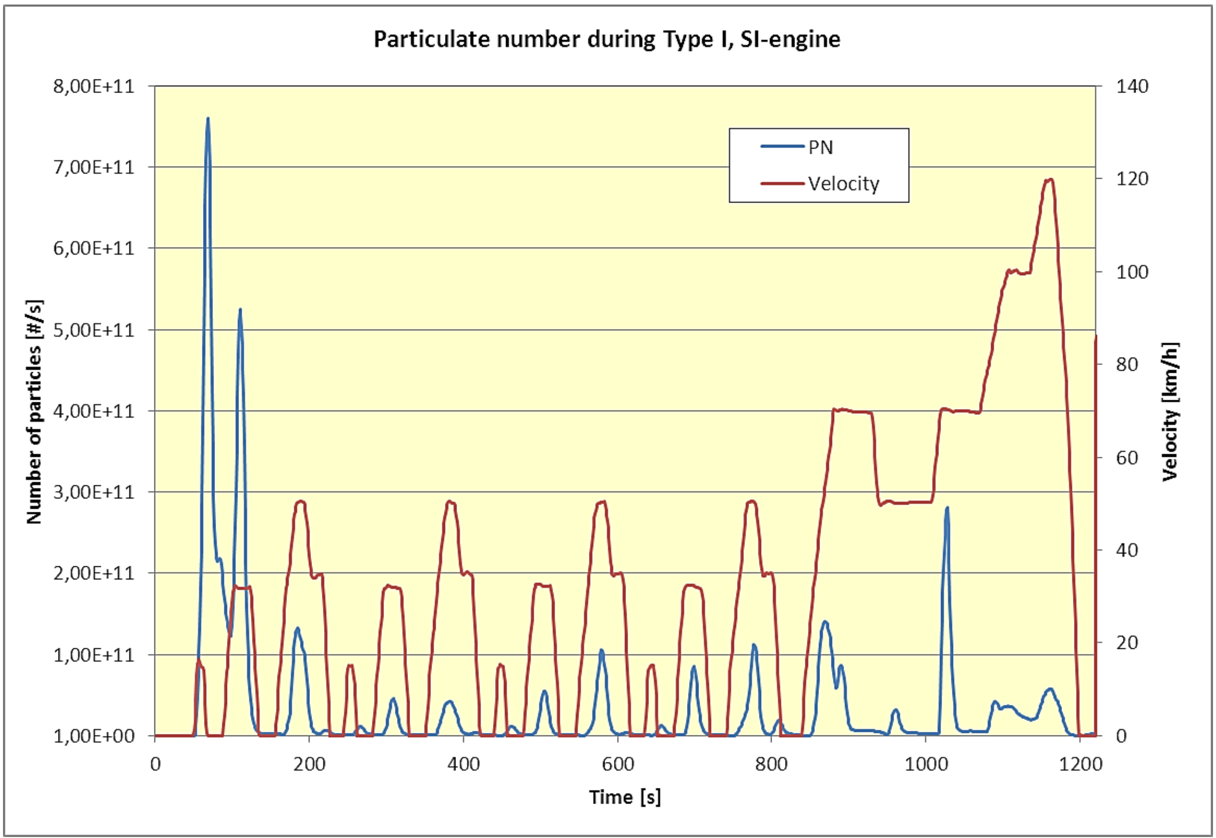

Figure 38 Particulate emissions of a Euro 4 vehicle with SI-engine during Type I test (NEDC)

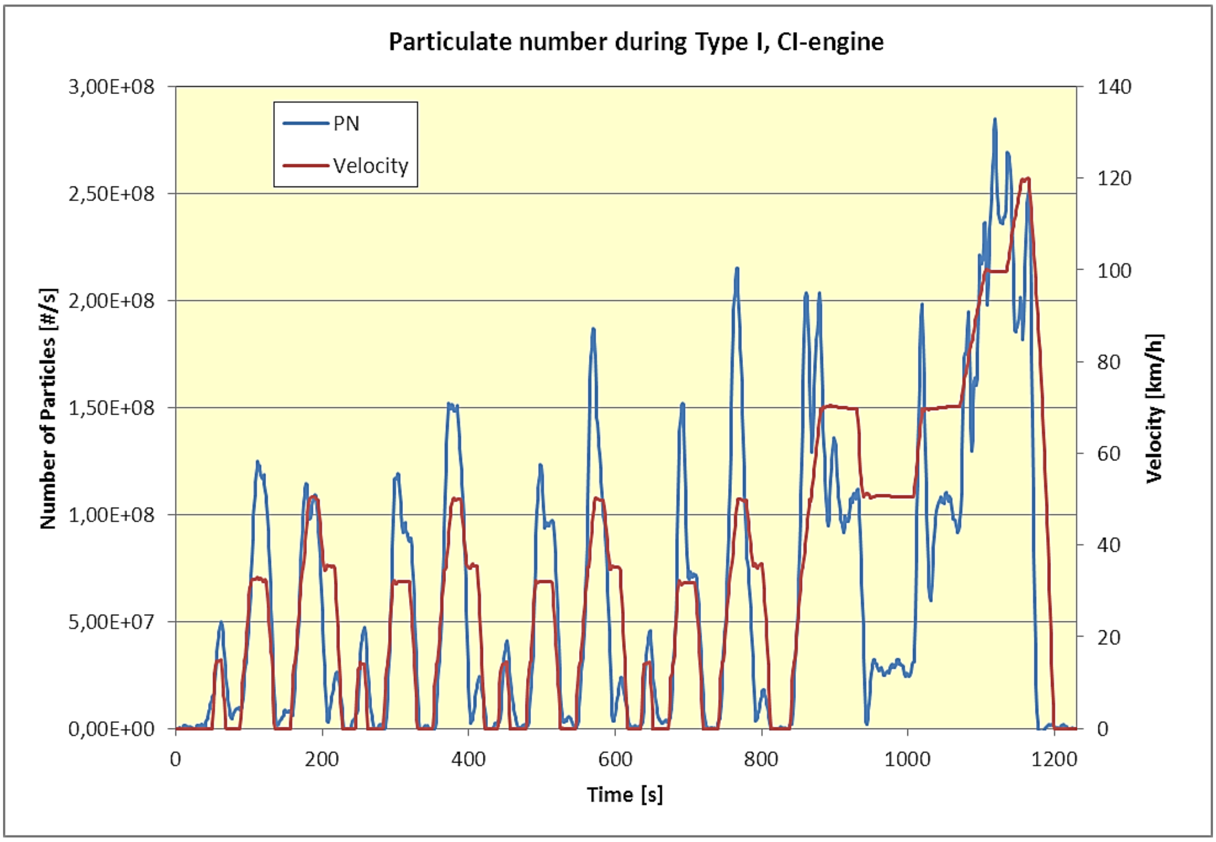

Figure 39 Particulate emissions of a Euro 4 M1 vehicle with CI-engine and DPF during Type I test (NEDC)

OBD System

Directive 70/220/EEC as amended by 2003/76/EC requires that all vehicles must be equipped with an OBD system so designed, constructed and installed in a vehicle as to enable it to identify types of deterioration or malfunction over the entire life of the vehicle.

In the 2011 In-Service Testing Programme different manipulated failures such as electrical disconnections of oxygen sensor, fuel injectors, mass air flow sensor, pressure sensors etc. were made. In total, one simulated failure was not detected.

References

- Directive 70/220/EEC including all amendments
- Directive 80/1268/EEC including all amendments
- Regulation 715/2007/ECC of the European Parliament and of the Council of 20 June 2007 on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information
- Particle Measurement Programme (PMP), Light-duty Inter-laboratory Correlation Exercise (ILCE_LD) Final Report

Appendix 1

Fuel specifications

According to Directive 70/220/EEC as amended by 2003/76/EC reference fuels shall be used when performing the Type 1 and Type VI tests.

The following tables show the content of the reference fuels that have been used during testing.

Petrol fuel composition:

PETROL FUEL:
The emissions are calculated according to directive 70/220/EEC, as last amended by directive 2003/76/EC. This means that the hydrocarbons are calculated as grams $CH_{1,85}$ per km. The fuel consumption is according to directive 80/1268/EEC, and later amendments, and thus based on carbon balance method. The carbon balance uses the fixed carbon weight fraction 0.866 for both the carbon content in the hydrocarbon emissions as well for the fuel.
The fuel density used in the calculation is according to certificate for the reference fuel, 0.753 kg/dm^3.
For the energy comparison the lower heating value 42.75 MJ/kg is used for the Petrol fuel.

