Swedish In-Service Testing Program

On Emissions from Passenger Cars and Light-Duty Trucks

Report for the Swedish Transport Agency

by Tobias Menrik
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

A4 / A5 / A6	4-speed / 5-speed / 6-speed automatic gearbox
CADC	Common Artemis Driving Cycle
CI	Compression Ignited
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of production
CPC	Condensation Particle Counter
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 in accordance with Directive 91/441/EEC
EURO 2	Type approval test in accordance with Directive 94/12/EEC
EURO 3	Type approval test in accordance with Directive 98/69/EC
EURO 4	Type approval test in accordance with Directive 98/69/EC, stricter requirements (incl. lower limit values in driving cycle, -7°C test)
FC	Fuel consumption
HBEFA	Handbook on Emission Factors for Road Transport
HC	Hydro Carbon
HEPA	High Efficiency Particulate air [Filter]
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 is therefore an important part of an overall concept in order to achieve sustainable reduction of emissions in 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 on emissions from passenger cars and light duty trucks.

In 2010 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. One of the vehicle families with SI-engine were of flex fuel (ethanol) type. All the CI-engine vehicles were equipped with particulate filters (DPF).

In addition a Volvo V50 1,6D DRIVe (model year 2010) was tested regarding comparison of three different aftermarket tuning kits. Results will be presented in a separate report.

The regulated emissions were measured on a chassis dynamometer. The fuel consumption was calculated from the emissions of the carbon-containing exhaust components.

The particulate measurement has been conducted both according to the directive 70/220/EEC including latest amendments and to the PMP-protocol which will be implemented in the EU from September 1st 2011 and is a part of UNECE reg.83.

All vehicles where tested in the respective type approval cycle, the "New European Driving Cycle“ (Type I /NEDC) in accordance with Directive 70/220/EEC as amended by 2003/76/EC. In addition to this, all vehicles 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).

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

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

Three vehicles in one vehicle family (SI-engine and four wheel drive) were in addition to the standard testing programme for SI-engine vehicles, also tested using Portable Emission Measurement System (PEMS). Details can be found in Appendix 4.

The reference fuels used were provided by Halterman. The fuel specifications are according to directive 2002/80/EC and can be found in Appendix 1.

Three of the vehicles with SI-engine and three of the vehicles with CI-engine exceeded the Euro 4 emission limit during the Type I test. All the vehicles that failed the Type I test were of different vehicle types which means that a minimum of four vehicles per type complied with the emission limits. According to the statistical procedure for In-Service testing defined in Directive 70/220/EEC as amended by 98/69/EC a sample of five vehicles has passed if at least four vehicles comply with the limits. Therefore all vehicle types fulfilled the legal requirements for In-Service testing.

During the NEDC test (Type 1), the deviation from the values supplied by the manufacturer was more than 10 percent for two of the tested vehicles, 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.

Four of the twenty vehicles tested exceeded the limit for evaporative emissions during the Type IV test. Average test result for all the tested vehicles was 1.46 g per test.

During the exhaust emission test at low ambient temperatures (Type VI test), one of the tested petrol fuelled SI-engine vehicles failed to comply with HC emission limits according to Directive 70/220/EEC as amended by 98/69/EC. None of the E85 vehicles complied with the HC emission limits.

During the tests of the OBD-systems all simulated failures were 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 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 servicing 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 the 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 with 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. One of the tested vehicle types were cars with flex fuel engines.

The measurements were carried out in accordance with Directive 70/220/EEC as amended by 2003/76/EC. 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 15 to 19.

During the measurements on the chassis dynamometer 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 integral values were determined.

For all vehicles tested during the 2010 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 is to be 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) in accordance with 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 (Type II test) and crankcase emissions (Type III test) were measured on all vehicles with SI-engine.

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

On two vehicles in each family with SI-engine, type approved according to EURO 4, were the exhaust emissions 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.

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 of the test programme where selected in collaboration with Swedish Transport Agency and spread across a wide spectrum of different manufacturers in order to cover all the aspects the STA wish to attain. In all, vehicles from 14 different manufacturers were tested in the programme of 2010.

Table 1 shows the exhaust emission limits valid for the type approval test of passenger cars 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]	HC [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	-	-
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	0,04
		N1 class III	1760 < RM	0,74	-	0,39	0,46	0,06
	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

(1) N1 limits are also valid for class M vehicles with maximum mass > 2500kg

Table 1: Emission limits for passenger cars and light-duty heavy vehicles

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 bee seen in table 2 and table 3.

No.	Manufacturer	Type	Trade name	Engine type	Engine capacity (cm^3)	Power (kW)	Emission approval	Swedish enviroment class	Milage min (km)	Milage max (km)	Registration
1	PEUGEOT	P	107	1KR	998	50	EURO4	2005	27637	47190	2006-01-12 to 2007-11-23
2	SAAB	YS3E	95 BioPower	B205E/BP	1985	110	EURO4	2005	37337	78302	2007-02-08 to 2007-06-08
3	MAZDA	BK	Mazda 3	Z	1598	77	EURO4	2005	33961	78506	2006-03-08 to 2007-04-14
4	TOYOTA	XP9F	Yaris	2SZ	1298	64	EURO4	2005	24833	52043	2006-09-10 to 2007-01-27
5	SKODA	1Z	Octavia	BSE	1595	75	EURO4	2005	54079	64377	2006-01-20 to 2006-08-31
6	MERCEDES	203 K	C 180 Komp	271946	1796	105	EURO4	2005	45536	77183	2006-03-13 to 2007-05-04
7	SUBARU(*)	BP	Legacy	EJ25	2457	121	EURO4	2005	38099	74904	2006-08-22 to 2006-12-05
8	OPEL	A-H	Astra	Z16XEP	1598	77	EURO4	2005	46700	69676	2006-03-06 to 2006-11-28
9	HYUNDAI	TB	Getz	G4EE-G	1399	71	EURO4	2005	32568	52820	2006-08-20 to 2007-02-07

Table 2: Test programme vehicles, spark ignited engines

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

No.	Manufacturer	Type	Trade name	Engine type	Engine capacity (cm^3)	Power (kW)	Emission approval	Swedish enviroment class	Milage min (km)	Milage max (km)	Registration
1	VOLVO	M	C30 D4	D4204T	1984	100	EURO4	2005PM	32374	71554	2007-01-29 to 2008-10-27
2	BMW	187	118d	N47D20A	1995	105	EURO4	2005PM	38168	71368	2007-09-11 to 2008-04-04
3	KIA	ED	CEED CRDi	D4FB	1582	84	EURO4	2005PM	50077	70262	2007-08-08 to 2008-04-30
4	VOLKSWAGEN	3C5376	Passat Tdi	BMR	1968	125	EURO4	2005PM	36046	79229	2006-03-10 to 2008-09-26
5	FORD	WA6	S-MAX	2.0 DW10	1997	103	EURO4	2005PM	58841	71895	2006-05-18 to 2007-11-06

Table 3: Test programme vehicles, compression ignited engines

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 as amended by 2003/76/EC. In order to obtain a reliable assessment if type-specific defects are present on a vehicle type, five vehicles per 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 for a minimum of 6 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.

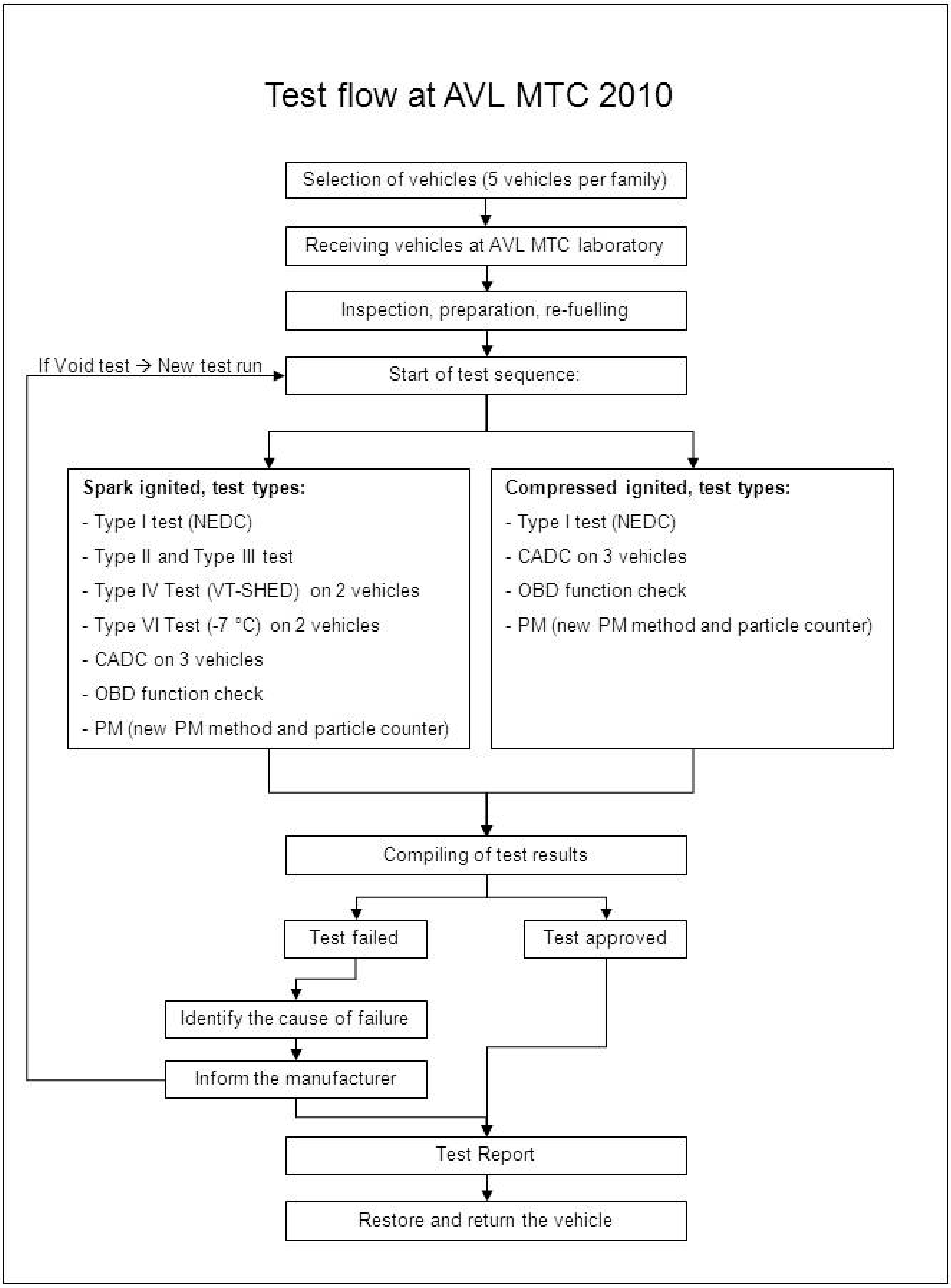


Figure 1: Illustration of the work flow for the In-Service Testing Programme at AVL MTC 2010

Test Fuels

According to Directive 70/220/EEC as amended by 2003/76/EC 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).

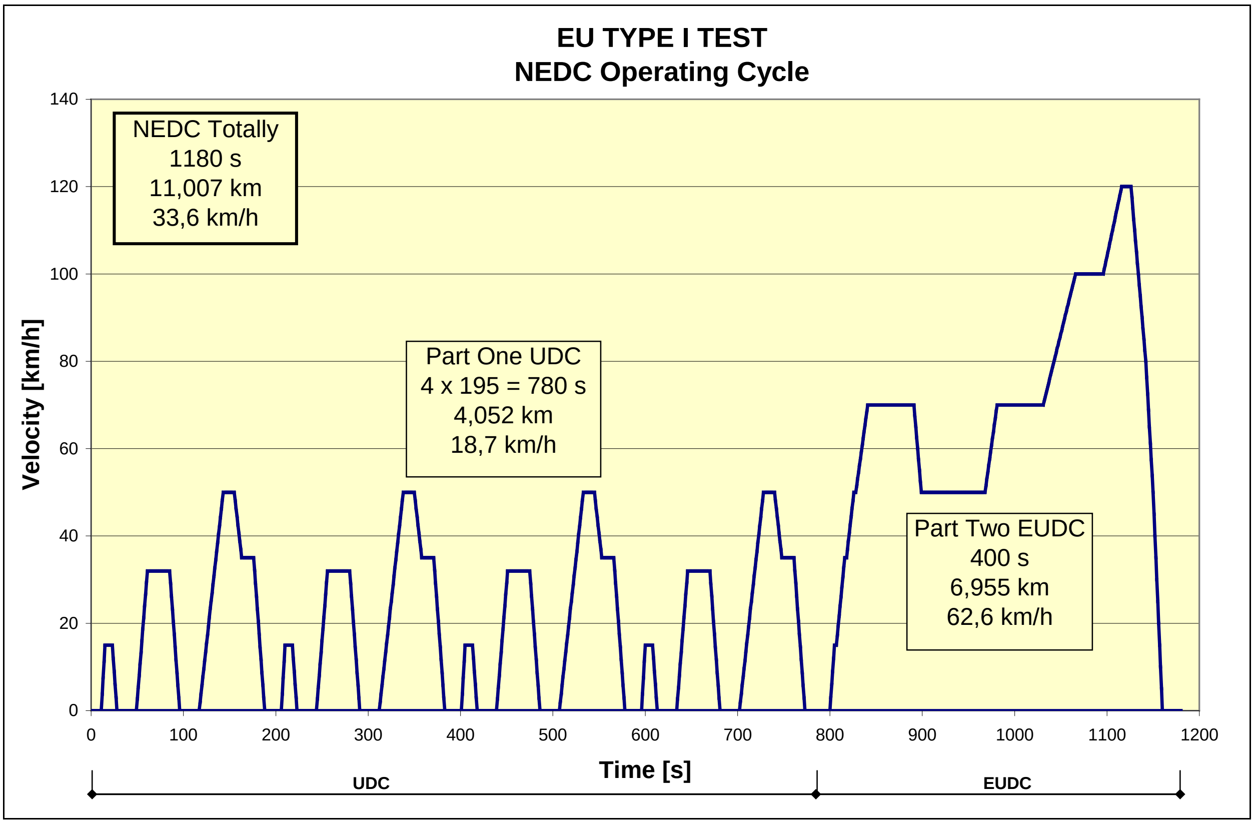


Figure 2: EU TYPE I Test - NEDC - New European Driving Cycle

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 2010, 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.

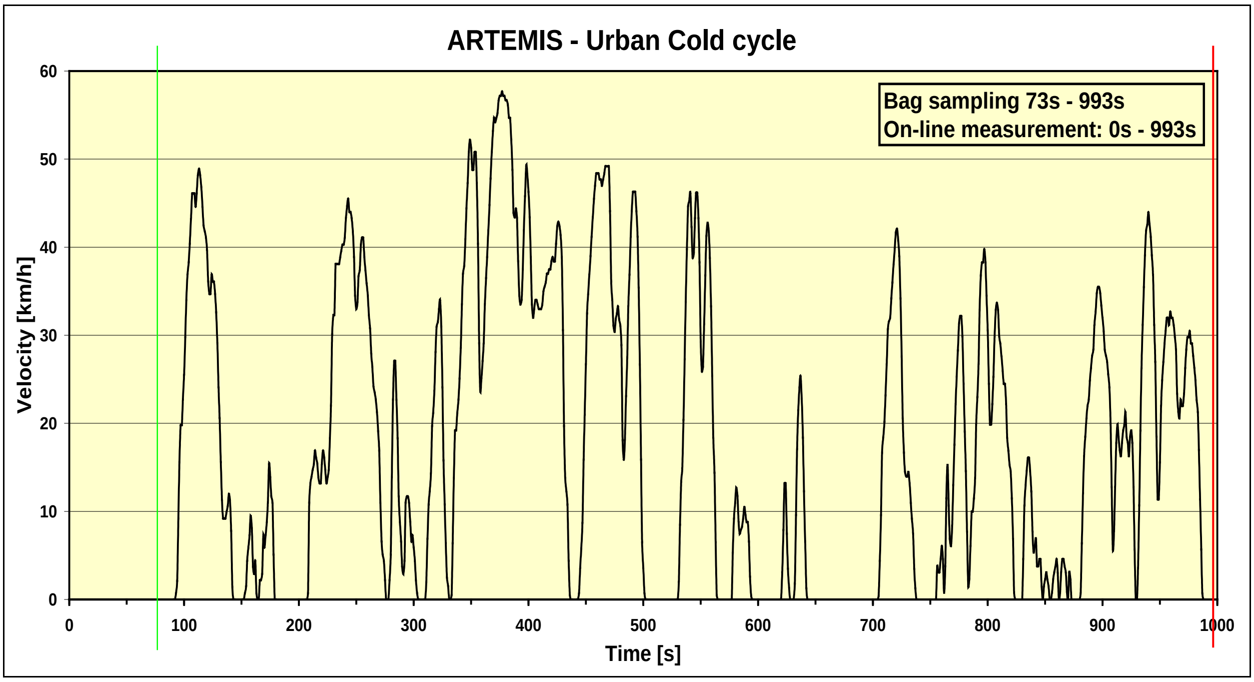


Figure 3: ARTEMIS – Urban Cold Cycle (without pre-conditioning)