CEC Legislative Petrol Fuel RF

Property	Units	Minimum	Maximum	Test Method
Research octane number (RON)		95	-	EN ISO 5164
Motor octane number (MON)		85	-	EN ISO 5163
Lead	mg/l	-	5	EN 237
Density @ 15°C	kg/m^3	740,0	754,0	EN ISO 12185
Sulphur content	mg/kg	-	10	ASTM D5453
Phosphorus content	mg/l	-	1,3	ASTM D3231
Oxidation stability	minutes	480	-	EN ISO 7536
Existent gum content (solvent washed)	mg/100ml	-	4	EN ISO 6246
Copper strip corrosion (3 h @ 50°C)	rating	-	-	EN ISO 2160
Olefins	vol %	-	10,0	ASTM D1319
Aromatics	vol %	29,0	35,0	ASTM D 1319
Benzene content	vol %	-	1,00	EN 12177
Oxygen content	mass %	-	0,1	EN 1601
Oxygenates content	vol %	-	-	EN 1601
Vapour Pressure	kPa	56,0	60,0	EN 13016-1 reported as DVPE
Distillation curve				EN ISO 3405
IBP	°C	-	-	
Dist. 10% v/v	°C	-	-	
Dist. 50% v/v	°C	-	-	
Dist. 90% v/v	°C	-	-	
E 70	vol %	24,0	40,0	
E 100	vol %	50,0	57,0	
E 150	vol %	83,0	87,0	
FBP	°C (max)	190,0	210,0	
Dist. residue	vol %	-	2,0	
Carbon	% wt	-	-	ASTM D3343
Hydrogen	% wt	-	-	ASTM D3343
C:H ratio (C=1)	-	-	-	ASTM D3343
Net Heating Value	MJ/kg	-	-	ASTM D3338
Net Heating Value	Btu/lb	-	-	ASTM D3338

E10-fuel used in evaporative emission test

Property	Units	EN 228		Test Method
Research octane number (RON)		≥ 95		EN ISO 5164:2005
Motor octane number (MON)		≥ 85		EN ISO 5163:2005
Lead	mg/l	≤ 5		EN 237:2004
Density @ 15°C	kg/m^3	720-775		EN ISO 12185 T1:99
Sulphur content	mg/kg	≤ 10		EN ISO 20884:2004
Oxidation stability	minutes	≥ 360		EN ISO 7536:1996
Existent gum content (solvent washed)	mg/100ml	≤ 5		EN ISO 6246:1998
Copper strip corrosion (3 h @ 50°C)	rating	class 1		EN ISO 2160:1998
Appearance		Bright and Clear		Visual inspection
Olefins	vol %	≤ 18,0		EN ISO 22854:2008
Aromatics	vol %	≤ 35,0		SS 15 51 20:1996
Benzene content	vol %	≤ 1,0		EN 238:1996/A1:04
Oxygen content	mass %	≤ 3,7		EN ISO 22854:2008
Oxygenates content -methanol -ethanol -iso-propyl alcohol -iso-butyl alcohol -tert-butyl alcohol -ethers (5 or more C-atoms) -other oxygenates	vol %	 ≤ 3 ≤ 10 ≤ 12 ≤ 15 ≤ 15 ≤ 22 ≤ 15		EN ISO 22854:2008
Vapour Pressure Summer (Sweden) Winter (Sweden)	kPa	 45 - 70 65 - 95		EN 13016-1:2007 reported as DVPE
Distillation curve		Summer	Winter	EN ISO 3405:2000
% evaporated at 70°C, E70	°C	20 - 48	22 - 50	
% evaporated at 100°C, E100	°C	46 - 71		
% evaporated at 150°C, E150	°C	≥ 75,0		
IBP	°C	-		
Temp. at 10% V/V evap.	°C	-		
Temp. at 50% V/V evap.	°C	-		
Temp. at 90% V/V evap.	°C	-		
FBP	°C	210		

E85/75[1] fuel composition:

ALCOHOL FUEL E85:
Since the directive 70/220/EEC does not describe how to handle emission and fuel consumption measurements for alcohol fuels, AVL MTC have chosen to handle it the following way (please note that the tested vehicles are Euro 4 spec.). The emissions are calculated according to directive 70/220/EEC, as last amended by directive 2003/76/EC, with the following exception: The "Fs" (the denominator in the formula for DF) is changed from 13.4 to 12.5 due to the change in stoichiometry using E85 (an influence that though is negligible in this case). The hydrocarbons are here also calculated as grams $CH_{1,85}$ per km, even if the composition of the hydrocarbon emissions using E85 fuel most likely will differ from the ones emitted by petrol fuel.

The FID instrument used for the HC analysis is still calibrated using propane gas and the response factor is set to 1 (same as for petrol fuel).

The same formula is used to calculate KH for the NO_X correction as in the petrol fuel case. The carbon balance is used to calculate the fuel consumption for the alcohol fuel as well. The carbon balance uses the fixed carbon weight fraction 0.866 for the carbon content in the hydrocarbon emissions as a consequence of the assumed hydrocarbon composition. For the fuel, the carbon weight fraction 0.564 is used. The fuel density used in the calculation is calculated according to composition for the E85 fuel used, that is 0.782 kg/dm³.

[1]In order to facilitate engine start at low temperatures, ethanol fuel sold in winter time contains only 75% ethanol compared to 85% in the summer, i.e. E75.

Summer and winter E85 (E75) used for in-use testing 2011:

Property	Units	SEKAB Summer E85	SEKAB Winter E85 (E75)	Minimum	Maximum	Test Method
Research octane number* (RON)		Not analyzed	Not analyzed	95	-	EN ISO 5164
Motor octane number* (MON)		Not analyzed	Not analyzed	85	-	EN ISO 5163
Sulphur content	mg/kg	<10	<10	-	10	EN ISO 20846 EN ISO 20884
Oxidation stability*	minutes	Not analyzed	Not analyzed	360	-	EN ISO 7536
Existent gum content* (solvent washed)	mg/100ml	Not analyzed	Not analyzed	-	5	EN ISO 6246
Ethanol	% (v/v)	85	77	75 (summer) 70 (winter)	86	EN 1601 EN 13132
Higher alcohols (C3 – C8)	% (v/v)	0,2	0,2	-	2,0	
Methanol	% (v/v)	0,4	0,4	-	1,0	
Ethers (5 or more C)	% (v/v)	1,3	2,1	-	5,2	
Phosphorus content	mg/l	Not analyzed	Not analyzed	Not detectable		ASTM D3231
Water content	% (v/v)	0,13	0,05	-	0,3	ASTM E 1064
Inorganic chloride content	mg/l	< 0,1	< 0,1	-	1	ISO 6227
pHe		9	6,7	6,5	9,0	ASTM D 6423
Copper strip corrosion* (3 h @ 50°C)	rating	Not analyzed	Not analyzed	-	Class 1	EN ISO 2160
Acidity, (as acetic acid)	% (m/m)	0,002	0,002	-	0,005	ASTM D1613
Vapour Pressure	kPa	41,2	52,2	35 (summer) 50 (winter)	70 (summer) 95 (winter)	EN 13016-1 reported as DVPE
FBP	°C (max)	80	150	-	205,0	EN ISO 3405 ASTM D3710
Dist. Residue	vol %	1,0	0,8	-	2,0	
Density @ 20°C	kg/m^3	782,0	776,2	-	-	EN ISO 12185

*) Solvent washed gum, Octane number, oxidation stability and copper strip corrosion not analyzed but guaranteed by supplier to be within specification.

Diesel fuel composition:

CEC Legislative Diesel Fuel RF

Property	Units	Minimum	Maximum	Test Method
Cetane number (CFR)		52	54	EN ISO 5165
Density @ 15°C	kg/m^3	833	837	EN ISO 3675 EN ISO 12185
Distillation curve				EN ISO 3405
IBP	vol %	-	-	EN ISO 3405
Dist. 10%	vol %	-	-	EN ISO 3405
Dist 50%	vol %	245,0	-	EN ISO 3405
Dist 90%	vol %	-	-	EN ISO 3405
Dist 95%	vol %	345,0	350,0	EN ISO 3405
FBP	°C	-	370,0	EN ISO 3405
Flash Point	°C	55	-	EN ISO 2719
CFPP	°C	-	- 5	EN 116
Cloud Point	°C	-	-	ISO 3015
Viscosity @ 40°C	cSt	2,300	3,300	EN ISO 3104
Aromatics, total	mass %	-	-	IP 391
Aromatics, mono	mass %	-	-	IP 391
Aromatics, Di	mass %	-	-	IP 391
Aromatics, Tri+	mass %	-	-	IP 391
Aromatics, Poly (2+)	mass %	3,0	6,0	IP 391
Suphur	mg/kg	-	10,0	EN ISO 6246
Copper strip corrosion (3 h @ 50°C)	rating	-	Max. 1	EN ISO 2160
Carbon Residue	mass %	-	0,20	EN ISO 10370
Ash Content	mass %	-	0,010	EN 13132 EN 14517
Water	mass %	-	0,0200	EN ISO 12937
Strong Acid Number (KOH/g)	mg	-	0,02	ASTM D974
Oxidation stability	mg/ml	-	0,025	EN ISO 7536
Carbon	mass %	-	-	ASTM D3343
Hydrogen	mass %	-	-	ASTM D3343
C:H ratio (H=1)	-	-	-	ASTM D3343
H:C ratio (C=1)	-	-	-	ASTM D3343
Net Heating Value	MJ/kg	-	-	ASTM D3338
Net Heating Value	Btu/lb	-	-	ASTM D3338
HFRR	µm	-	400	EN ISO 12156-1
FAME	vol %	-	Non added	Local

Appendix 2

CADC/ARTEMIS driving cycles

Comparison between CI and SI-engines

The following figures on page 58 to 70 shows the comparison between a SI- and a CI-engine vehicle regarding CO, HC and NO_X emissions during the different CADC sub cycles