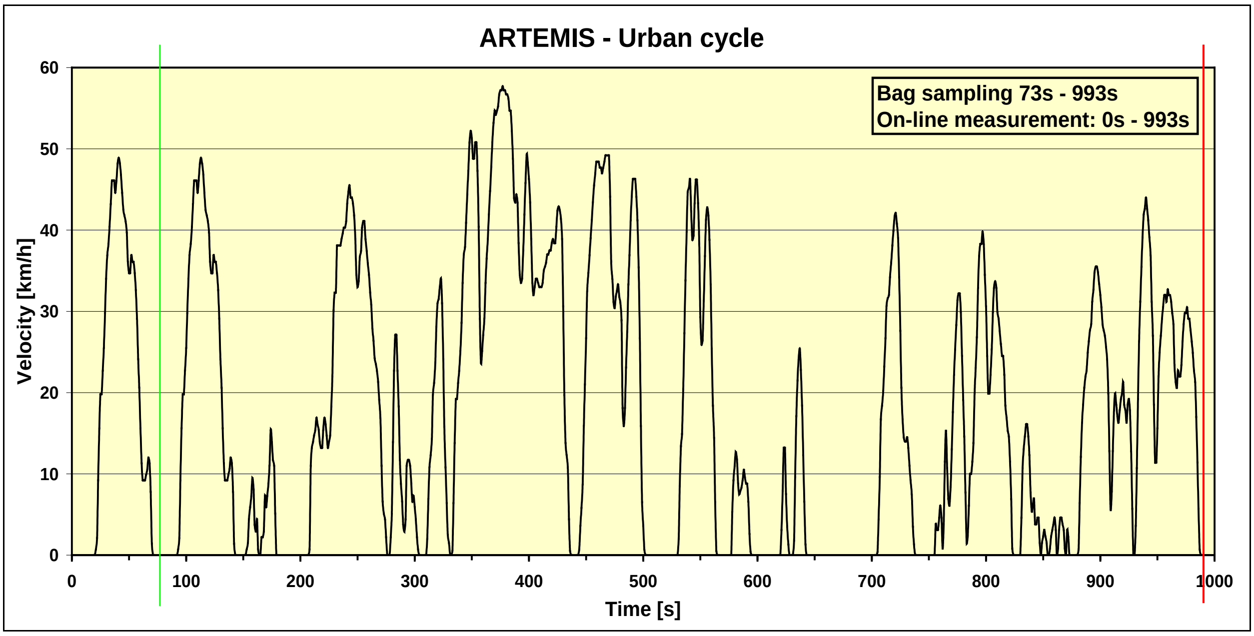


Figure 4: ARTEMIS – Urban Cycle

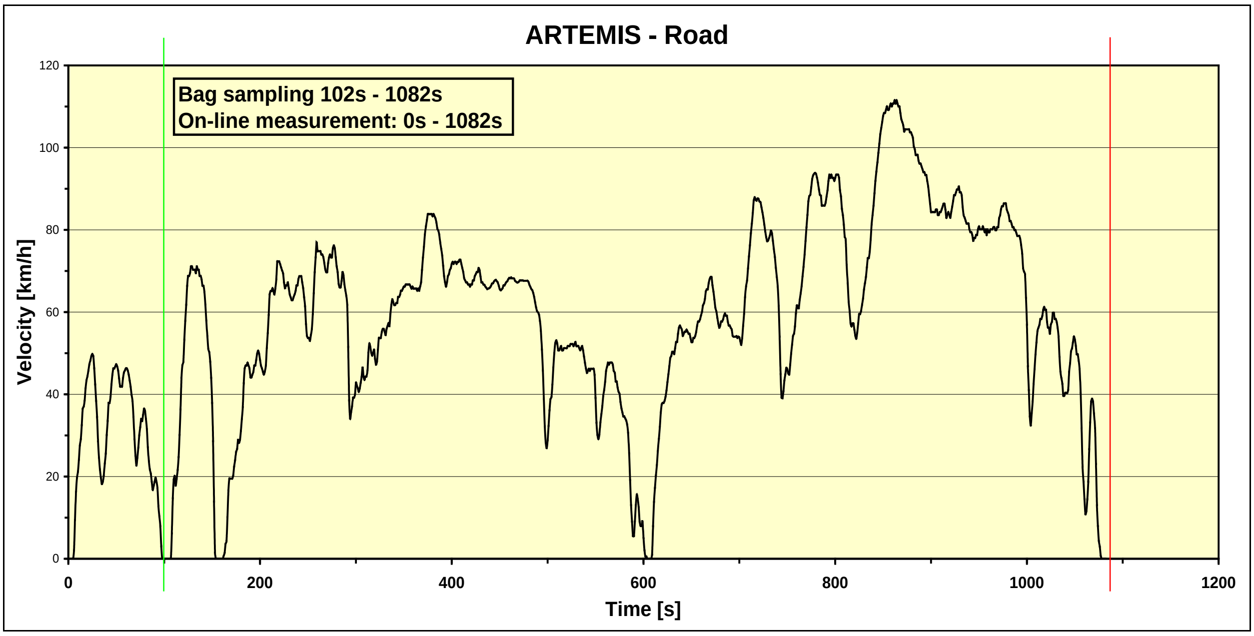


Figure 5: ARTEMIS – Road Cycle

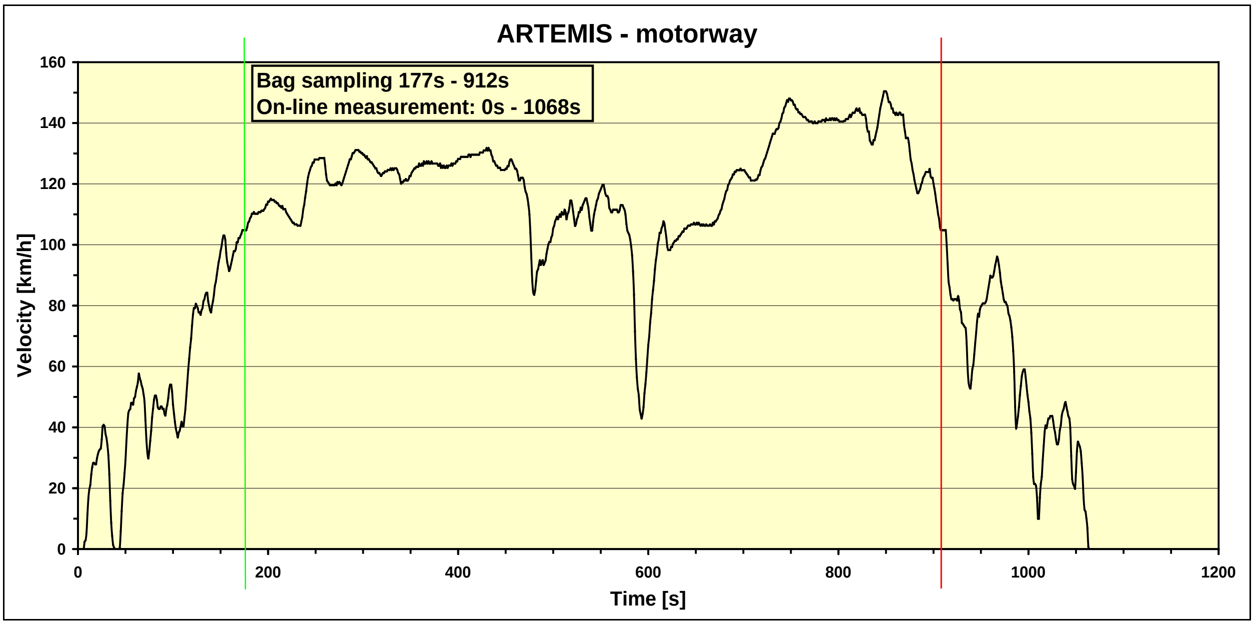


Figure 6: ARTEMIS – Motorway Cycle

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).

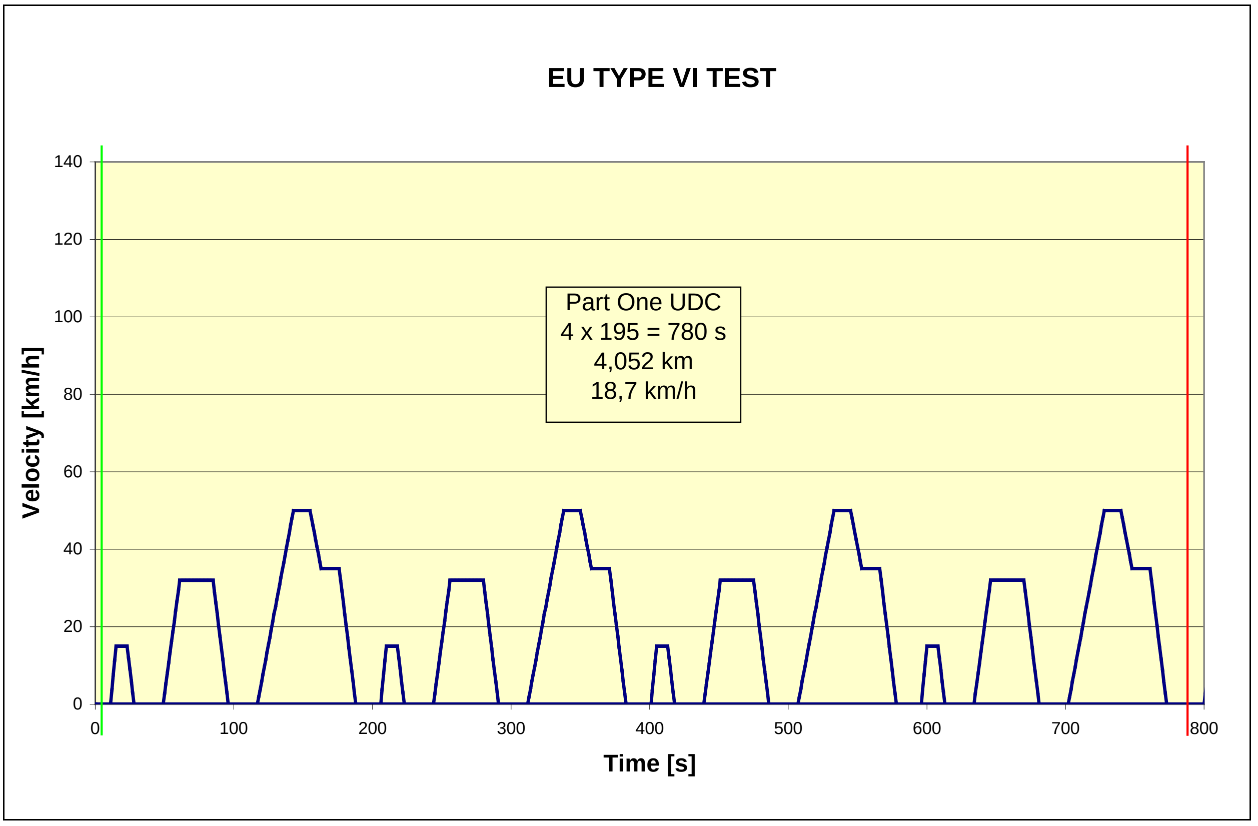


Figure 7: Type VI test cycle

Results

Emissions from Type I Test

The following sections show the average values for 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 values are presented in relevant categories. One of the tested vehicle types with CI-engine failed to comply due to high emissions of NO_X.

Category	Emission level	CO [g/km]	HC [g/km]	NOx [g/km]	HC+NOx [g/km]	CO2 [g/km]	Fc [L/100km]	PM-PMP [g/km]	PN [#]
Positive Ignition	Euro4	0,38	0,06	0,01	0,07	113	4,7	0,0013	3,71E+11
	Euro4	0,36	0,05	0,02	0,07	171	7,2	0,0003	3,18E+11
	Euro4	0,31	0,04	0,02	0,06	144	6,0	0,0006	1,85E+11
	Euro4	1,00	0,10	0,07	0,17	172	7,3	0,0002	3,70E+11
	Euro4	0,40	0,05	0,02	0,06	213	8,9	0,0008	1,59E+12
	Euro4	0,28	0,04	0,05	0,09	155	6,5	0,0001	3,18E+10
	Euro4	0,32	0,04	0,03	0,07	166	7,0	0,0004	1,12E+11
	Euro4	0,22	0,05	0,01	0,07	220	9,2	0,0001	6,52E+11
	Euro4	0,44	0,05	0,02	0,07	232	9,7	0,0006	4,74E+11
E85[(1)]	Euro4	0,81	0,07	0,01	0,08	214	13,4	0,0003	1,83E+11
Limit	Euro4	**1,0**	**0,10**	**0,08**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Compression Ignition	Euro4	0,15	0,02	0,16	0,18	153	5,8	0,0003	4,91E+10
	Euro4	0,33	0,03	0,22	0,25	128	4,9	0,0002	5,20E+10
	Euro4	0,22	0,03	0,23	0,26	146	5,6	0,0001	3,59E+10
	Euro4	0,09	0,02	0,20	0,22	173	6,6	0,0002	1,50E+10
	Euro4 N1 class III	0,19	0,02	0,43	0,45	165	6,2	0,0004	1,89E+11
Limit	Euro4	**0,50**	**N/A**	**0,25**	**0,30**	**N/A**	**N/A**	**0,005 [(2)]**	**N/A**
	Euro4 N1 class III	**0,74**	**N/A**	**0,39**	**0,46**	**N/A**	**N/A**	**0,060**	**N/A**

(1) E85 vehicles are type approved as a petrol vehicle and follow the Euro 4 emission regulations
(2) PM level according to MK 2005PM

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

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.