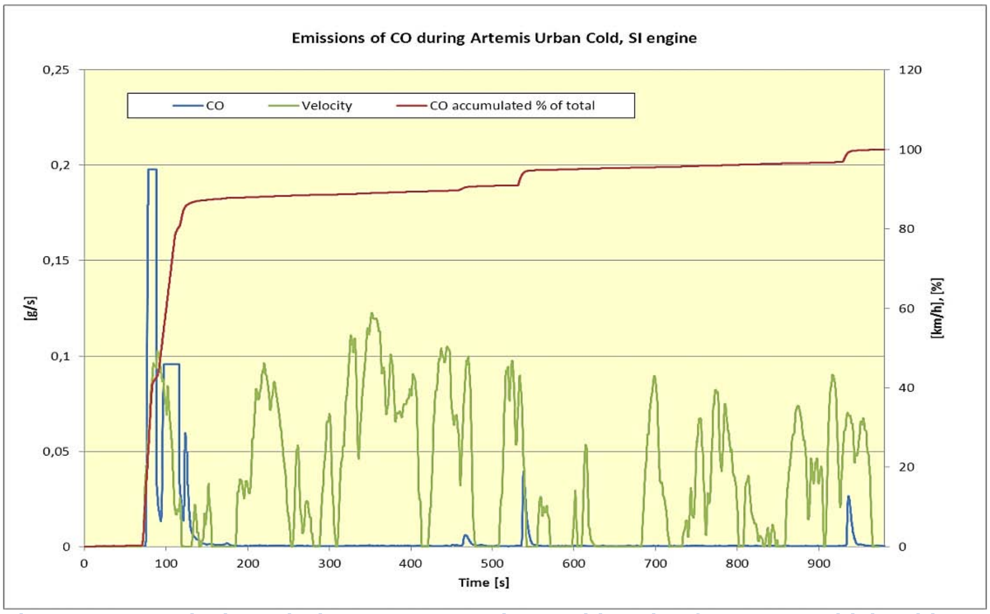

Figure 1: CO emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

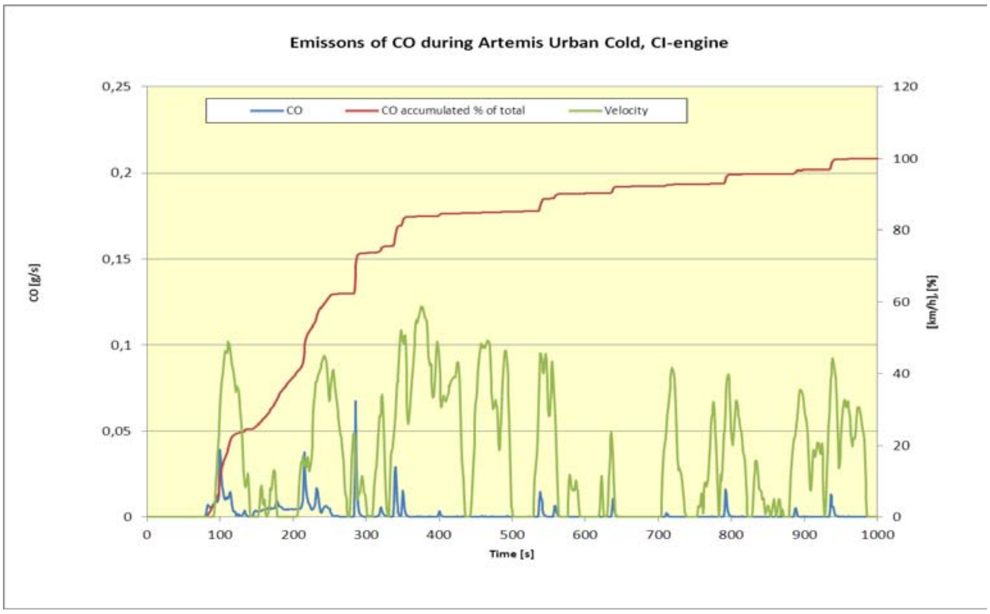

Figure 2: CO emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

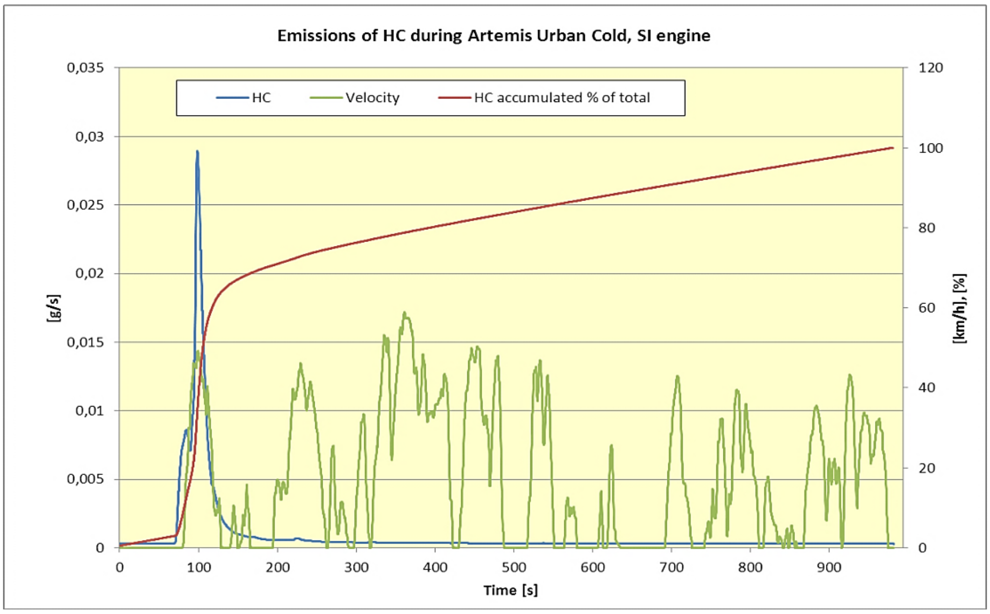

Figure 3: HC emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

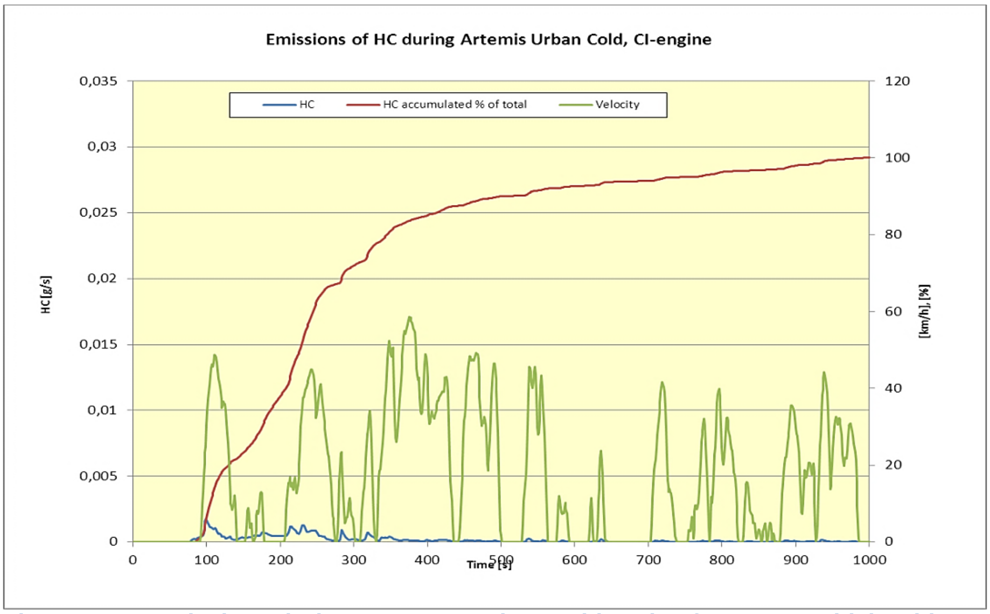

Figure 4: HC emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

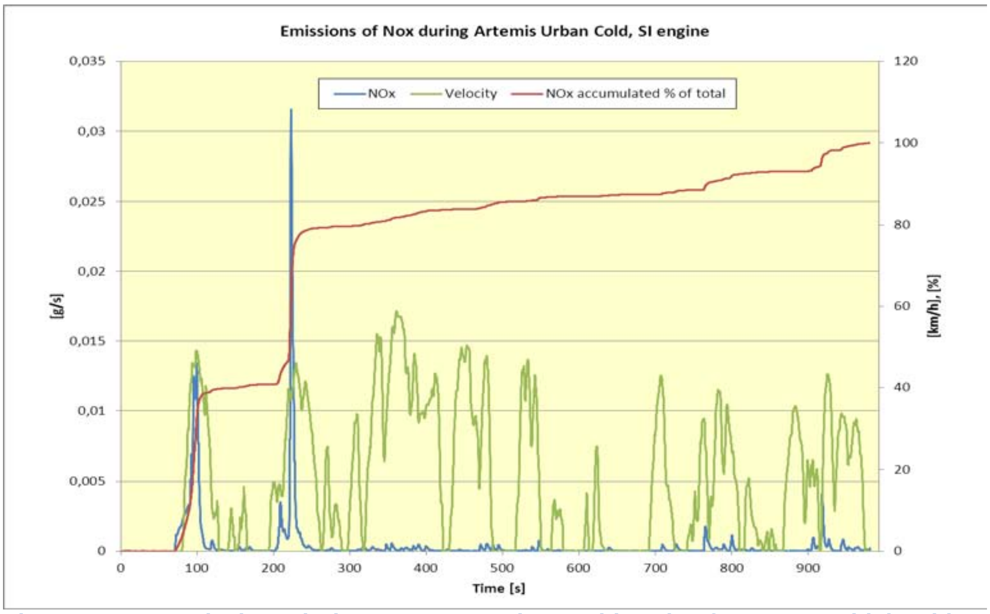

Figure 5: NOX emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

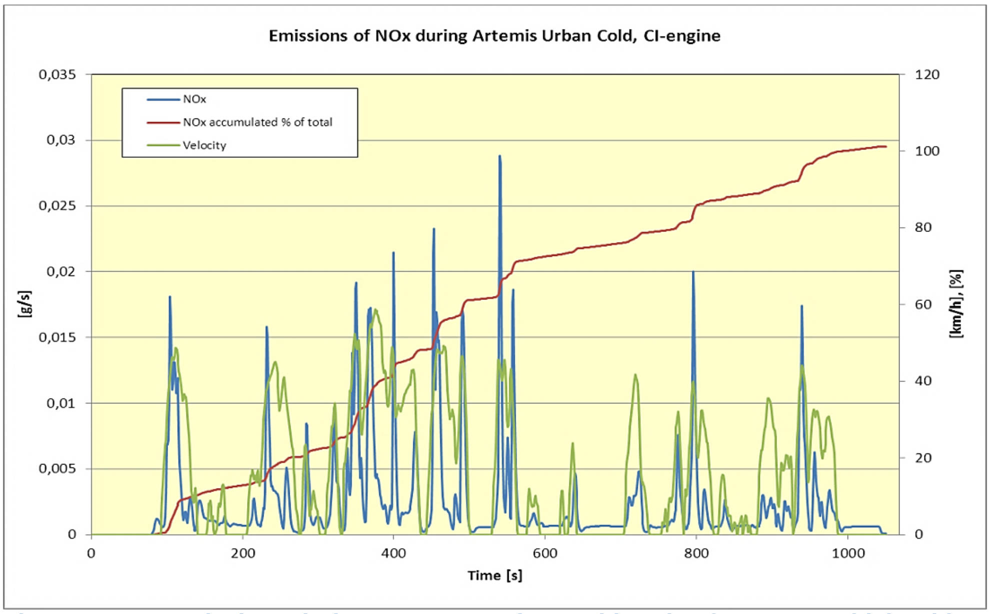

Figure 6: NOX emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