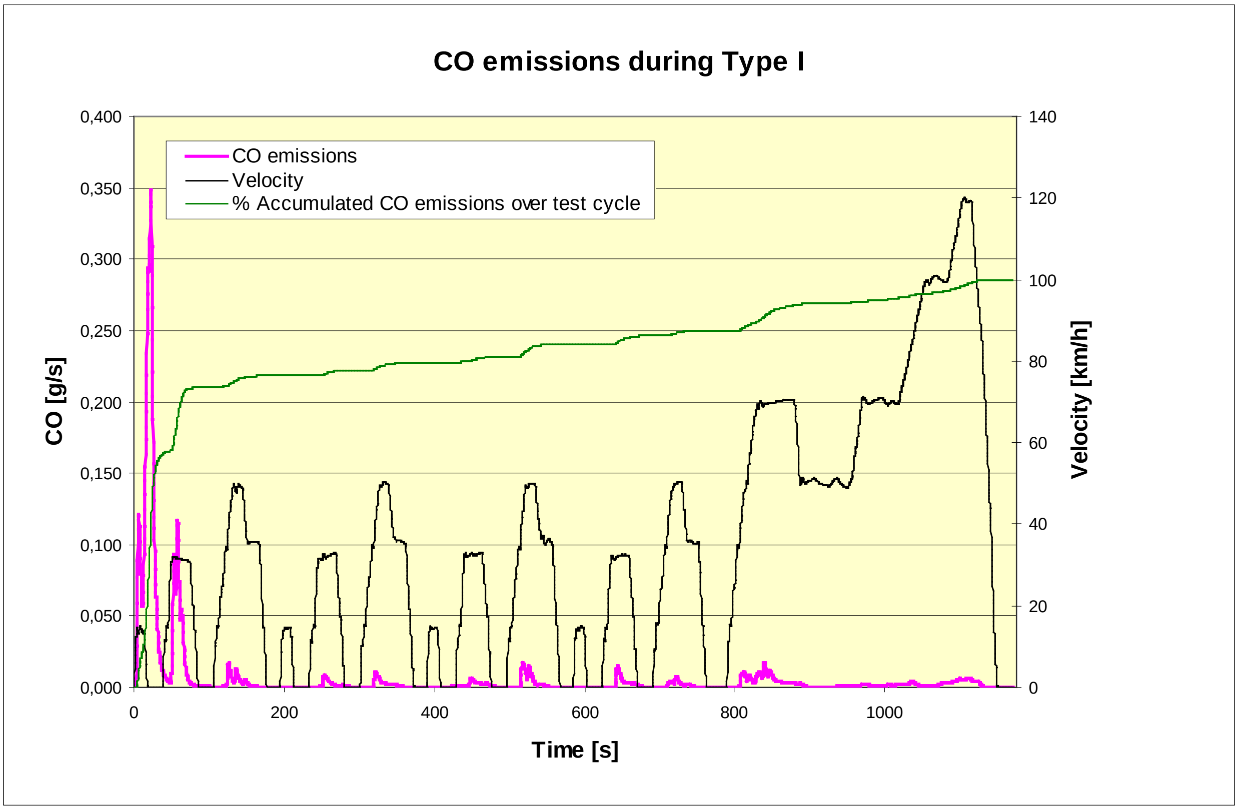


Figure 7: Average CO emitted by a SI-engine vehicle during Type I test

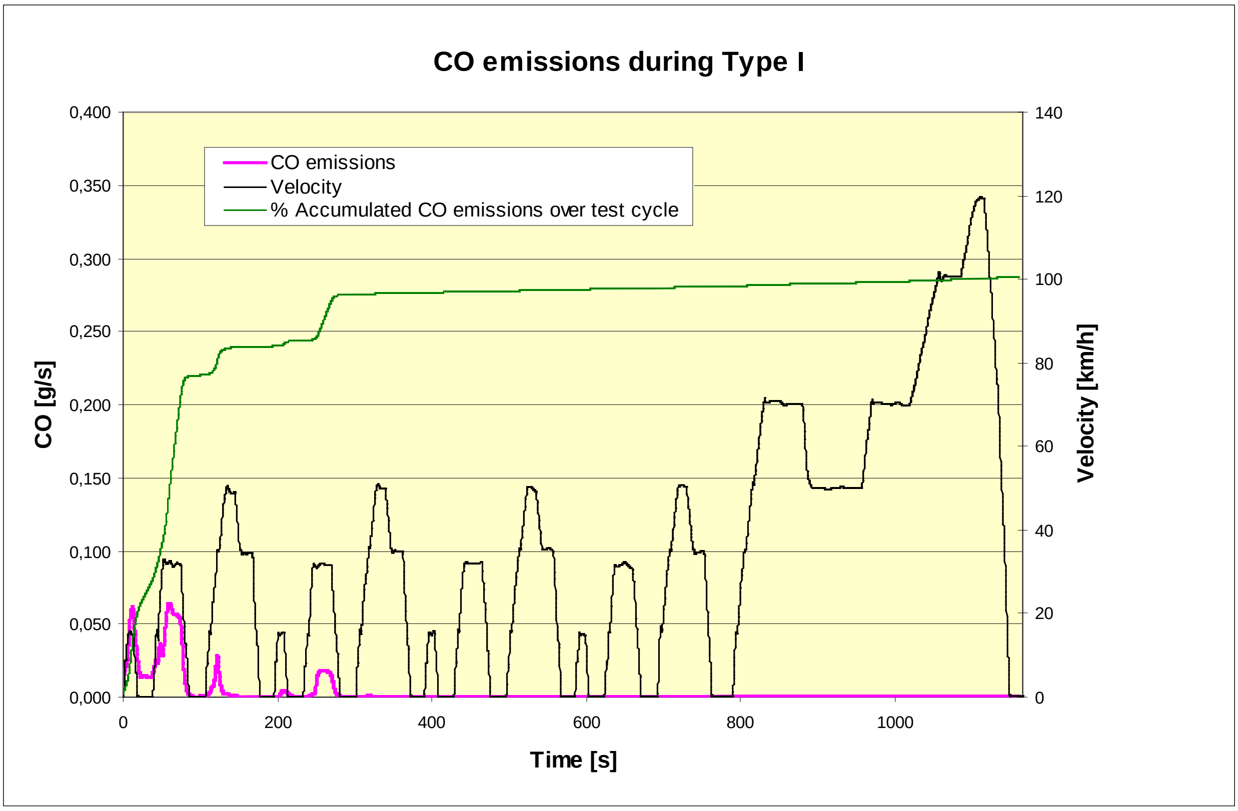


Figure 8: Average CO emitted by a CI-engine vehicle during Type I test

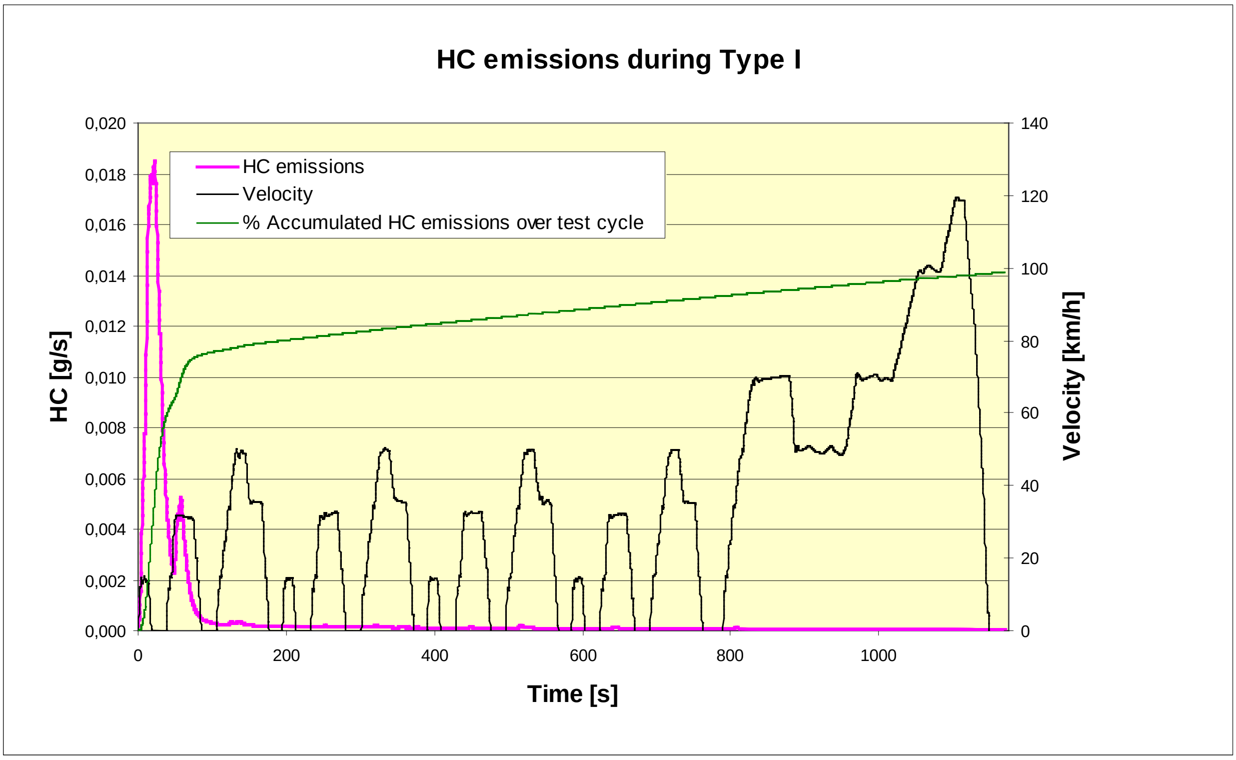


Figure 9: Average HC emitted by a SI-engine vehicle during Type I test

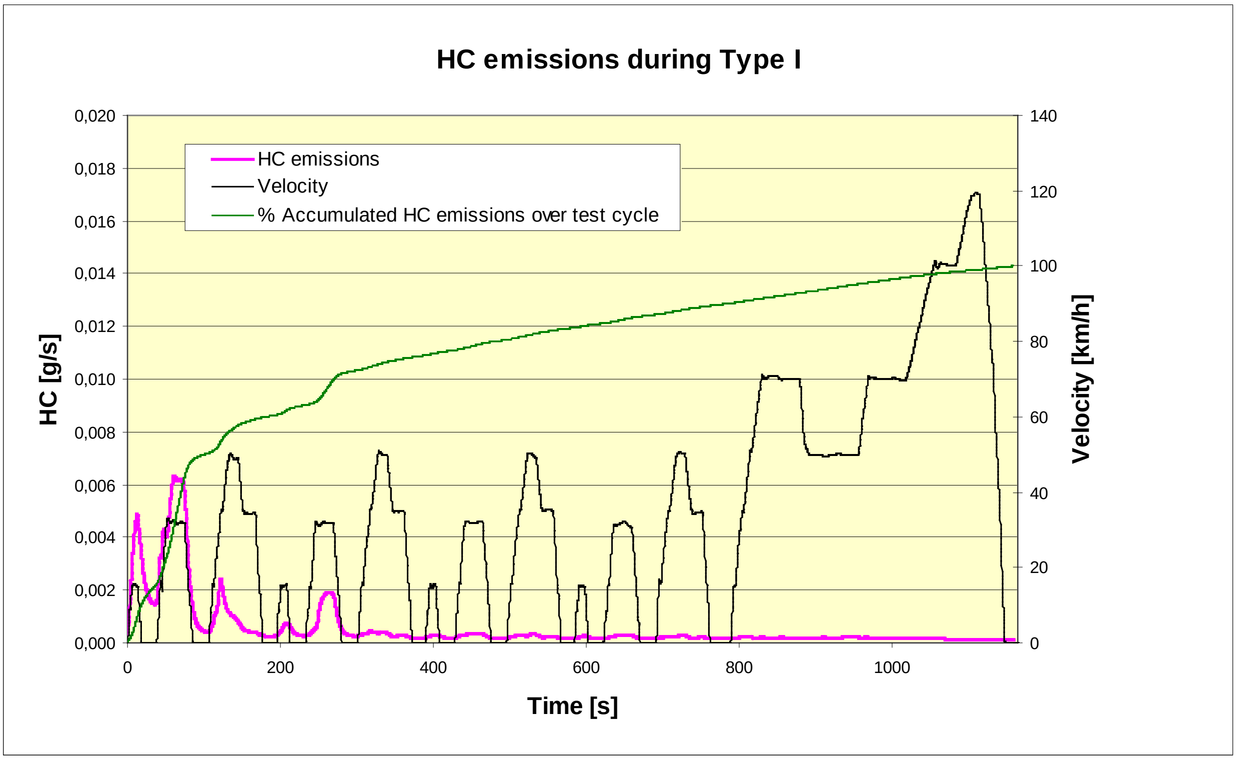


Figure 10: Average HC emitted by a CI-engine vehicle during Type I test

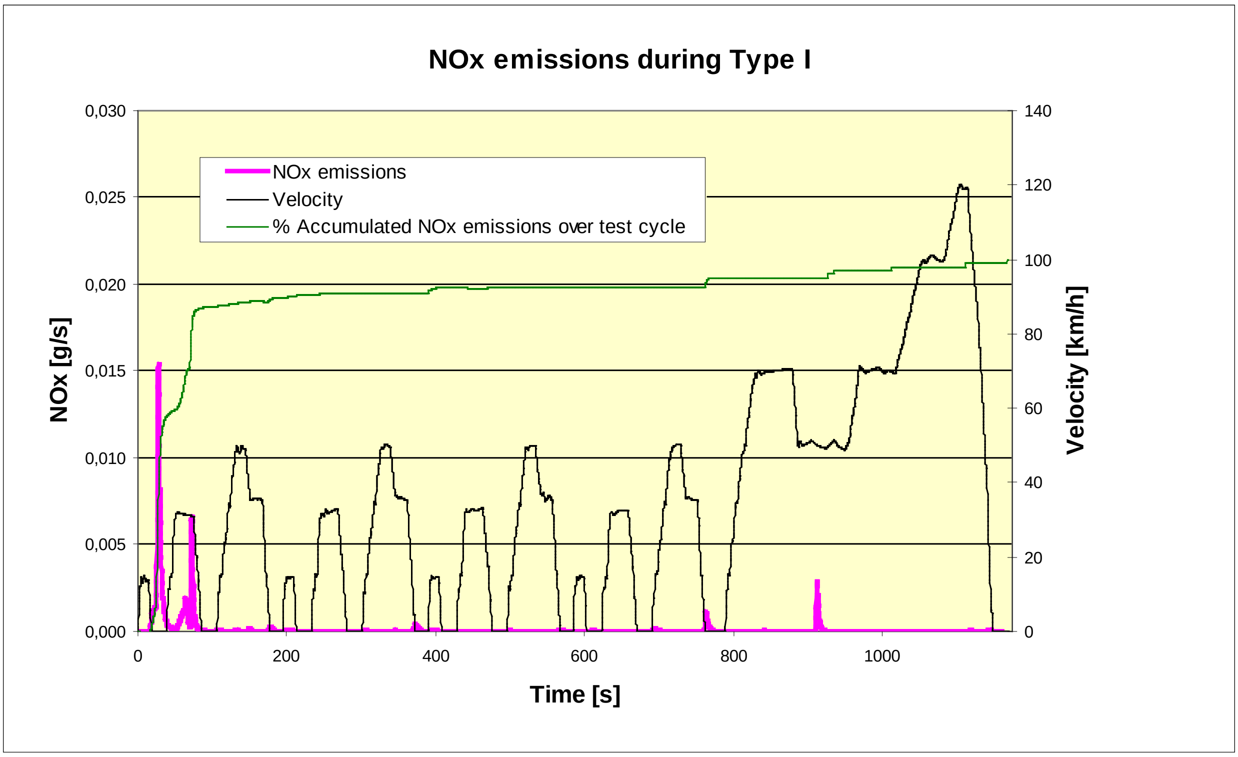


Figure 11: Average NO_X emitted by a SI-engine vehicle during Type I test

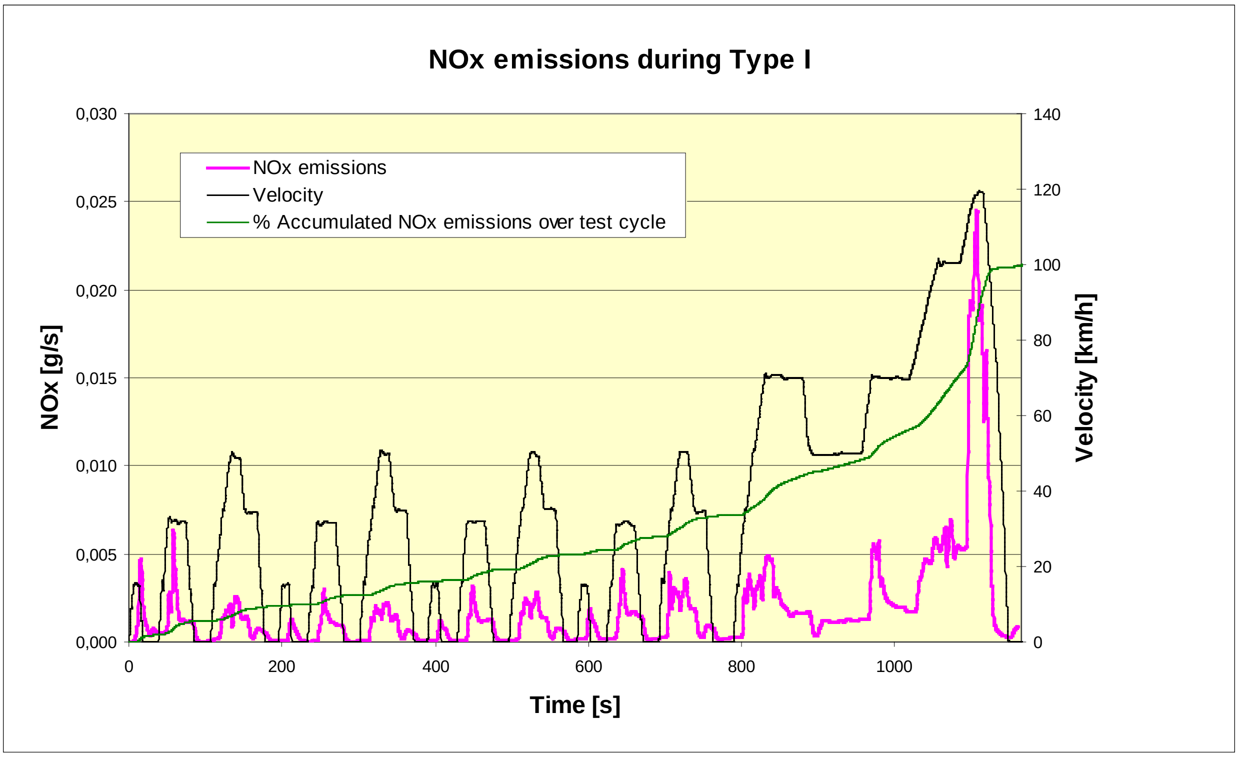


Figure 12: Average NO_X emitted by a CI-engine vehicle during Type I test

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

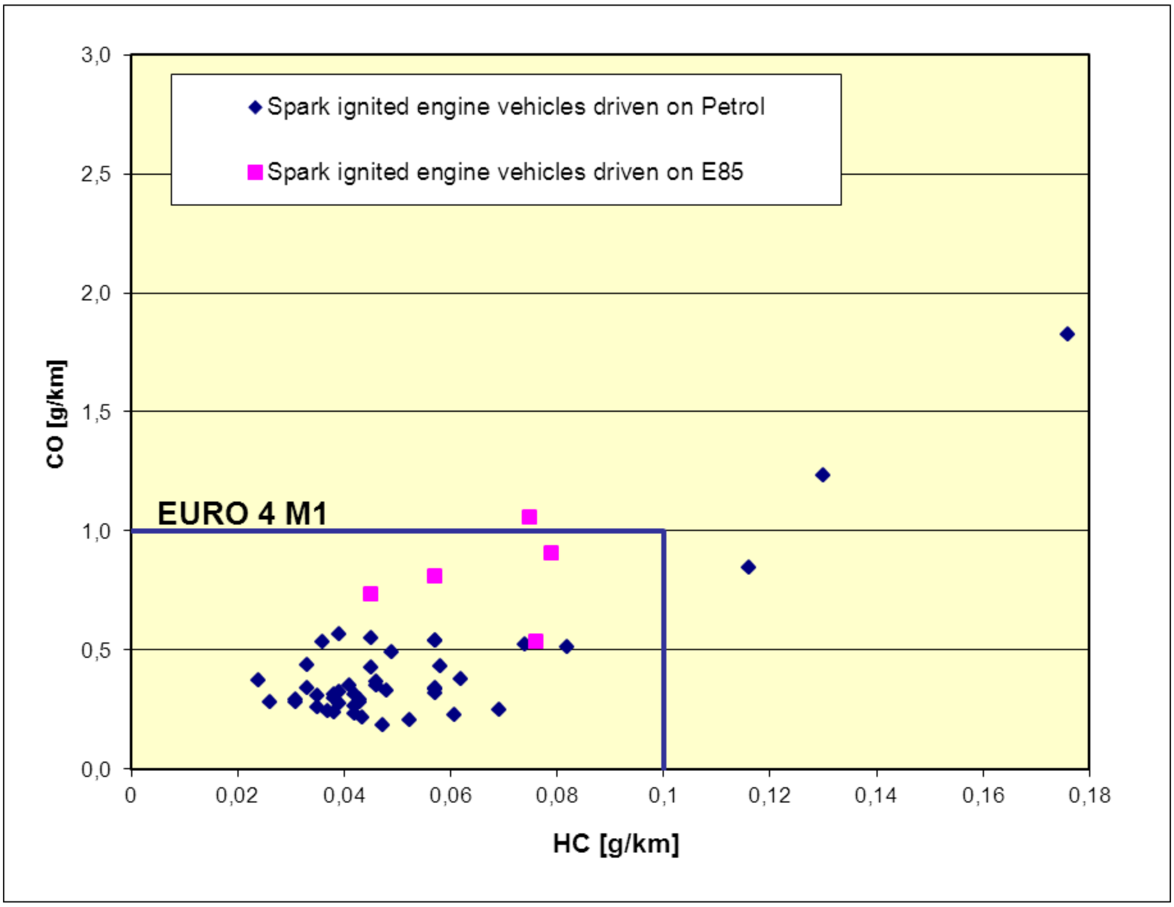


Figure 13: CO and HC emissions of vehicles with SI-engine during Type I test

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

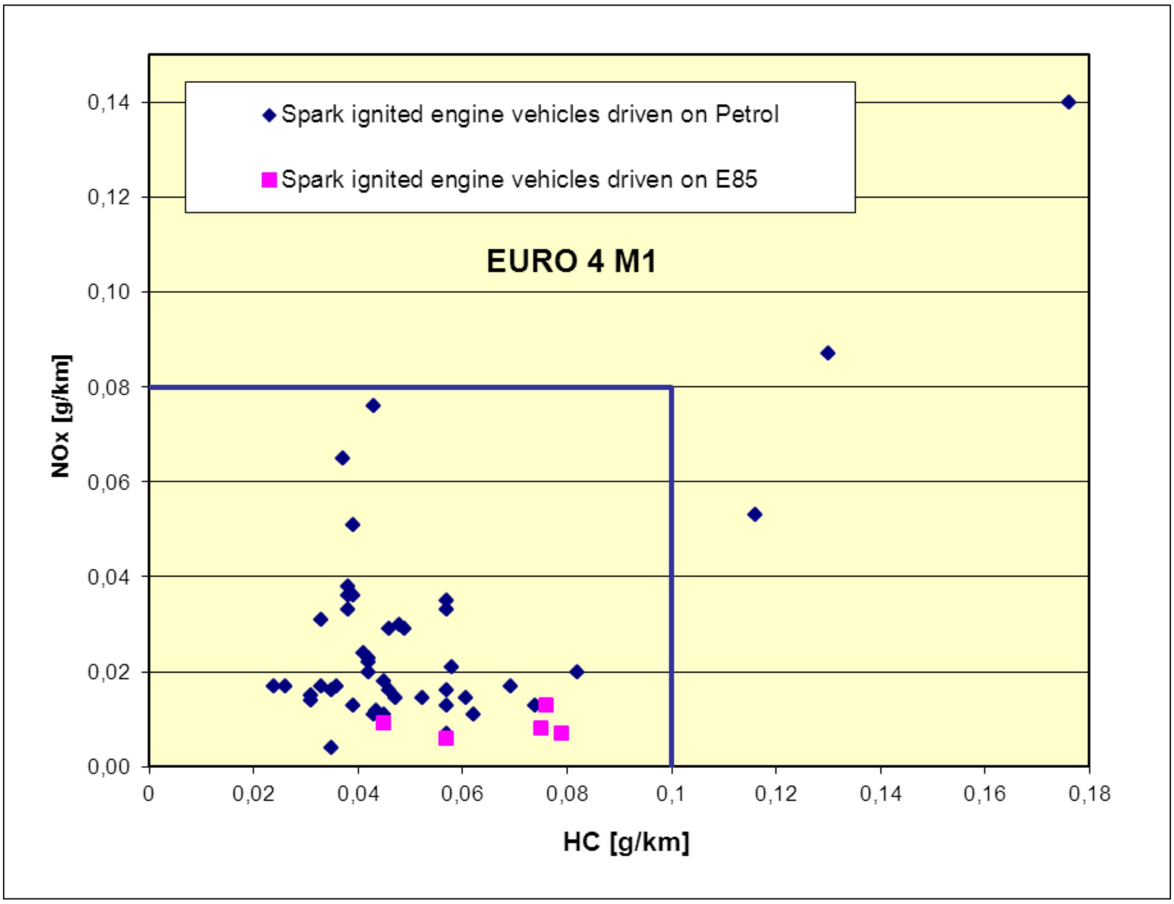


Figure 14: NO_X and HC emissions of vehicles with SI-engine during Type I test

Figure 15 shows the average CO and NO_X emissions during Type I test of CI-engine vehicles. As can be seen two of the Euro 4 N1 class III vehicles and one of the Euro 4 M1 vehicles exceeded the Euro 4 limit.

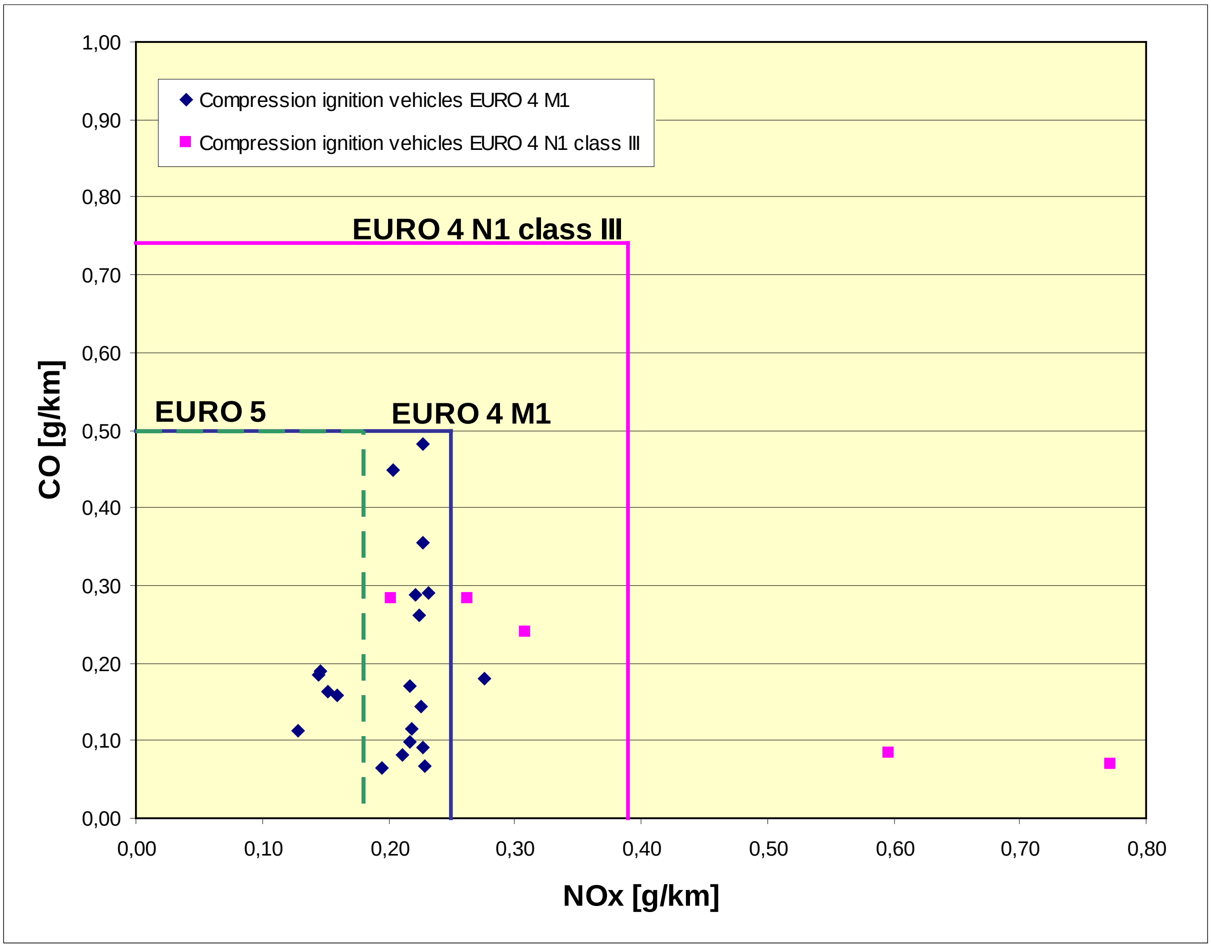


Figure 15: CO and NO_X emissions from Euro 4 M1 vehicles and Euro 4 N1 class III vehicles with CI-engine during Type I test

PM and NO_X emissions during Type I test of CI-engine vehicles. As can be seen two of the Euro 4 N1 class III vehicles and one of the Euro 4 M1 vehicles exceeded the Euro 4 limit. The N1 class III vehicles were also equipped with Diesel Particulate Filter (DPF).

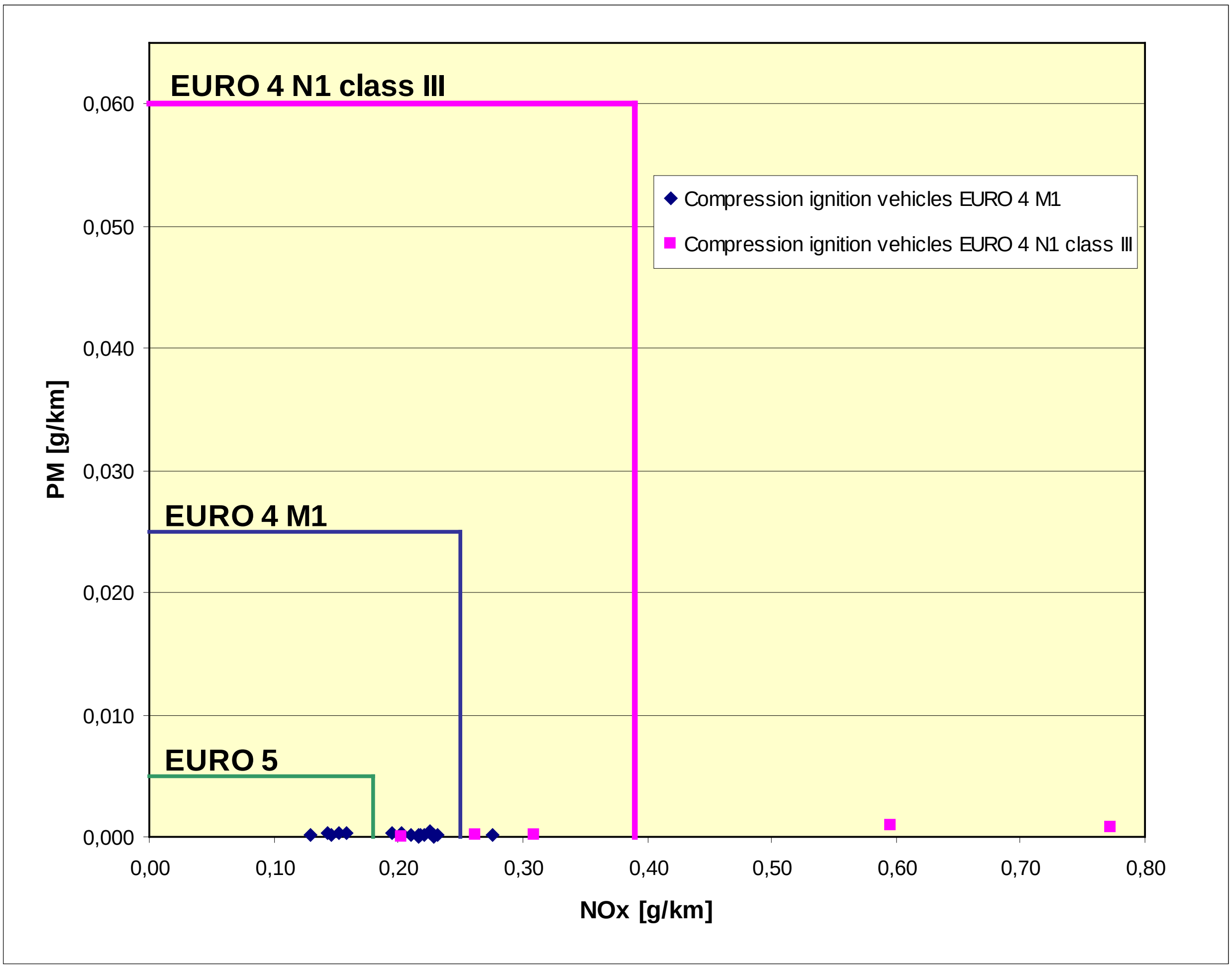


Figure 16: PM and NO_X emissions from Euro 4 M1 vehicles and Euro 4 N1 class III vehicles with CI-engine during Type I test

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 emission 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 of at least 3,000 km, but for less than 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.

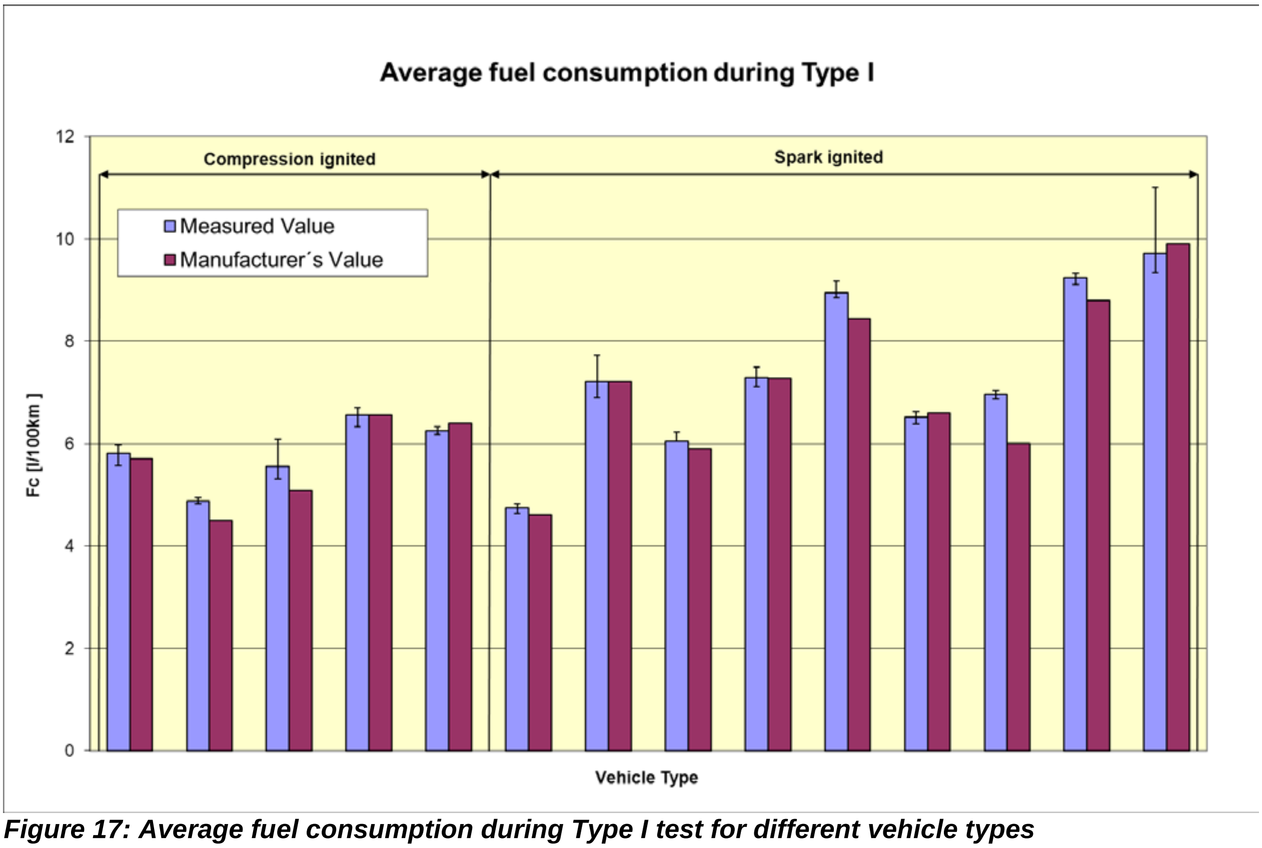


Figure 17: Average fuel consumption during Type I test for different vehicle types

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

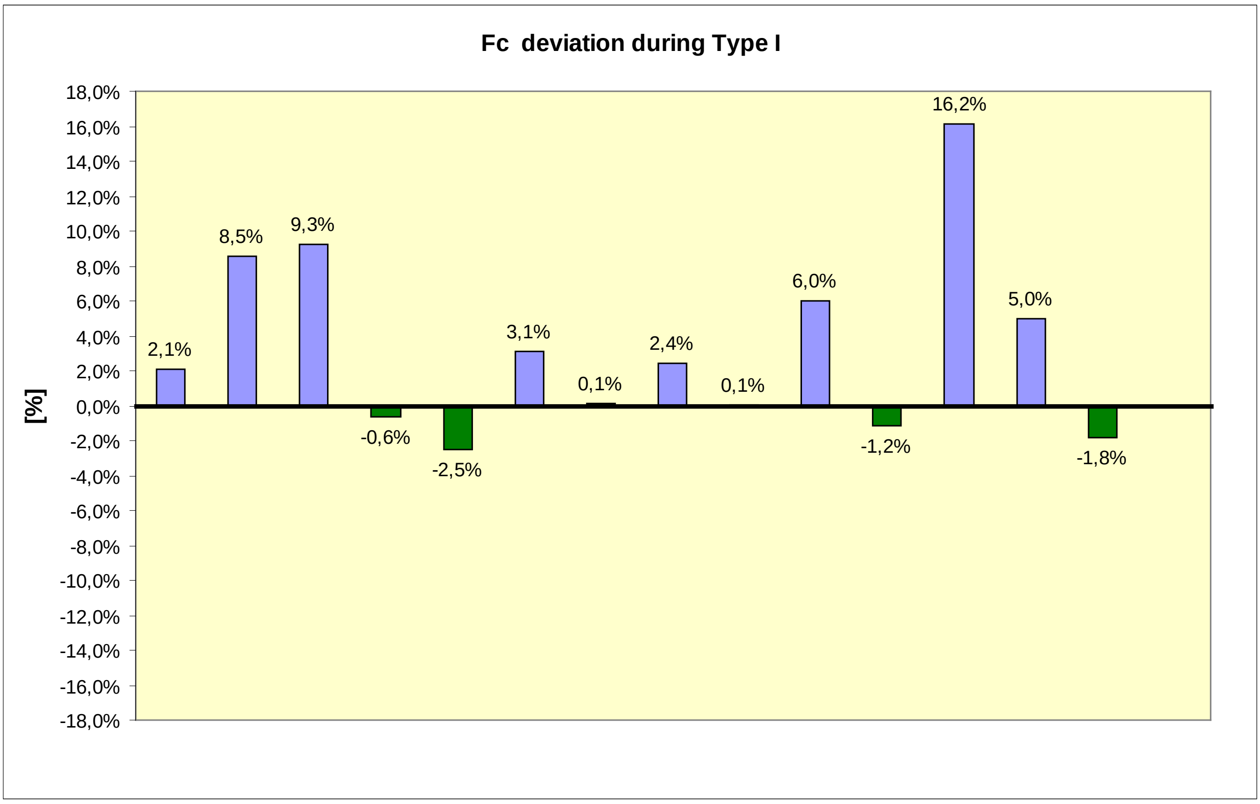


Figure 18: Relative deviation of the FC towards the manufacturer's values during Type I test for different vehicles types