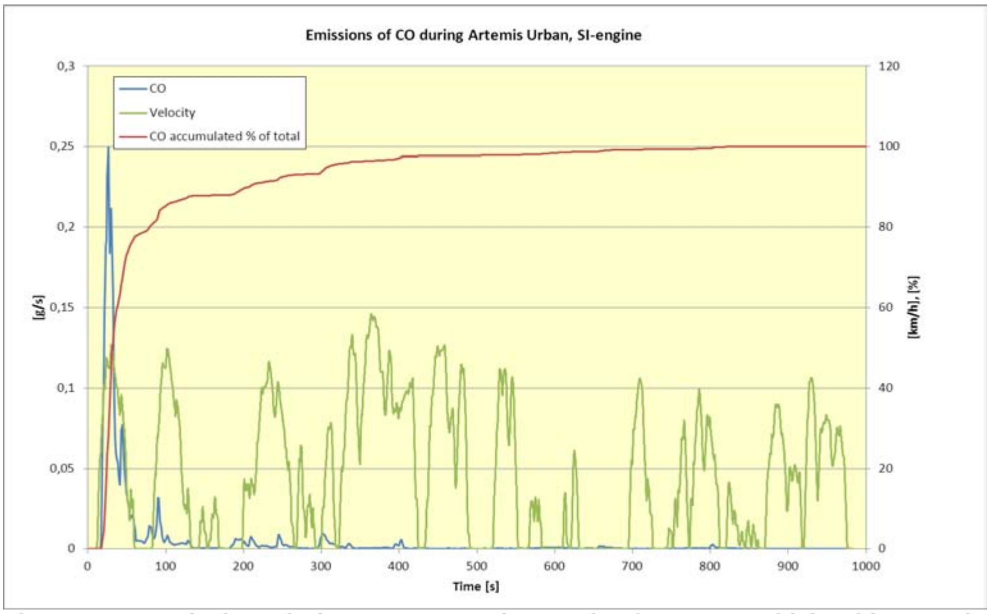

Figure 7: CO emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

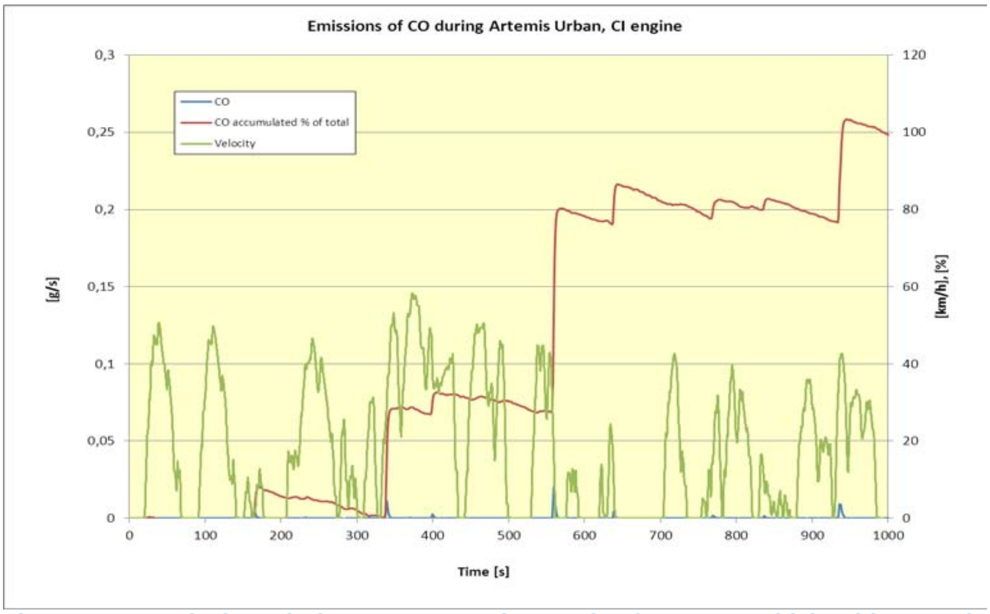

Figure 8: CO emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

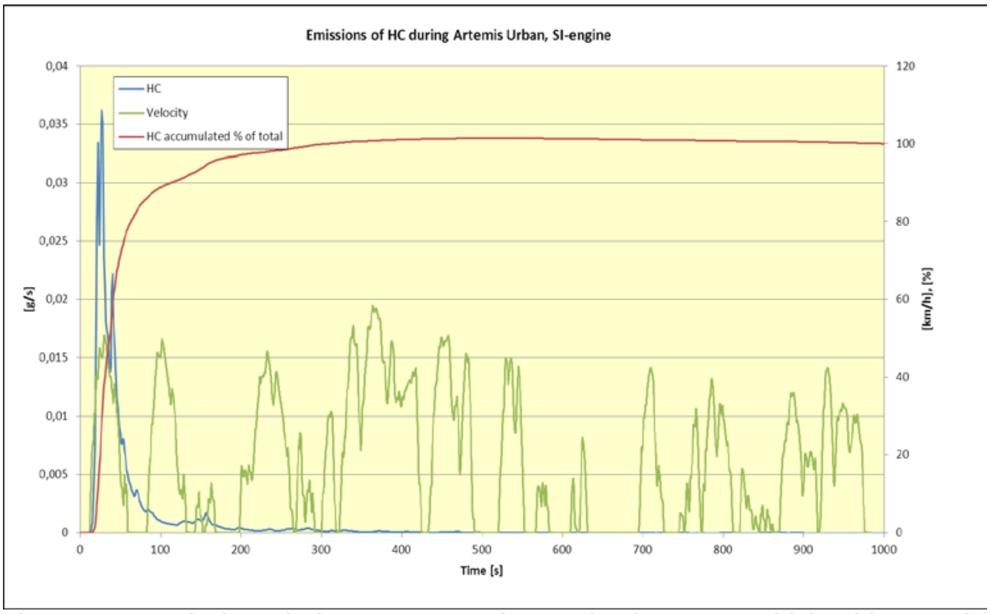

Figure 9: HC emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

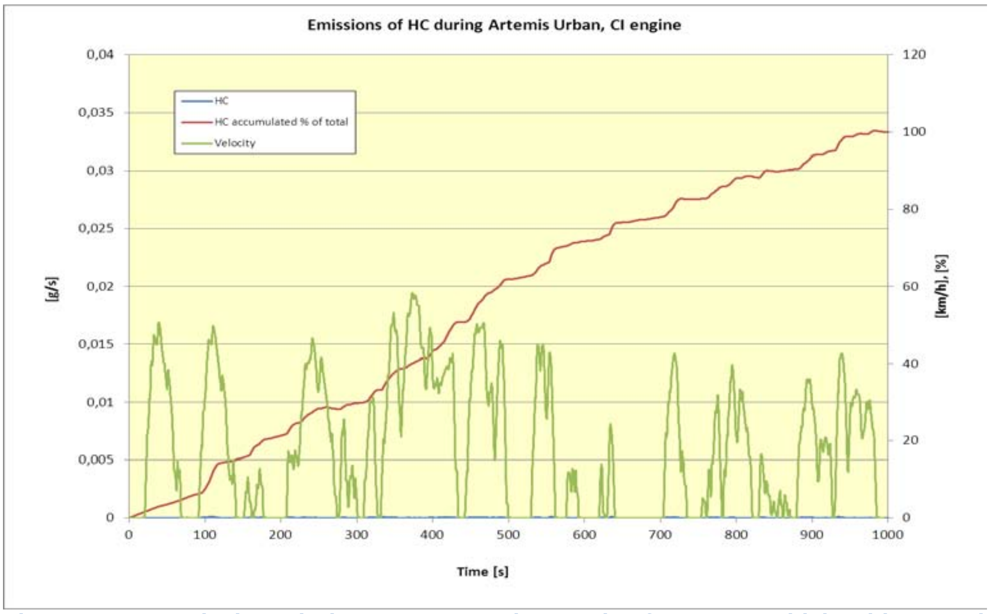

Figure 10: HC emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

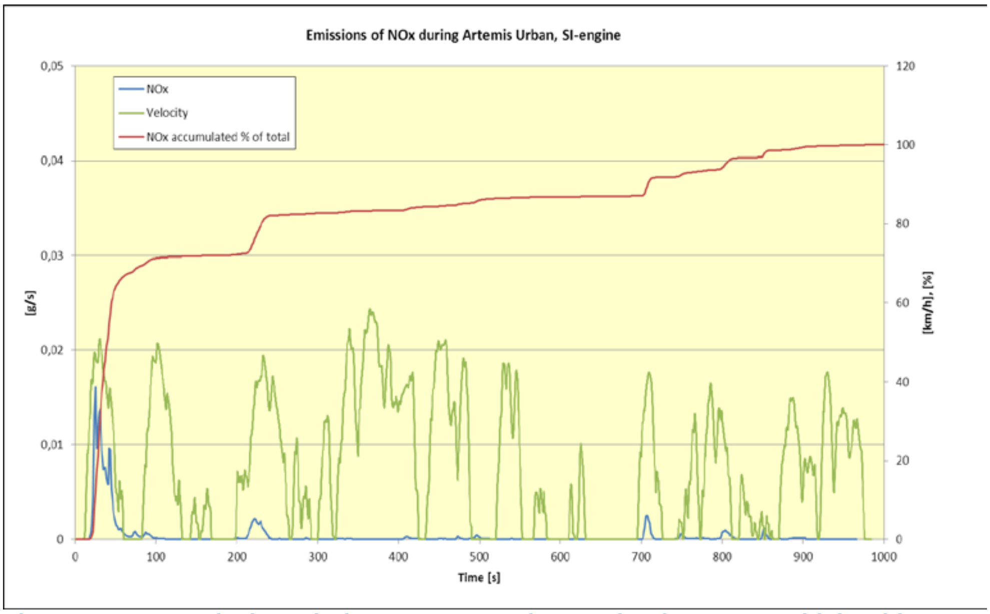

Figure 11: NOx emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

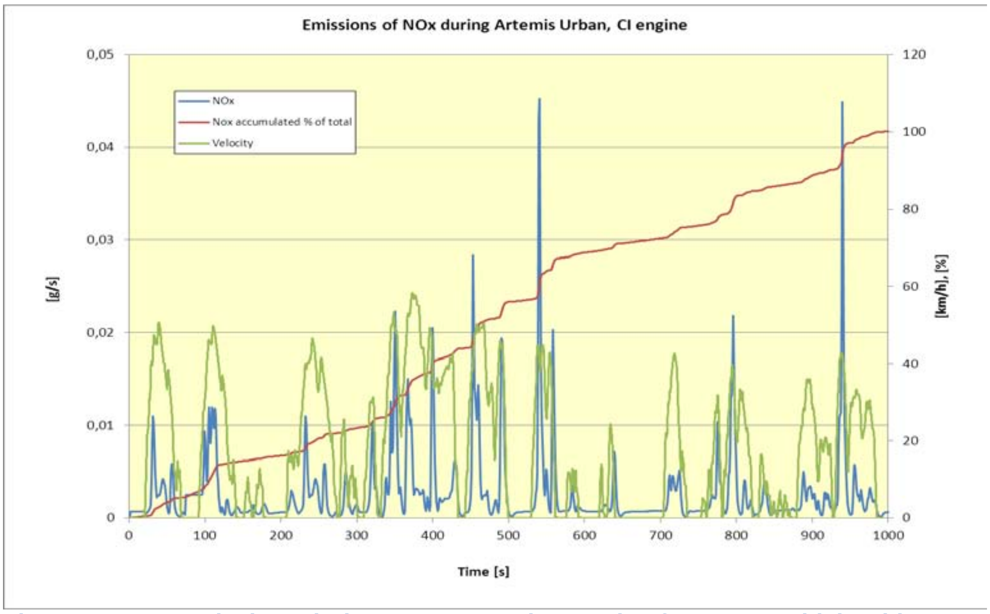

Figure 12: NOx emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

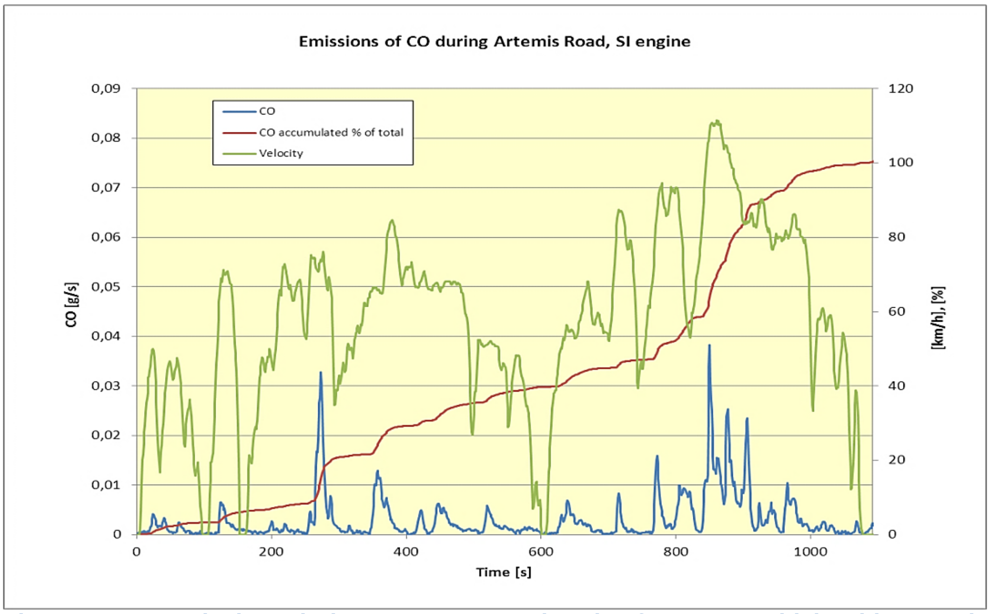