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

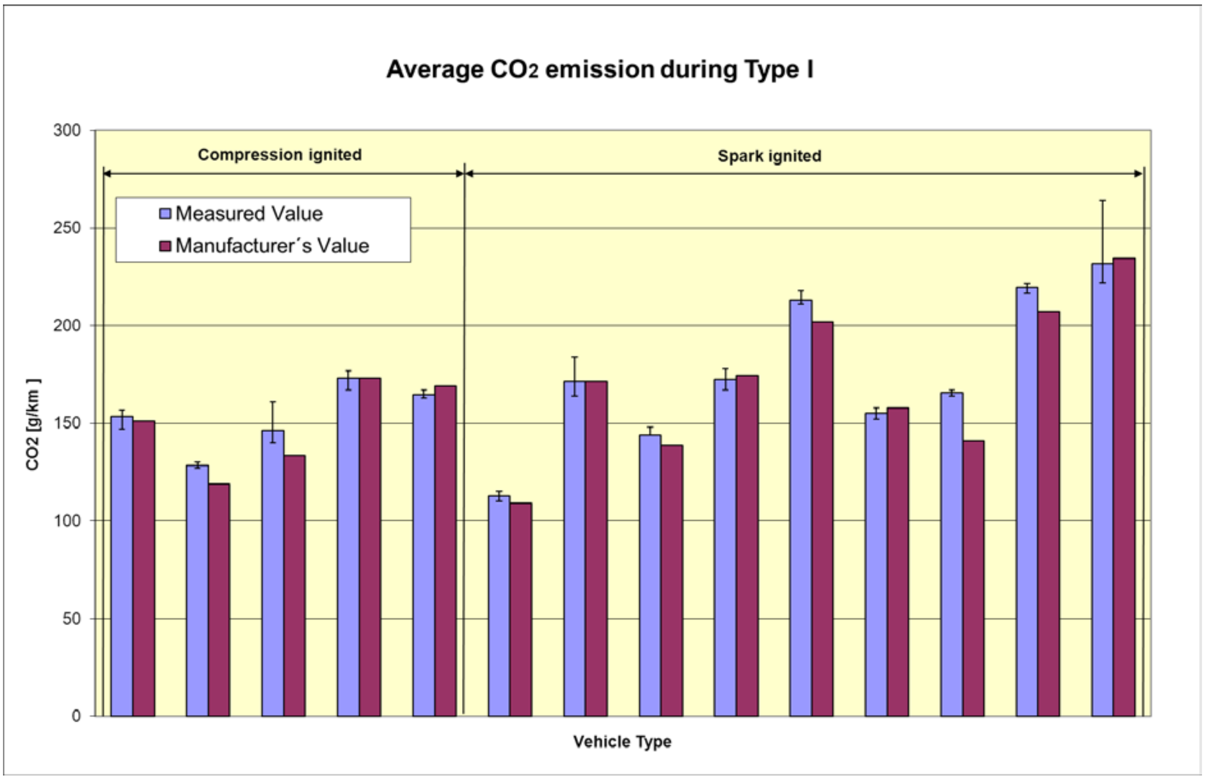


Figure 19: Average CO_2 emissions during Type I test for different vehicle types

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

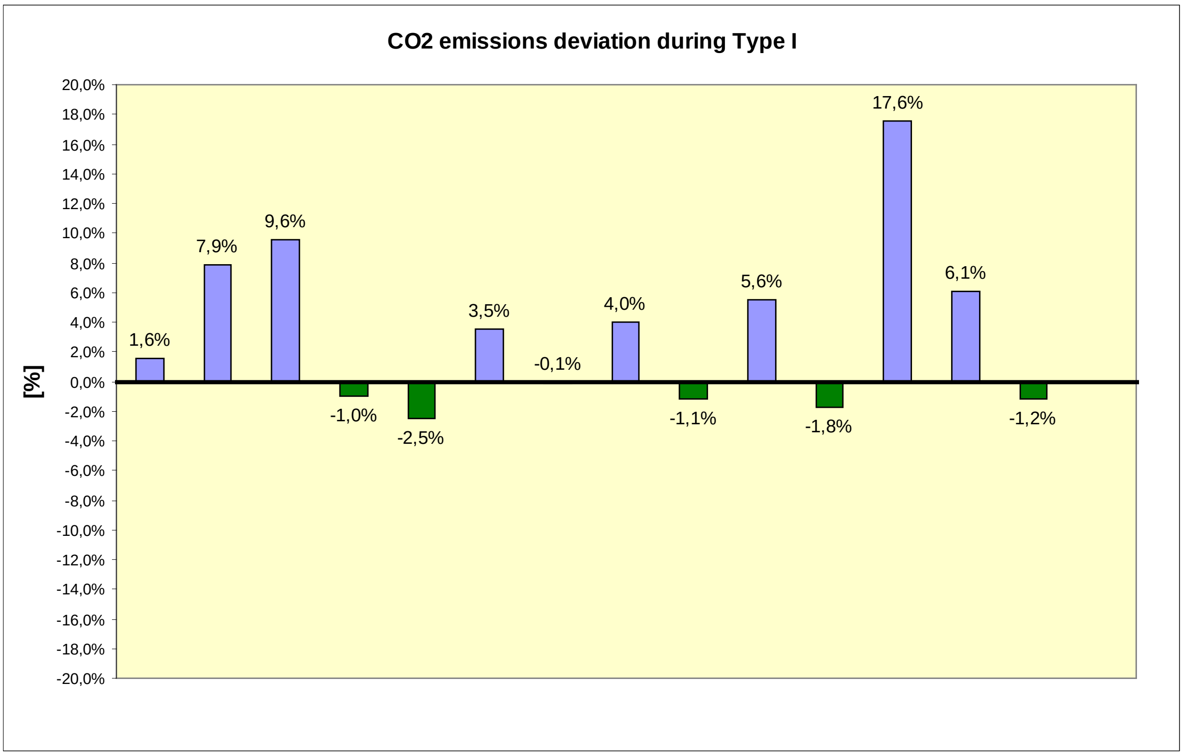


Figure 20: Relative deviation of the CO_2 emissions towards the manufacturer's values during Type I test for different vehicles types

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 every vehicle complied within 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]	CO_2 [%vol.]	λ
Average Gasoline	0,004	3	14,9	0,985
Limits	3,5	-	-	-
	High Idle (2.500 rpm)			
	CO [%vol.]	HC [ppm]	CO_2 [%vol.]	λ
Average Gasoline	0,002	2	14,9	1,007
Limits	-	-	-	-
	Idle			
	CO [%vol.]	HC [ppm]	CO_2 [%vol.]	λ
Average E85	0	0	11,8	0,801
Limits	3,5	-	-	-
	High Idle (2.500 rpm)			
	CO [%vol.]	HC [ppm]	CO_2 [%vol.]	λ
Average E85	0	1	11,8	0,801
Limits	-	-	-	-

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.

On two out of forty-five vehicles crankcase overpressure were detected at different loads.

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

Evaporative Emissions (Type IV test)

When the fuel system of petrol (or ethanol) fuelled vehicles for some reason is exposed to heat, the vapour pressure in the fuel system increase and some of the vapour may begin to 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.

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 this In-Service Testing Programme of 2010, measurement of evaporative emissions was carried out on two vehicles per type with SI-engine. Prior to testing, all loose things, such as perfumes, rugs, bottles etc. were removed in order to not influence the results. Vehicles carrying for example a plastic fuel container on board were not tested due to risk for hydrocarbon contamination.

Figure 21 illustrates the Type IV test flow.

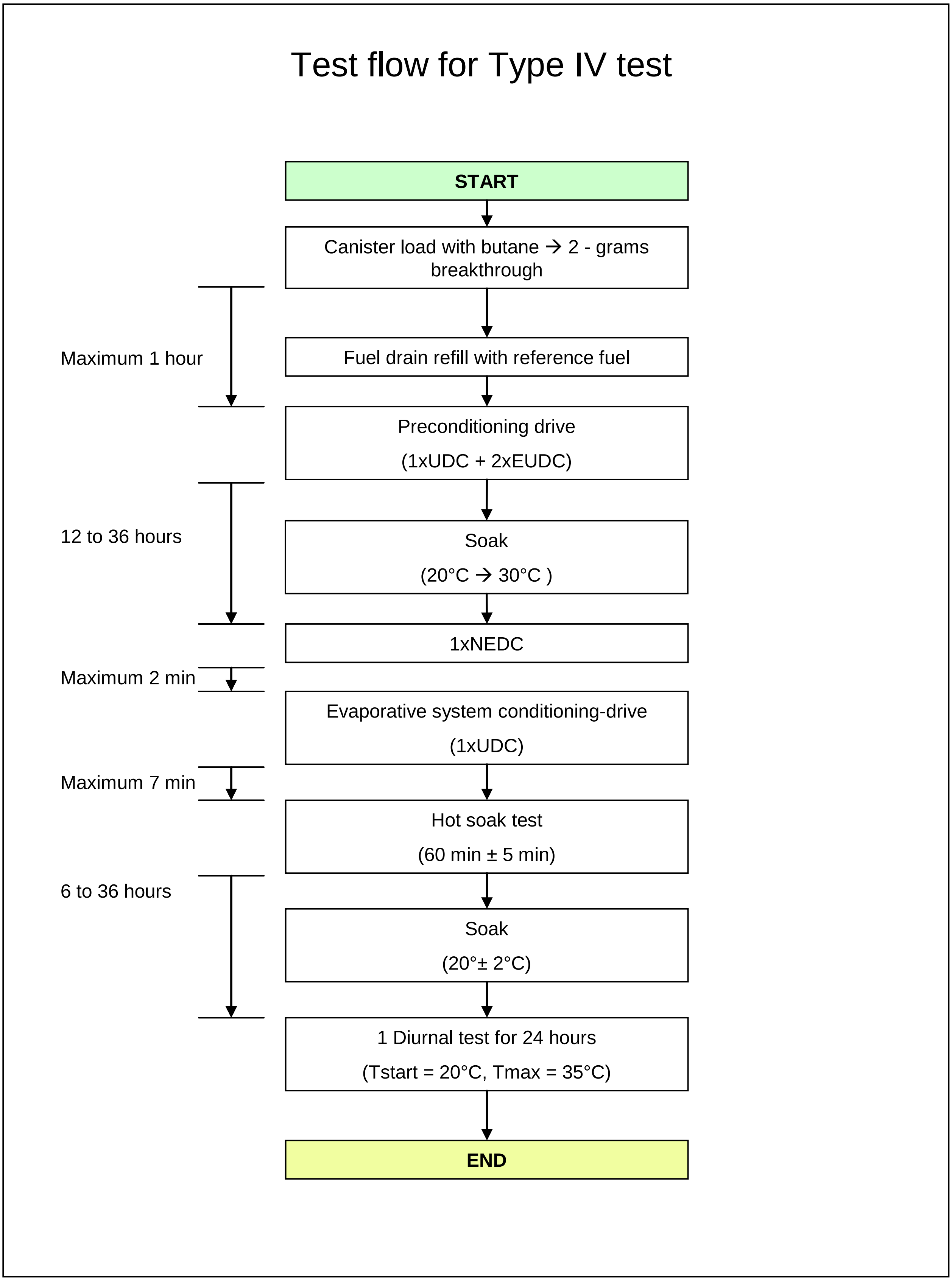


Figure 21: Type IV test procedure

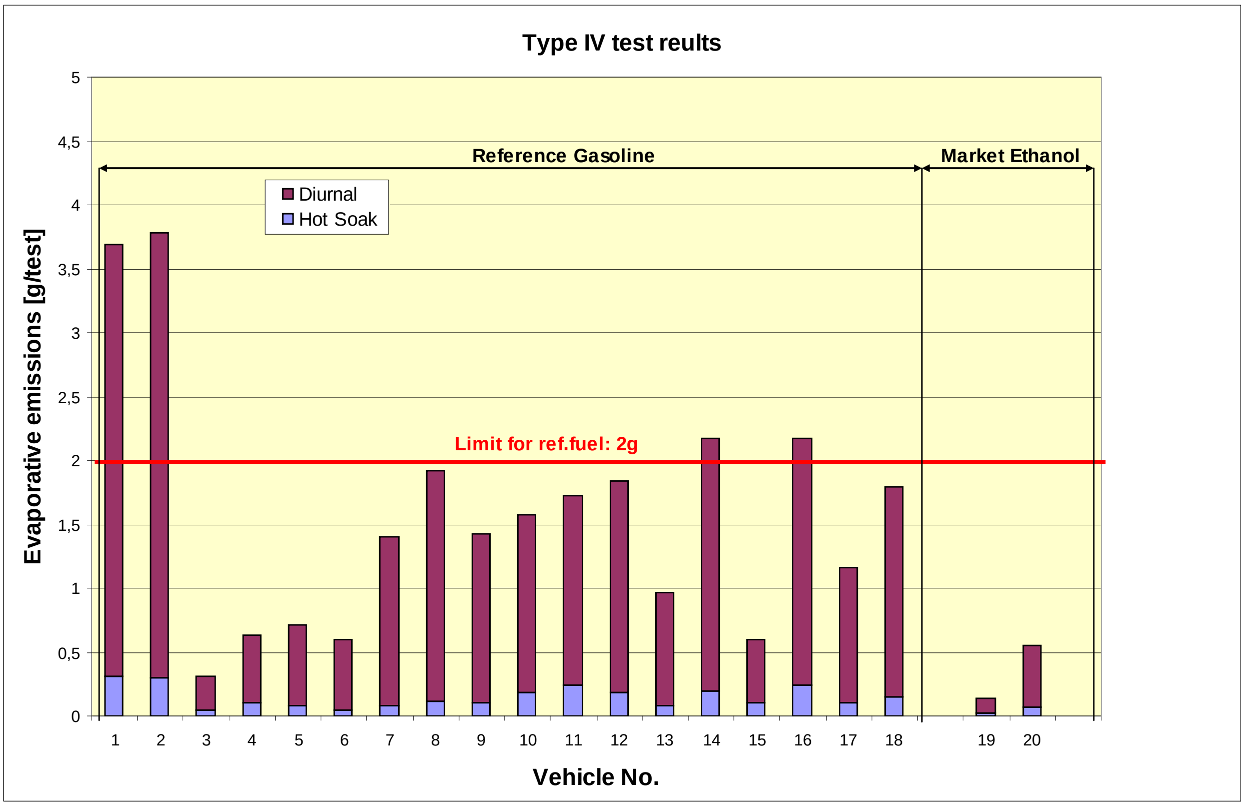


Figure 22: Results from Type IV test

For the 2010 In-Service Testing Programme, gasoline and E85 were used as fuel for SI-engine vehicles. In total, 20 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 1,46 g HC/test. Based on the directive, four of the gasoline vehicles failed to comply with the Euro 4 limits. The ethanol fuelled vehicles fulfilled the emission regulation limit.

Note that vehicle 3 and 4 are tested on gasoline and again the same vehicles (No.19 and No.20) were tested on ethanol (E85).