Figure 13: CO emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

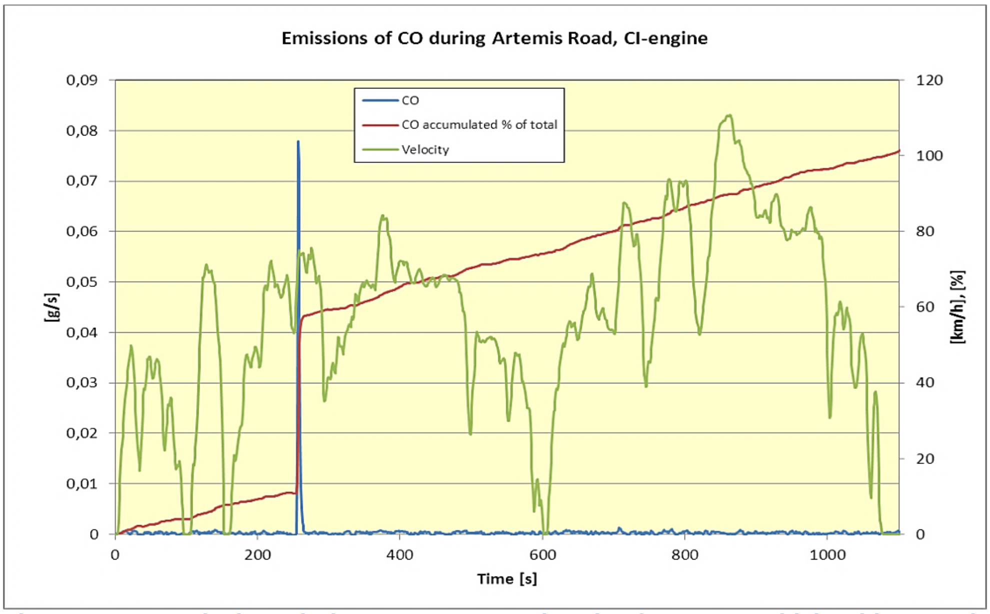

Figure 14: CO emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

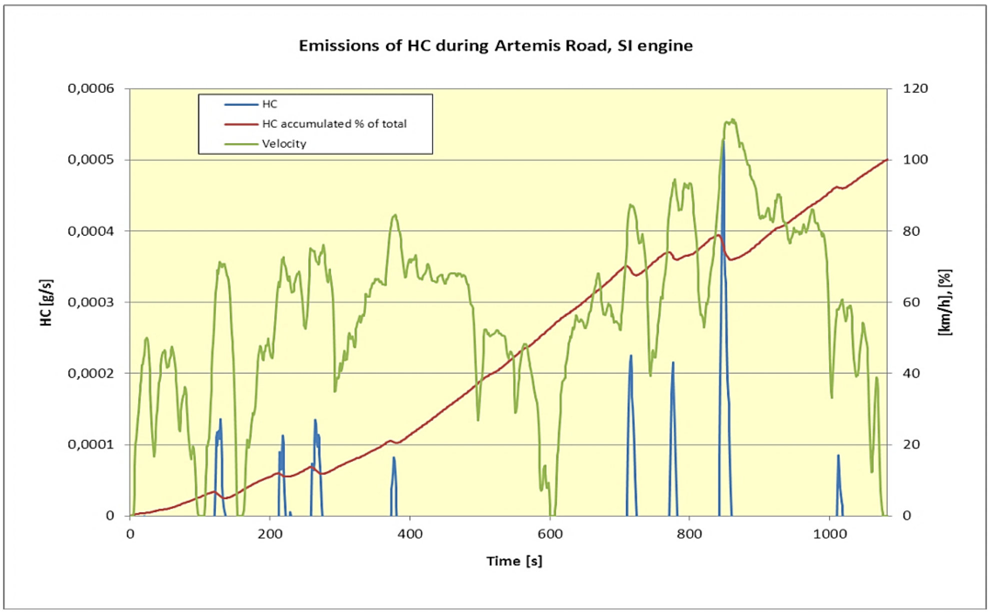

Figure 15: HC emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

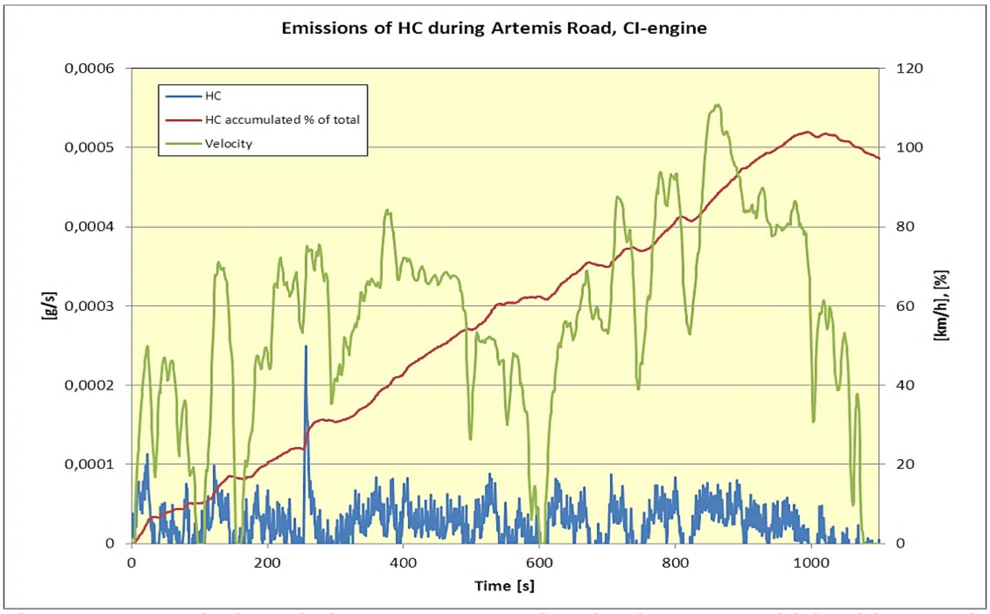

Figure 16: HC emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

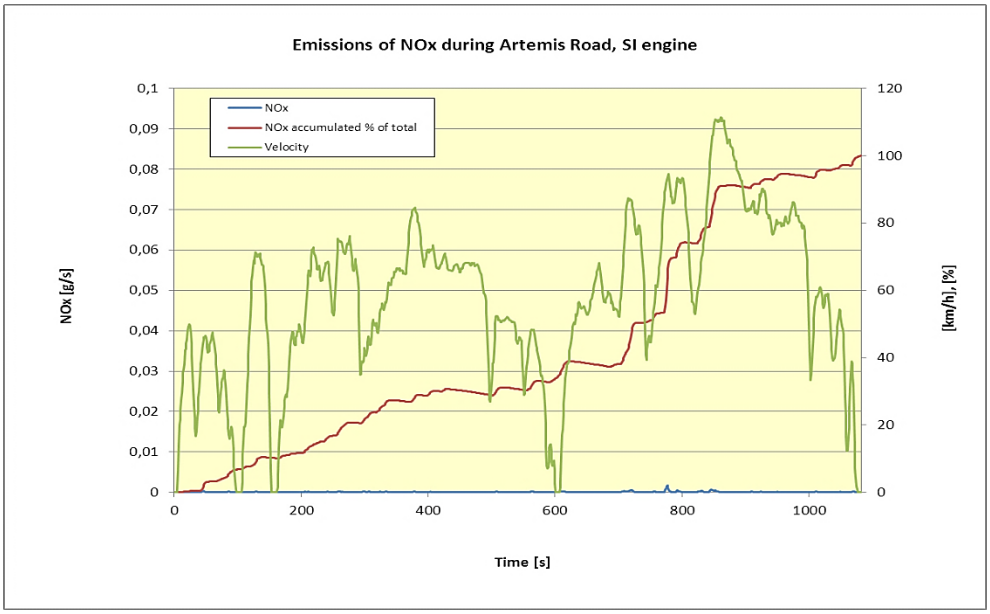

Figure 17: NOx emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

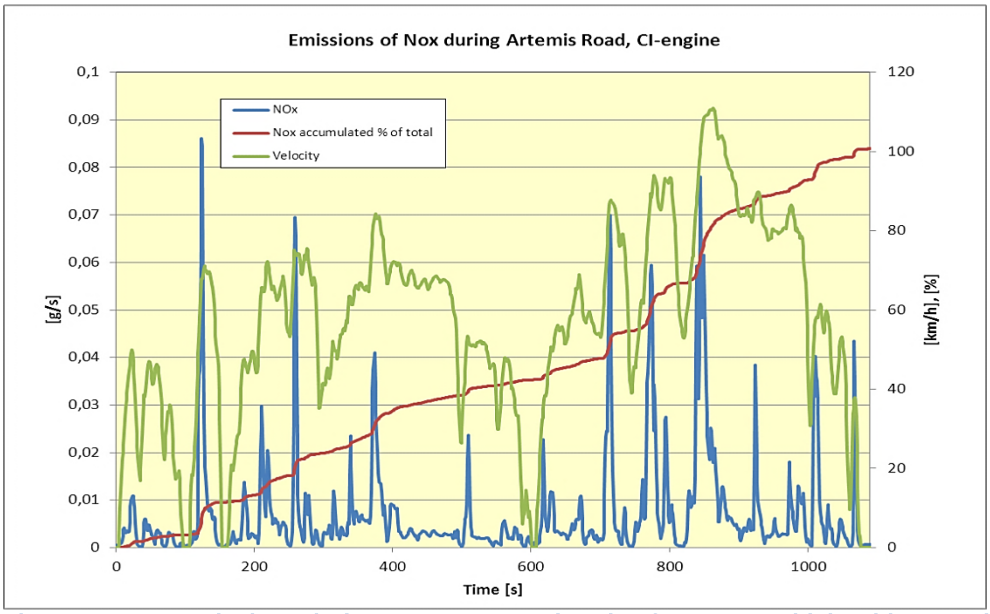

Figure 18: NOx emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

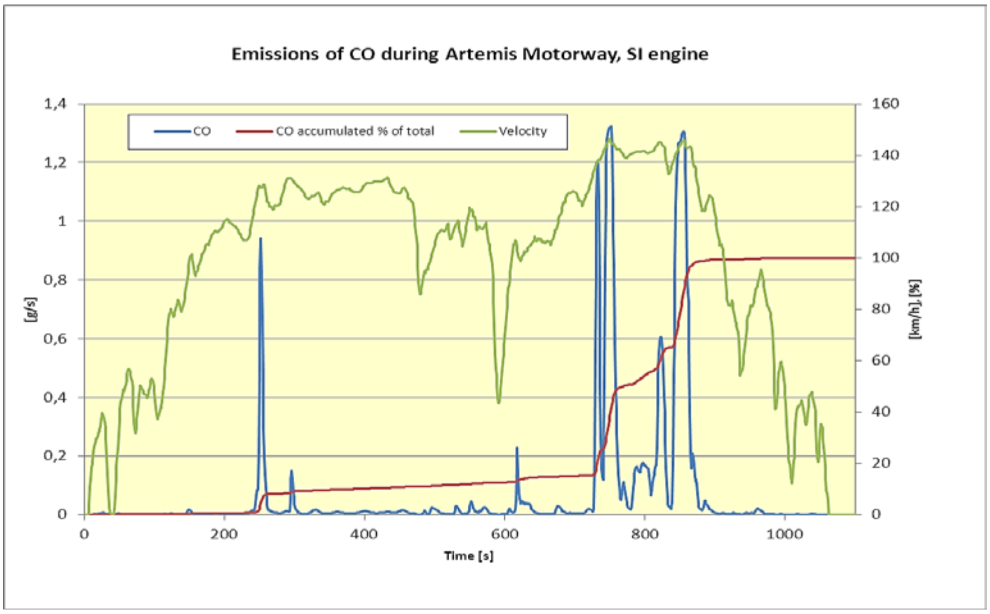