	Evaporative emissions [g HC]		
Vehicle No.	**Hot Soak**	**Diurnal**	**Total**
1	0,315	3,376	3,691
2	0,294	3,486	3,78
3	0,041	0,272	0,313
4	0,103	0,532	0,635
5	0,028	0,107	0,135
6	0,069	0,479	0,548
7	0,08	0,628	0,708
8	0,047	0,553	0,6
9	0,086	1,322	1,408
10	0,117	1,807	1,924
11	0,099	1,328	1,427
12	0,183	1,391	1,574
13	0,244	1,48	1,724
14	0,185	1,656	1,841
15	0,086	0,877	0,963
16	0,193	1,98	2,173
17	0,105	0,488	0,593
18	0,238	1,940	2,178
19	0,102	1,064	1,166
20	0,154	1,64	1,794
	Average		
	0,14	**1,32**	**1,46**
	Limit		
	—	—	**2**

Table 8: Type IV Average evaporative emissions

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

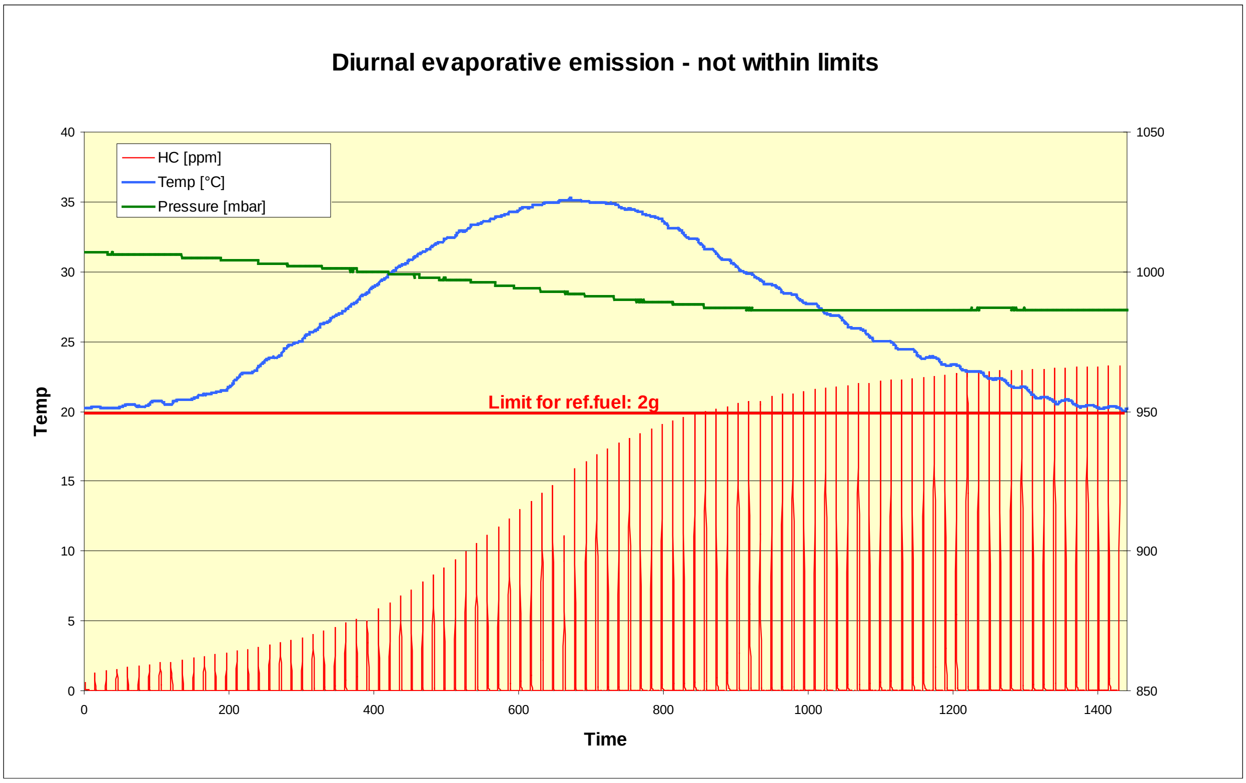


Figure 23: Type IV test - vehicle not within limits

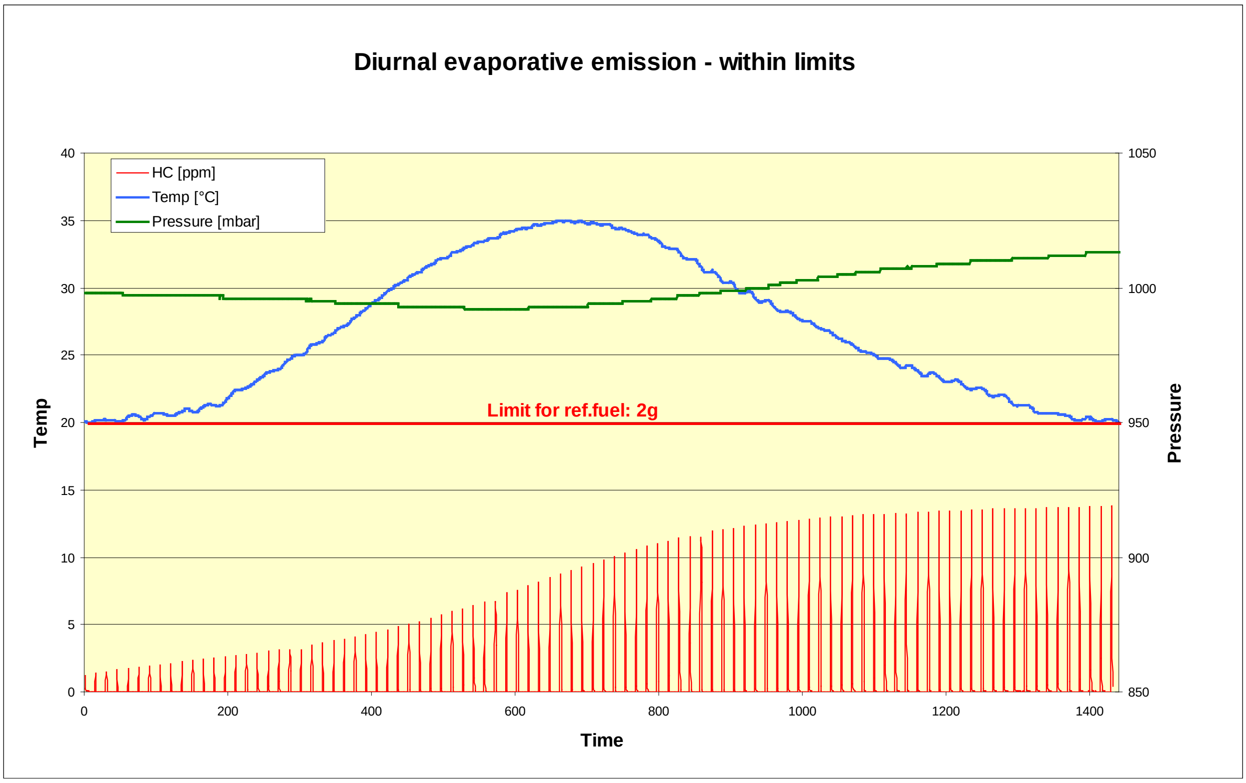


Figure 24: Type IV test – vehicle within limits

The correlation between diurnal loss and total result of the Type IV test is shown I Figure 25.

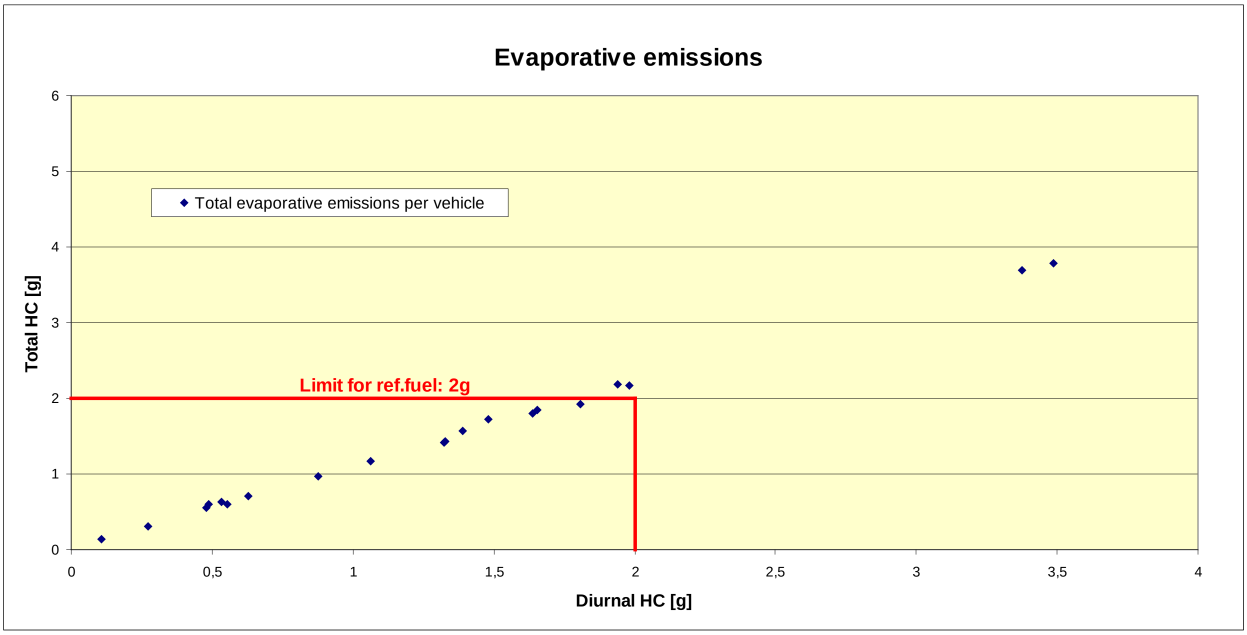


Figure 25: Evaporative emissions correlation from Type IV test

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 2010 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. Note worthy is that none of the tested ethanol fuelled vehicles did comply within the Type VI test directive regarding HC emissions.

Vehicles with SI-engine		Exhaust emissions			
Test	**Cycle**	**CO [g/km]**	**HC [g/km]**	**NOx [g/km]**	**CO2 [g/km]**
Type I	UDC Gasoline	0,950	0,137	0,059	238
	UDC E85	2,163	0,174	0,021	310
Type VI	UDC Gasoline	5,214	1,090	0,122	263
	UDC E75 (1)	10,615	3,505	0,067	339
Limit VI	**UDC Gasoline**	**15**	**1,8**	**-**	**-**

(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.

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

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).

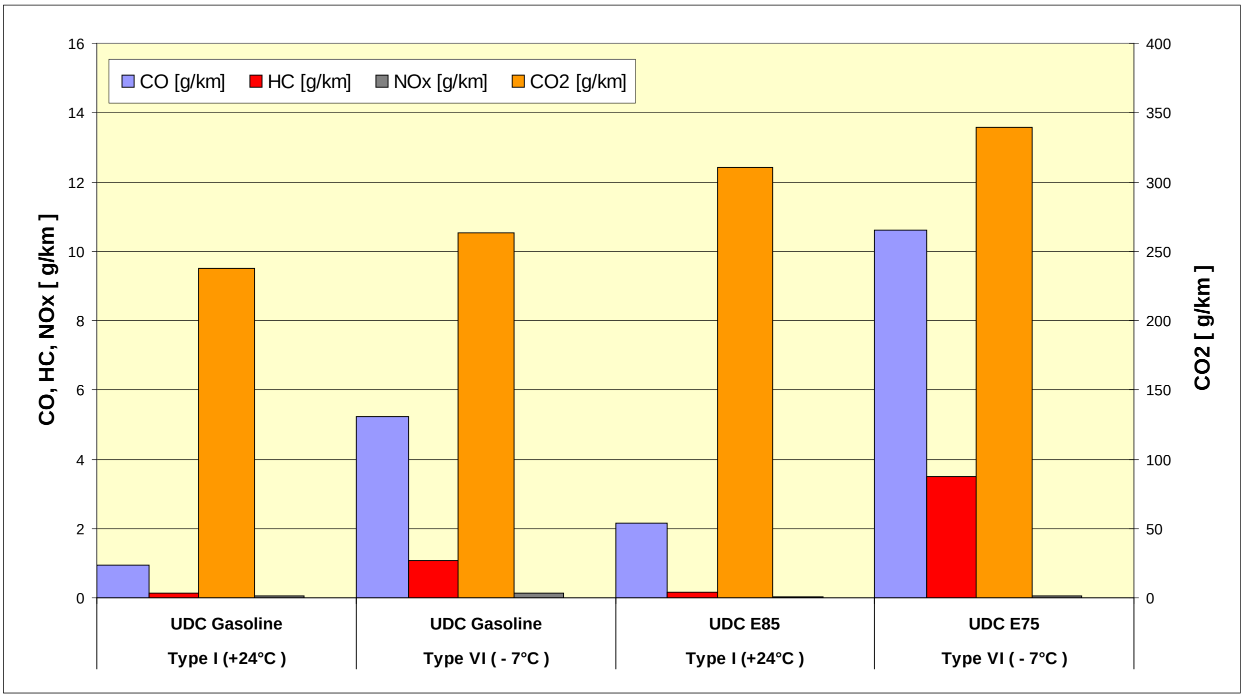


Figure 26: Compilation of average exhausts emissions at low ambient temperatures during Type VI compared with Type I test

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

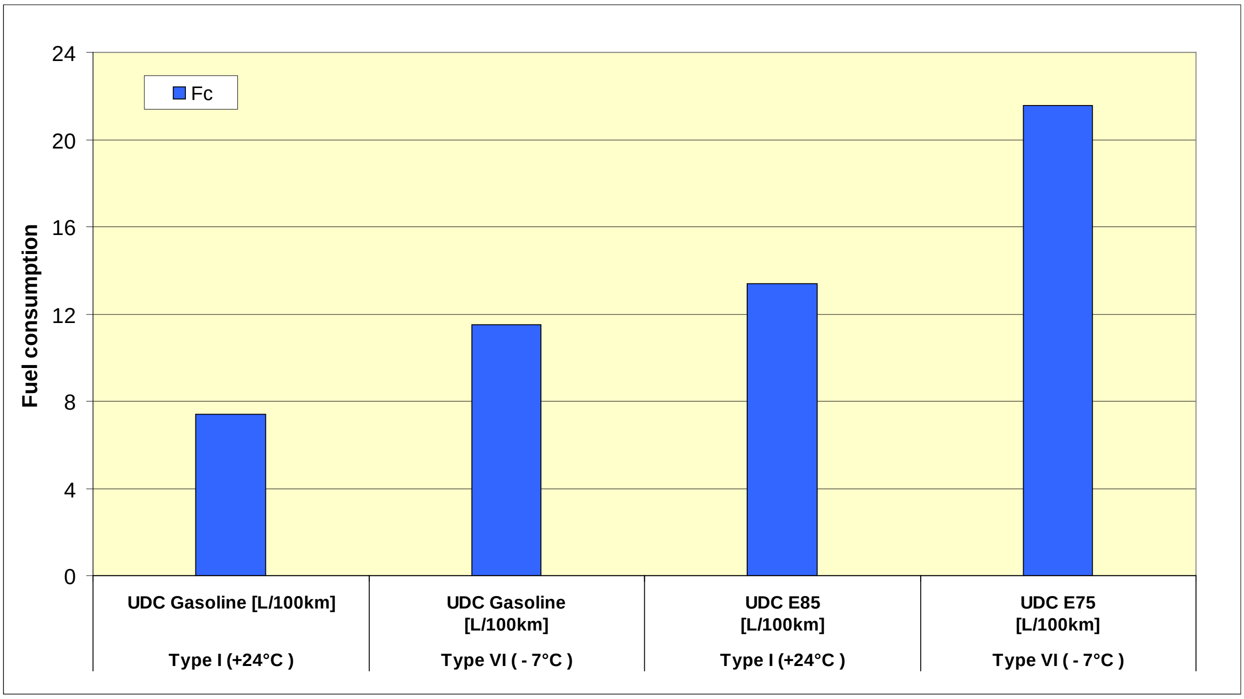


Figure 27: Average fuel consumption at low ambient temperatures during Type VI compared with Type I test

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

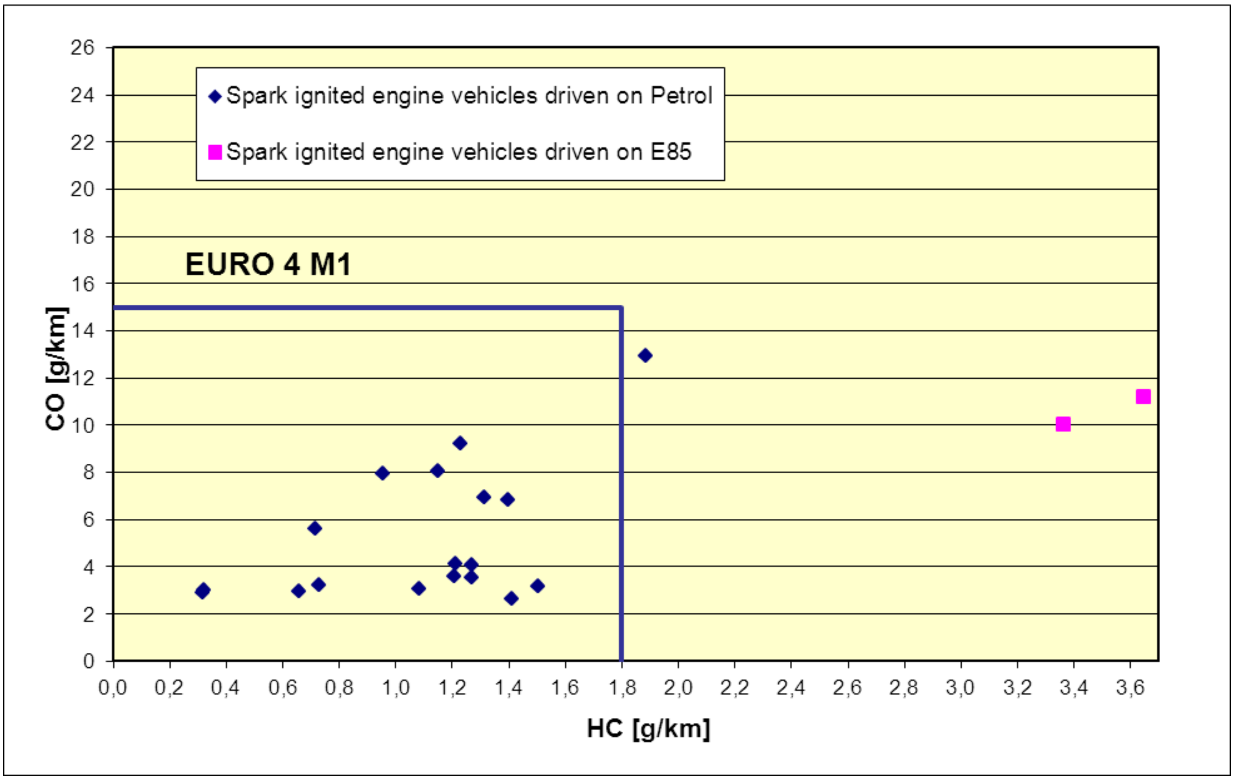


Figure 28: CO and HC emissions at low ambient temperatures (Type IV (- 7°C))