Figure 19: CO emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

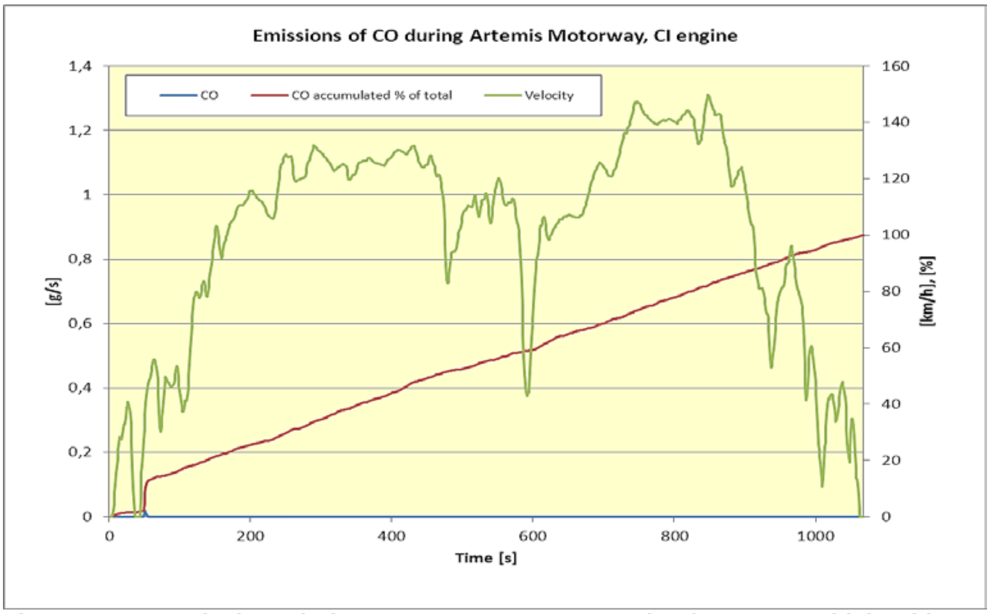

Figure 20: CO emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI- engine

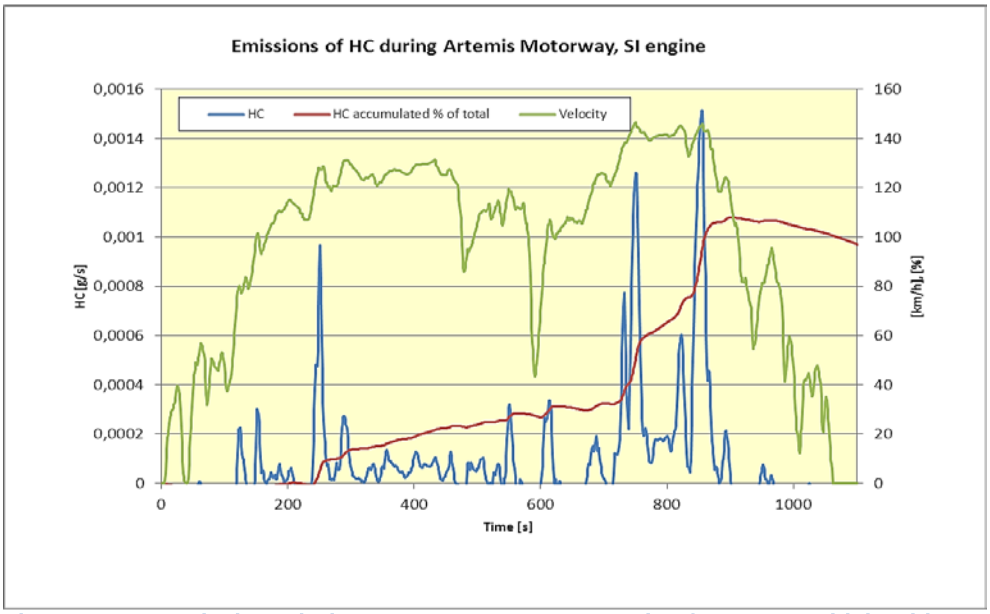

Figure 21: HC emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

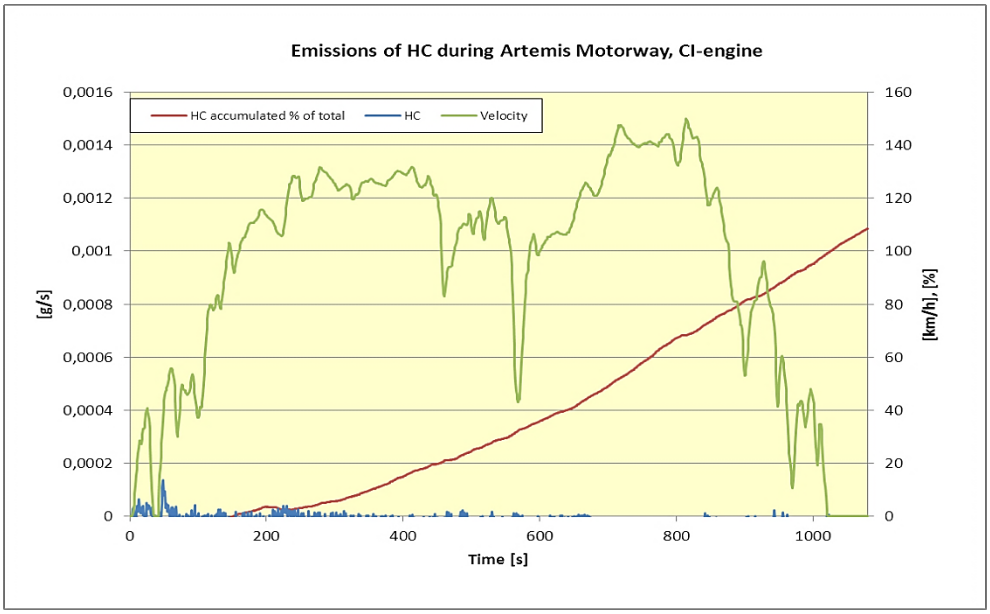

Figure 22: HC emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI-engine

The difference between SI- and CI-engine vehicles regarding NO_X emissions on the Motorway-part becomes evident when looking at figure 23 and figure 24.

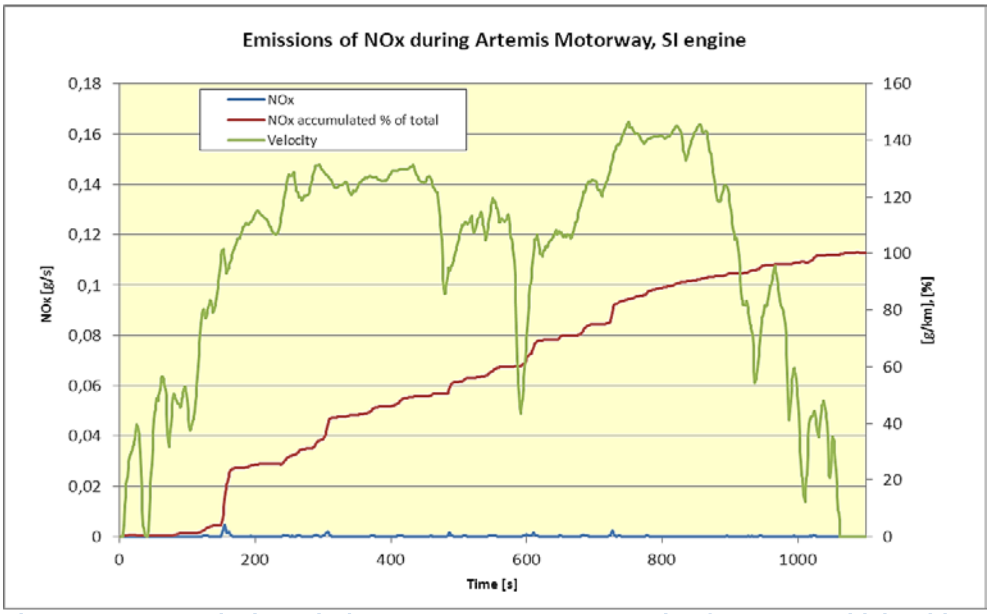

Figure 23: NOX emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