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

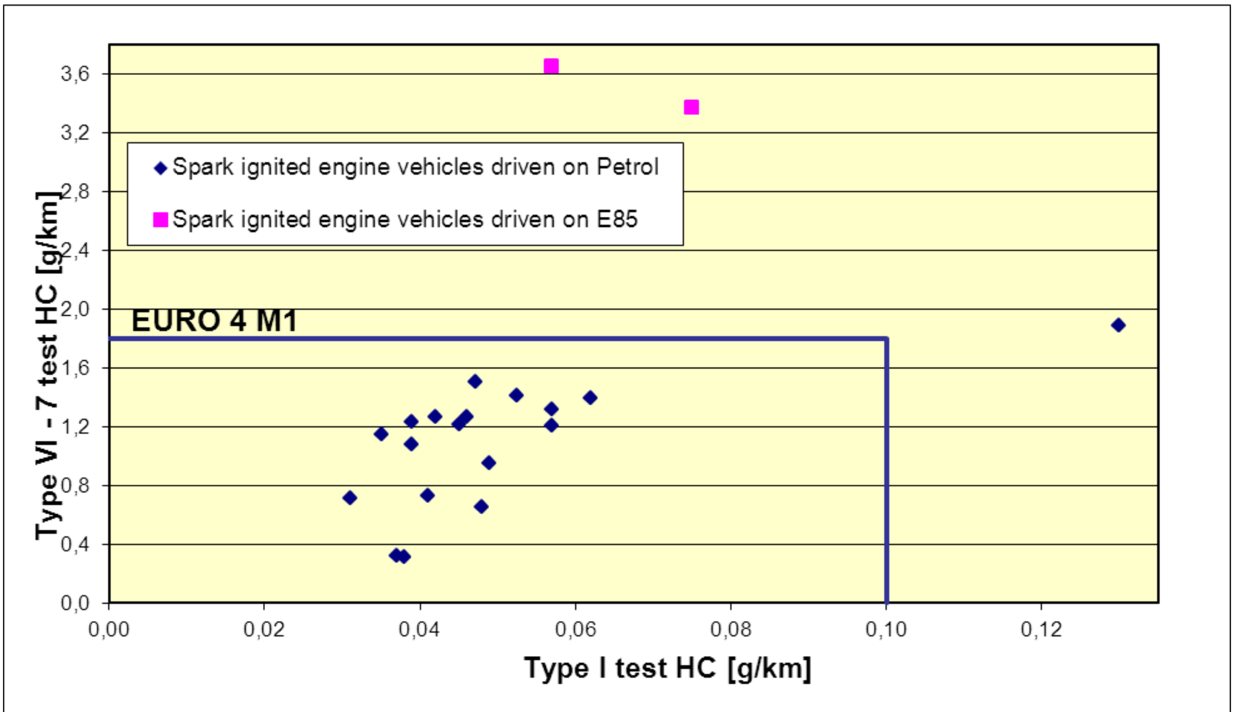


Figure 29: HC emissions during Type I and Type VI test (- 7°C)

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]	PM2 [g/km]
Gasoline Euro 4	NEDC	Average	0,4117	0,0520	0,0278	0,0005	0,0006
		Std.dev.	0,1246	0,0160	0,0122	0,0003	0,0004
	ARTEMIS Urban Cold	Average	1,5765	0,1512	0,1251	0,0020	0,0021
		Std.dev.	0,0862	0,0119	0,0087	0,0002	0,0003
	ARTEMIS Urban	Average	0,4458	0,0115	0,0580	0,0005	0,0005
		Std.dev.	0,0733	0,0017	0,0110	0,0001	0,0001
	ARTEMIS Road	Average	0,3090	0,0042	0,0194	0,0005	0,0006
		Std.dev.	0,0355	0,0006	0,0024	0,0001	0,0003
	ARTEMIS Motorway	Average	2,1231	0,0177	0,0246	0,0022	0,0018
		Std.dev.	0,1278	0,0011	0,0048	0,0002	0,0005
Diesel Euro 4 M1	NEDC	Average	0,1962	0,0216	0,2490	0,0002	0,0002
		Std.dev.	0,0800	0,0101	0,0686	0,0002	0,0001
	ARTEMIS Urban Cold	Average	0,3535	0,0318	0,6943	0,0007	0,0007
		Std.dev.	0,0303	0,0029	0,0591	0,0001	0,0004
	ARTEMIS Urban	Average	0,0631	0,0071	0,8837	0,0013	0,0021
		Std.dev.	0,0108	0,0043	0,0647	0,0002	0,0004
	ARTEMIS Road	Average	0,0380	0,0066	0,4751	0,0007	0,0013
		Std.dev.	0,0140	0,0013	0,0311	0,0001	0,0002
	ARTEMIS Motorway	Average	0,0114	0,0025	0,8214	0,0009	0,0012
		Std.dev.	0,0008	0,0006	0,0494	0,0001	0,0011
Diesel Euro 4 N1 class III	NEDC	Average	0,1922	0,0204	0,4282	0,0004	0,0005
		Std.dev.	0,1072	0,0099	0,2446	0,0004	0,0003
	ARTEMIS Urban Cold	Average	0,4345	0,0180	0,8446	0,0009	0,0011
		Std.dev.	0,0239	0,0027	0,1589	0,0001	0,0001
	ARTEMIS Urban	Average	0,1757	0,0051	0,9714	0,0017	0,0014
		Std.dev.	0,0183	0,0005	0,1451	0,0001	0,0002
	ARTEMIS Road	Average	0,0116	0,0028	0,4877	0,0013	0,0011
		Std.dev.	0,0022	0,0004	0,0581	0,0000	0,0000
	ARTEMIS Motorway	Average	0,0094	0,0001	0,8021	0,0010	0,0008
		Std.dev.	0,0011	0,0002	0,0371	0,0001	0,0001
Euro 4 E85	NEDC	Average	0,8074	0,0664	0,0086	0,0003	0,0003
		Std.dev.	0,1952	0,0148	0,0027	0,0002	0,0001
	ARTEMIS Urban Cold	Average	3,2557	0,2271	0,0411	0,0010	0,0008
		Std.dev.	0,2109	0,0182	0,0015	0,0002	0,0003
	ARTEMIS Urban	Average	0,0860	0,0102	0,0133	0,0008	0,0007
		Std.dev.	0,0186	0,0017	0,0050	0,0002	0,0002
	ARTEMIS Road	Average	0,0492	0,0037	0,0064	0,0004	0,0007
		Std.dev.	0,0064	0,0010	0,0024	0,0001	0,0002
	ARTEMIS Motorway	Average	0,2344	0,0259	0,0036	0,0008	0,0008
		Std.dev.	0,0185	0,0039	0,0006	0,0001	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 (1^{st} part of the NEDC-cycle) and also during ARTEMIS Urban Cold cycle (see fig 30).

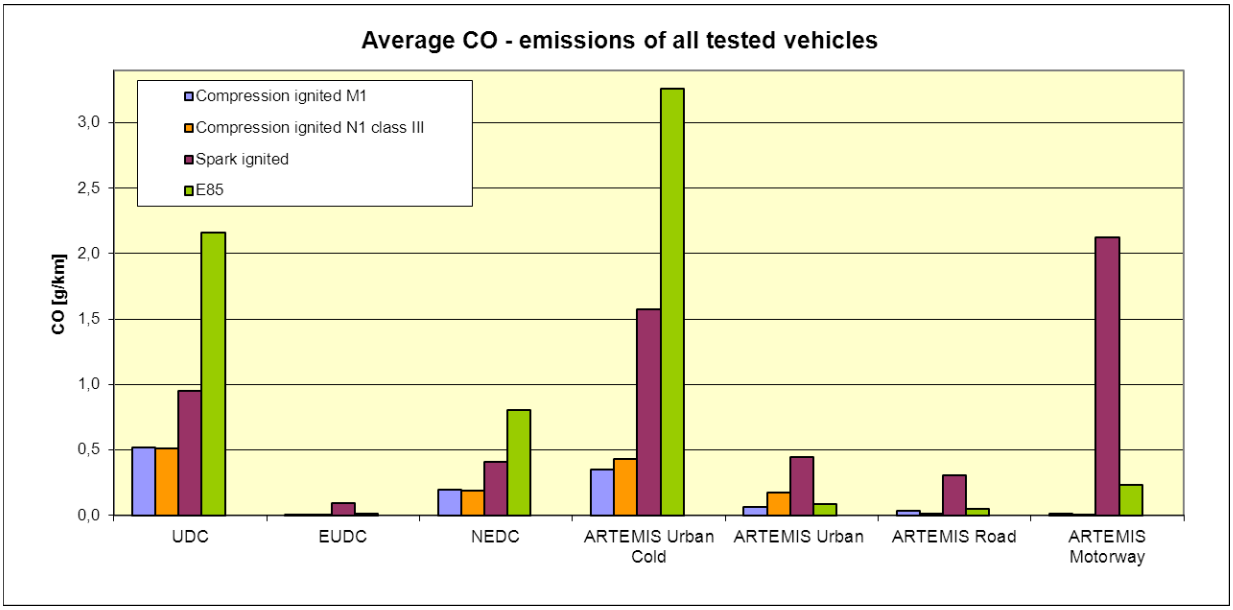


Figure 30: Average CO emissions of all tested vehicles during CADC

Figure 31 show the HC emissions from the different cycles.

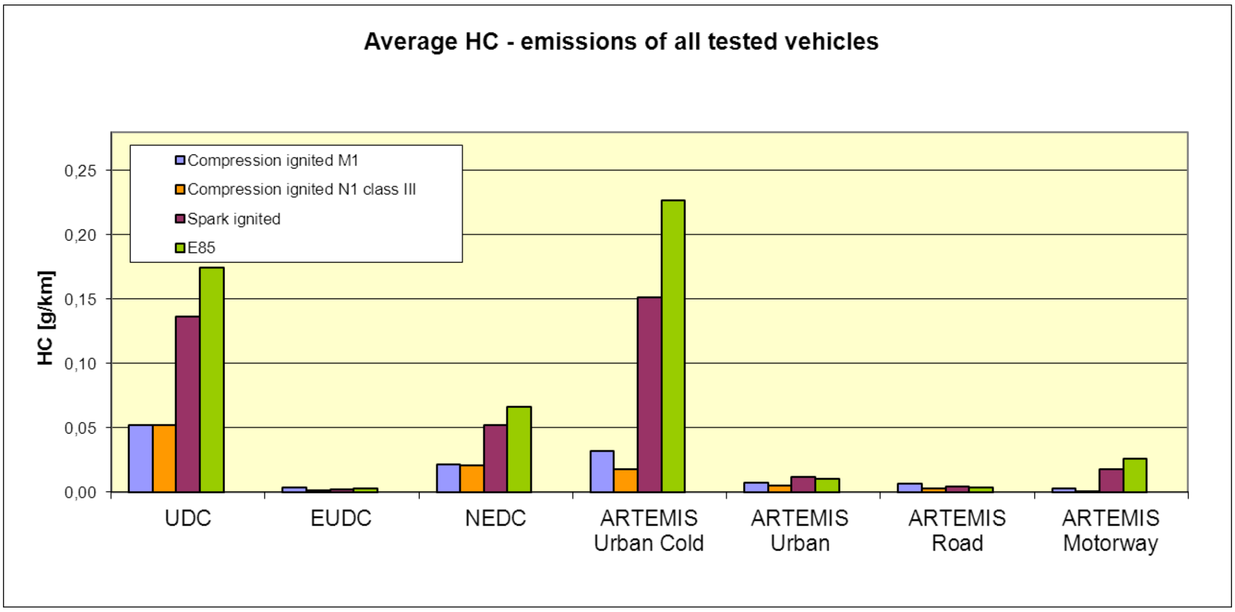


Figure 31: Average HC emissions of all tested vehicles during CADC

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.

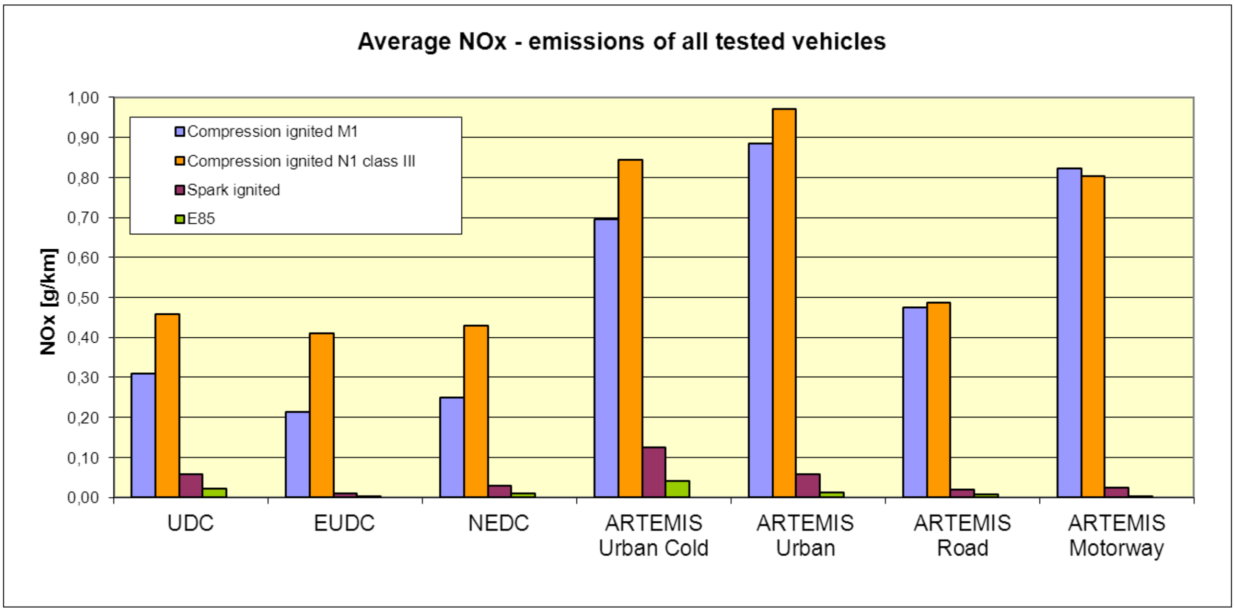
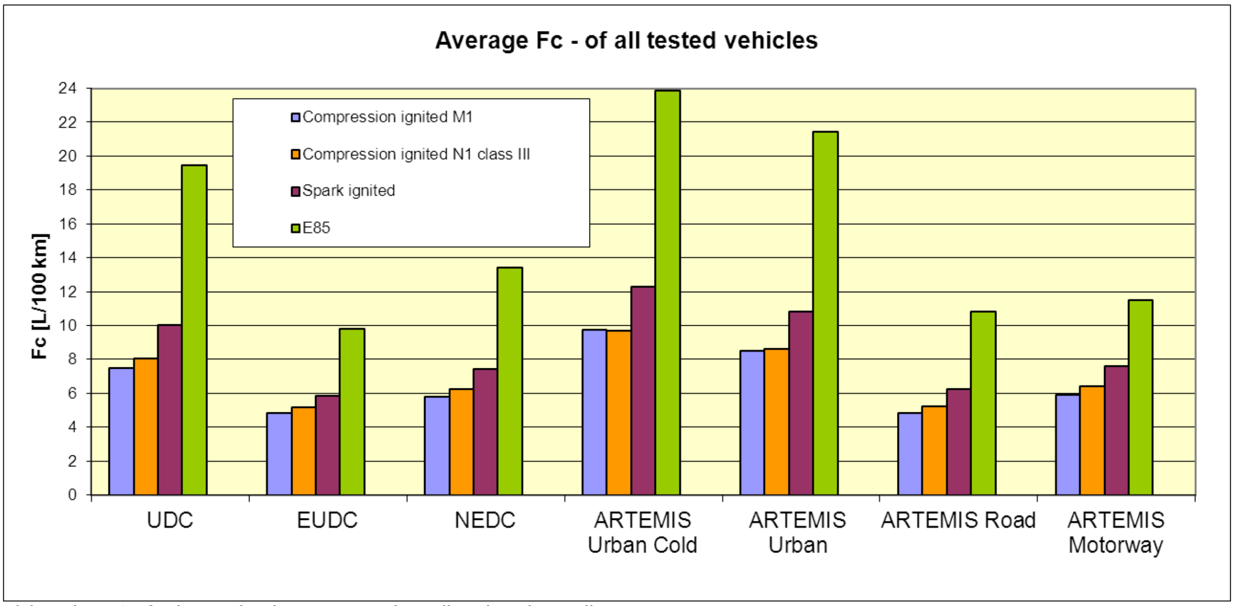


Figure 32: Average NO_X emissions of all tested vehicles during CADC

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.



(1) The E85 fuel contains less energy than diesel and gasoline

Figure 33: Average FC of all tested vehicles during CADC

Figure 34 Note that the PM level, during Type I test, tends to be higher for SI-engine vehicles without DPF compared to the CI-engine vehicles with DPF.

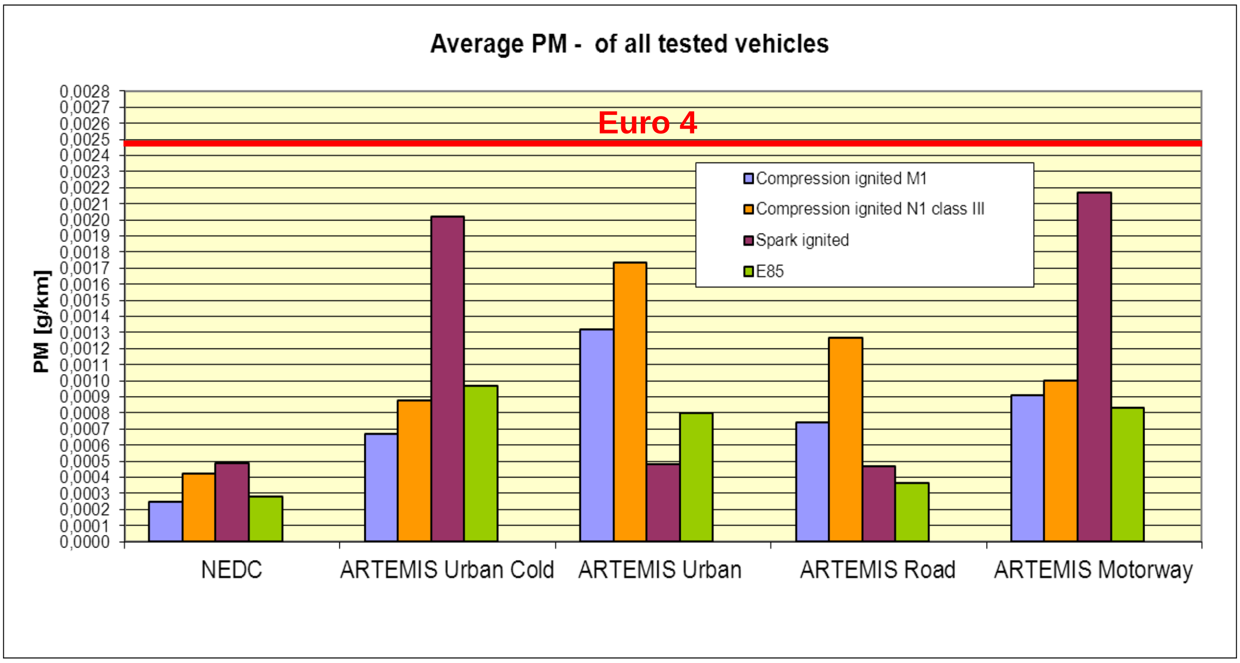


Figure 34: Average PM of all tested vehicles during CADC

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. As the PMP measurement protocol now is being finalised (ECE Regulation R83), new measurement systems have been developed in order to fulfil the criteria set in the regulation.