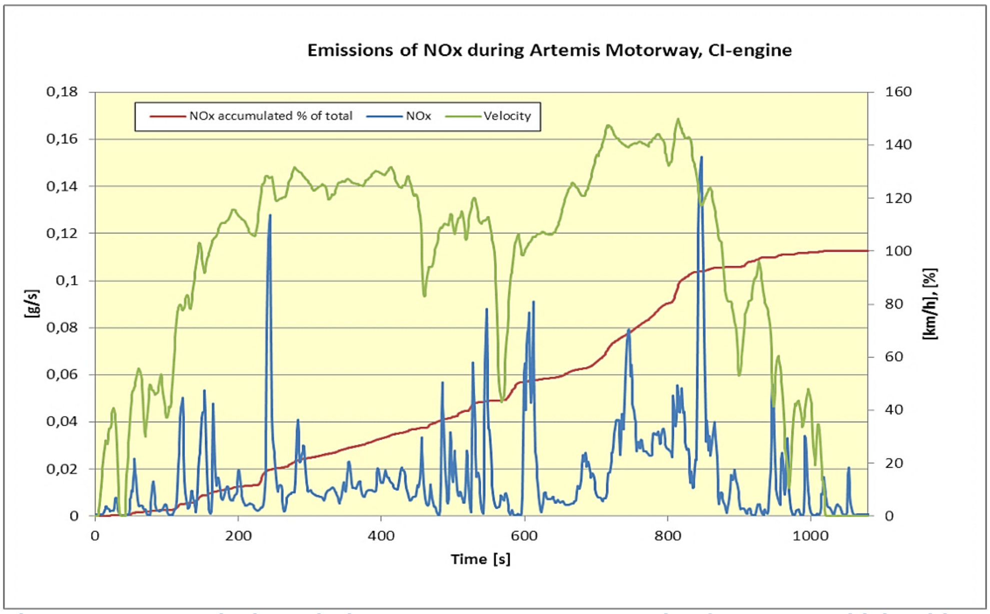

Figure 24: NOX emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI-engine

Appendix 3

On-road testing - PEMS

In Table 2, section "Test Programme Vehicles" on page 11, all tested cars with CI-engines are presented. These vehicles were tested on chassis dynamometer according to Directive 70/220/EEC as amended by 2003/76/EC. In addition, one vehicle family, (CI-engine vehicle, four wheel drive), was tested with a Portable Emission Measurement System (PEMS). The PEMS instrument is an on-board emission analyzer that enables tailpipe emissions to be measured and recorded simultaneously while the vehicle is in operation.

The instrument, Semtech-DS, is developed by Sensors for testing all classes of diesel, petrol and natural gas powered vehicles, both light as well as heavy duty vehicles and the instrument measures under real-world operating conditions.

The following measurement subsystems are included in the Semtech-DS emission analyzer:
- Heated Flame Ionization Detector (HFID) for total hydrocarbon (THC) measurement
- Non-Dispersive Ultraviolet (NDUV) analyzer for nitric oxide (NO) and nitrogen dioxide (NO_2) measurement
- Non-Dispersive Infrared (NDIR) analyzer for carbon monoxide (CO) and carbon dioxide (CO_2) measurement
- Electrochemical sensor for oxygen (O_2) measurement

The instruments are operated in combination with an electronic vehicle exhaust flow meter, Semtech E_xFM. The Semtech-DS instrument uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size. A 2,5" flow meter was used, which is suitable for the engine size of the tested vehicles. The program for emission calculation was supplied by Joint Research Centre (JRC).

Figure 1: Vehicle with PEMS test equipment,

The on-road testing and calculation has been performed in accordance with the PEMS protocol.

According to the PEMS protocol the driving routes should include urban, suburban, and highway driving. Where possible, the trips should include:

- Hill climbs
- Segments with cruising at constant speed and segments that is highly transient in their character
- Different altitudes
- Typical driving for the vehicle type

The test rout used was the PEMS route used for the heavy duty pilot programme.

***Test route description**:*
Below are the test route presented with data in Table 1 and as a plot (speed vs. time) in Figure 2.

Trip duration (s)	4248
Trip distance (km)	75
Average speed (km/h)	64

Table 1: Total test route data, PEMS test route.

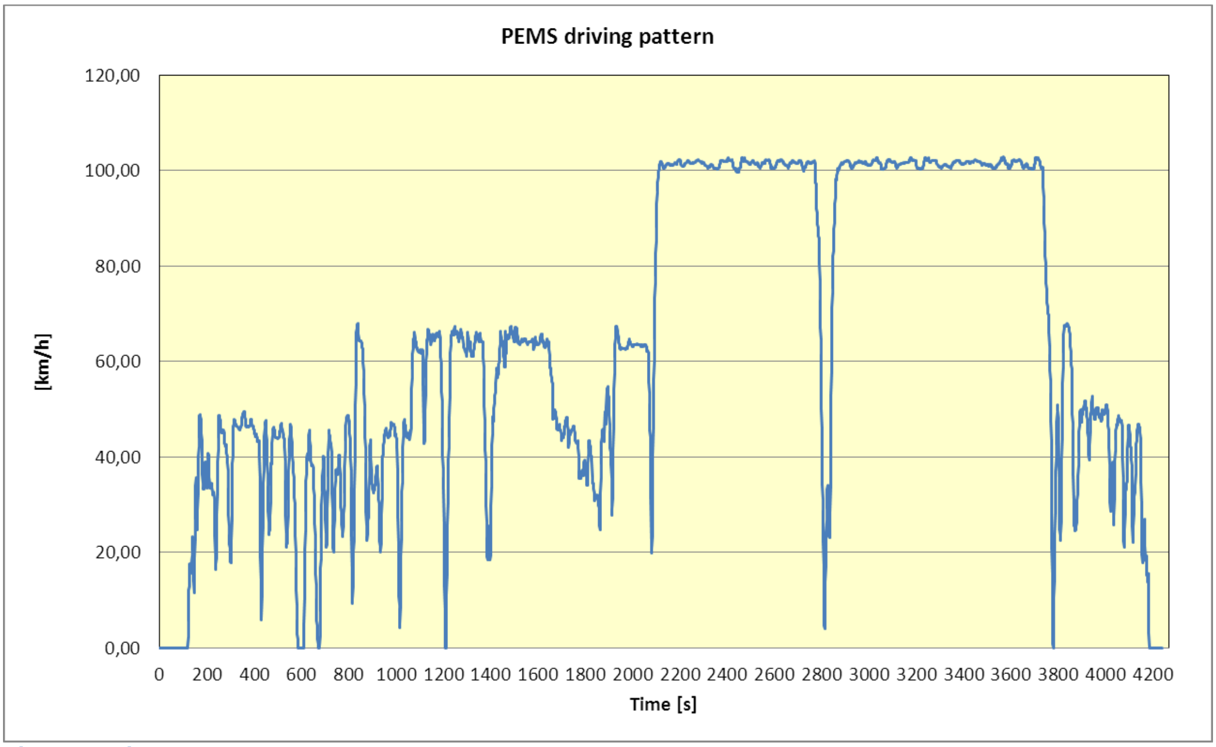

Figure 2: The PEMS test route

Prior testing, the vehicles were prepared and soaked according to the standard test procedure i.e. 22 °C. The test route was carried out at an ambient temperature of 17 °C.

PEMS test results, HD test route

	CO g/km	HC+NOx g/km	NOx g/km	CO_2 g/km	Fc l/100km
Vehicle no 2, PEMS	0,05	0,60	0,60	168	6,4
Vehicle no 4, PEMS	0,04	0,54	0,54	174	6,6
Vehicle no 5, PEMS	0,10	0,49	0,49	160	6,1
Average	*0,06*	*0,55*	*0,54*	*168*	*6,4*
Euro 4 Limit	**0,50**	**0,30**	**0,25**	-	-

Table 2: Emissions and fuel consumption from on-board (PEMS) measurements and chassis dynamometer testing.

In order to compare the PEMS route results with chassis dynamometer testing, emissions from the first 20 minutes of driving were calculated i.e., the same duration (and similar driving pattern) as NEDC. This test route has earlier been referred to as the PEMS light duty test route.

Test route description*:*
Below is the approximate test route presented with data in Table 3 and as a plot (speed vs. time) in Figure 3.

Trip duration (s)	1200
Trip distance (km)	13,9
Average speed (km/h)	42

Table 3 Total test route data, PEMS LD test route.

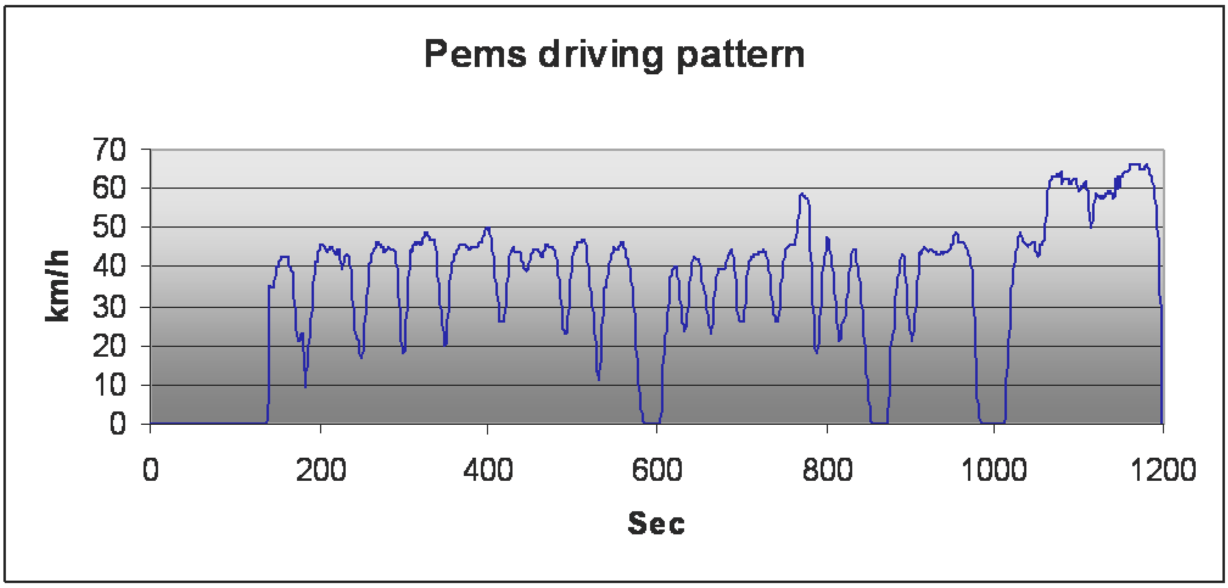

Figure 40 The light duty PEMS test route

PEMS test results, LD test route

From the results in Table 4 it can be seen that the emissions of CO are 50 to 60% higher when tested on the road compared to the chassis dynamometer test results for vehicle no 2 and 5. However, vehicle no 4 showed an almost 80% decrease of CO emissions.

Regarding the NO_X emission, all vehicles showed increases (50-65%) when tested on the road compared to the chassis dynamometer test result.

The fuel consumption and the emissions of CO_2 are between 15 % and 30% higher on the road compared to on chassis dynamometer.

	CO g/km	HC+NOx g/km	NOx g/km	CO_2 g/km	Fc l/100km
Vehicle no 2, CD	0,23	0,23	0,21	156	5,9
Vehicle no 2, PEMS	0,43	0,59	0,57	205	7,8
Vehicle no 4, CD	0,27	0,24	0,22	157	6,0
Vehicle no 4, PEMS	0,05	0,62	0,61	230	8,7
Vehicle no 5, CD	0,15	0,26	0,25	161	6,1
Vehicle no 5, PEMS	0,41	0,54	0,53	190	7,2
Euro 4 Limit	**0,5**	**0,3**	**0,25**	**-**	**-**

Table 4 Emissions and fuel consumption from on-board (PEMS) measurements and chassis dynamometer testing.