For all the vehicles tested during the 2010 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 (EURO 5), which is to be 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 measuring set-up is illustrated in figure 35 below.

Exhaust gas is sampled from a CVS tunnel and diluted with HEPA filtered compressed air. Inside the evaporation tube the diluted exhaust gas is heated to a degree that causes the volatile emission components to vaporize, leaving only the solid particles behind. After that, the exhaust gas is diluted once again using a porous tube diluter and fed into the Condensation Particle Counter (CPC).

In the CPC, butanol is condensed on to the exhaust gas particles in order to enlarge them so that they become visually detectable. The enlarged particles are then counted based on the scattered light pulses generated when the particles pass through the laser beam. This makes it possible to determine the number of particles per volume unit. According to PMP specifications, particles that exceed the size of 23nm are measured with an efficiency of 50±12% and particles exceeding 30nm are measured with an efficiency of 70±12%. Particles any smaller are not measured.

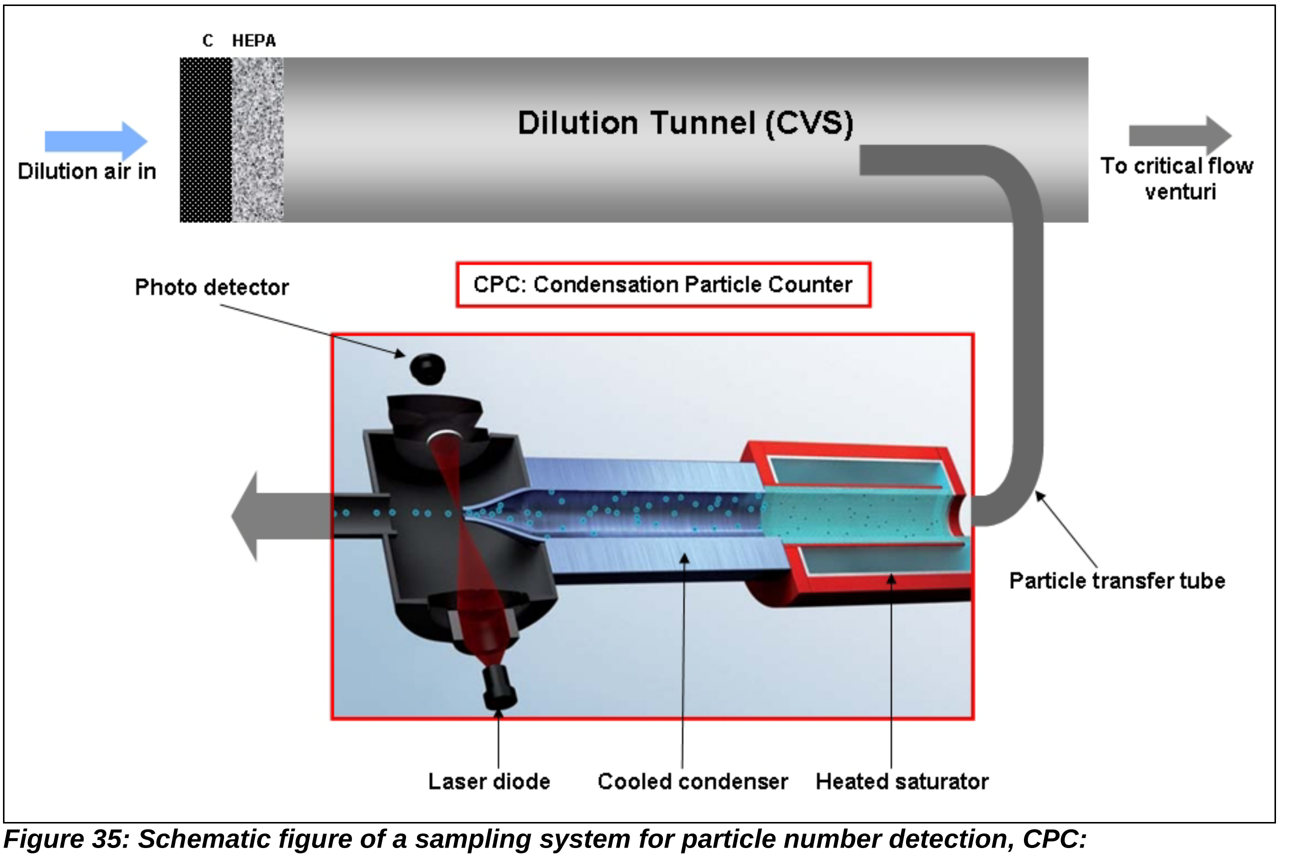


Figure 35: Schematic figure of a sampling system for particle number detection, CPC: Condensation Particle Counter

The Euro 6 limit for Particulate Matter (PM) is 4,5 mg/km and the Particle Number (PN) limit is $6{,}00 \cdot 10^{11}$. The regulation shall be effective from September 1st, 2011 for the type-approval on new types of vehicles and from January 1st, 2013 for all new vehicles sold, registered or put into service in the 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 to be implemented in the EU from September 1st, 2011 and is a 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
Compression ignited vehicles Euro 4 M1	PM - PMP [mg/km]	0,2	0,7	1,3	0,7	0,9
	PM [mg/km]	0,2	0,7	2,1	1,3	1,2
	PN [#/km]	6,8E+10	3,7E+11	3,0E+10	1,2E+10	2,1E+10
Compression ignited vehicles Euro 4 N1 class III	PM - PMP [mg/km]	0,4	0,9	1,7	1,3	1,0
	PM [mg/km]	0,5	1,1	1,4	1,1	0,8
	PN [#/km]	1,9E+11	5,4E+11	1,4E+10	1,4E+10	2,5E+10
Spark ignited vehicles Euro 4	PM - PMP [mg/km]	0,5	2,0	0,5	0,5	2,2
	PM [mg/km]	0,6	2,1	0,5	0,6	1,8
	PN [#/km]	4,6E+11	3,2E+12	2,7E+11	5,2E+11	8,0E+11
Spark ignited vehicles E85 Euro 4	PM - PMP [mg/km]	0,3	1,0	0,8	0,4	0,8
	PM [mg/km]	0,3	0,8	0,7	0,7	0,8
	PN [#/km]	1,8E+11	2,1E+12	6,2E+11	2,3E+11	5,0E+11

Table 12: Average particle mass and particle number.

Figure 36 shows the difference, for all tested vehicles types during Type 1 test (NEDC), between Particulate Matter measured with PM-PMP (EURO 5) compared to Particulate Matter measured with PM (EURO 4). From the result below it can be seen that the PM (EURO4) method with backup filter gather over all slightly more Particulate Matter than the PM-PMP method with single filter.

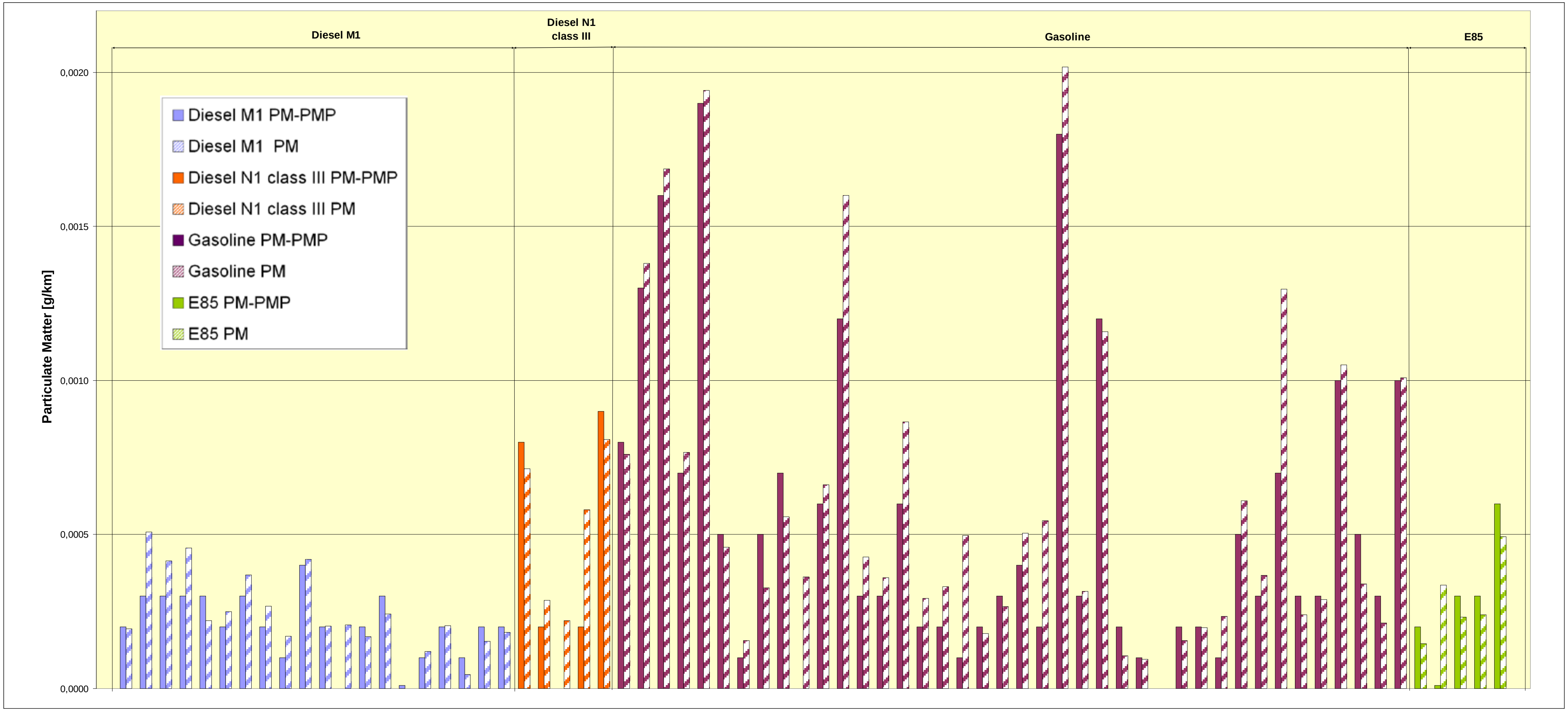


Figure 36 Difference between Particulate Matter (PM-PMP vs. PM) for all tested vehicles types during Type I test (NEDC)

Figure 37 shows the average PN# for each tested vehicle during Type I test. Both the Diesel N1 class III vehicles and the Diesel M1 vehicles were equipped with DPF.

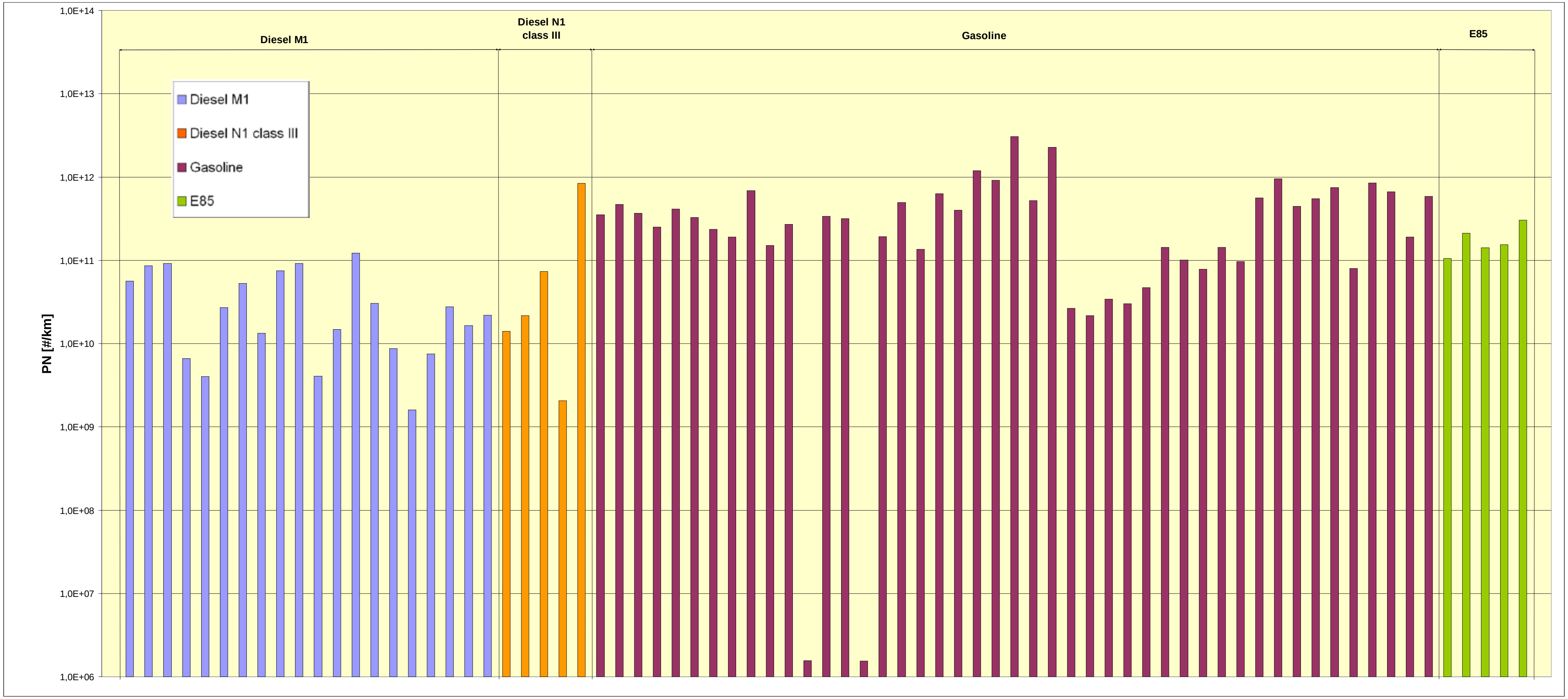


Figure 37: Particle number collection for all tested vehicles types during Type I test (NEDC)

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.

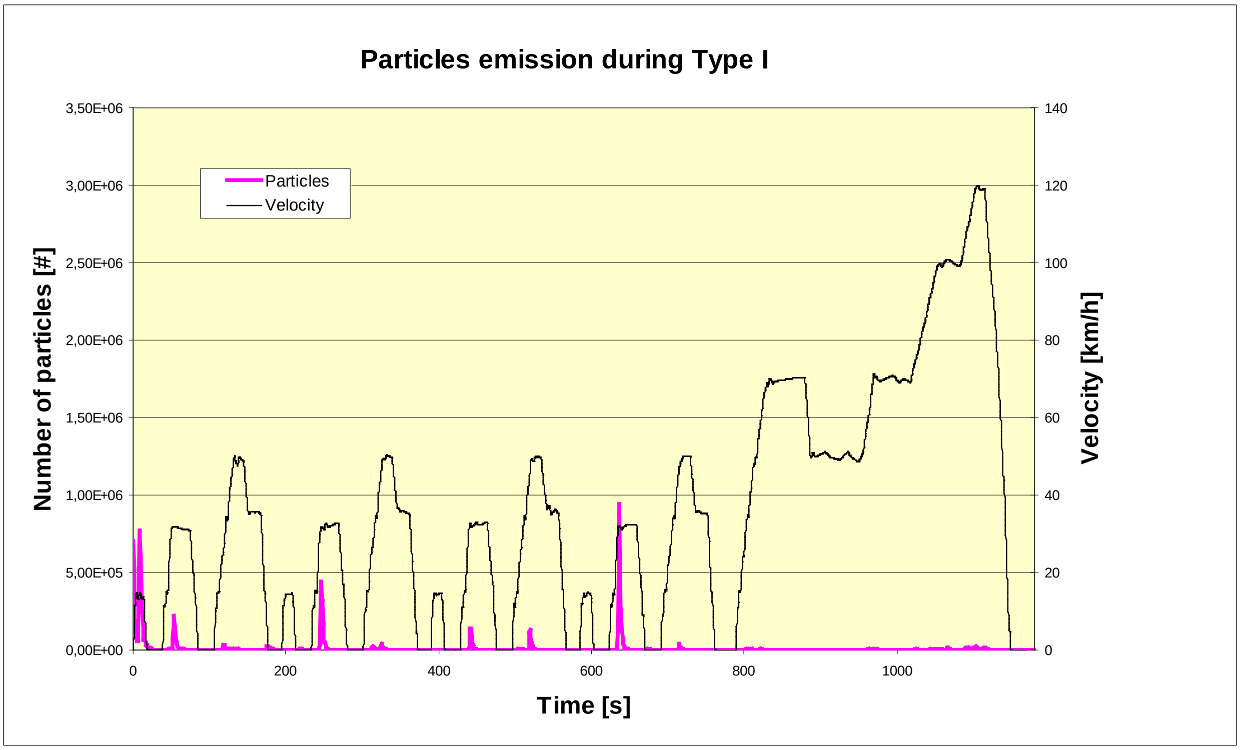


Figure 38: Particulate emissions of a Euro 4 vehicle with SI-engine during Type I test (NEDC)

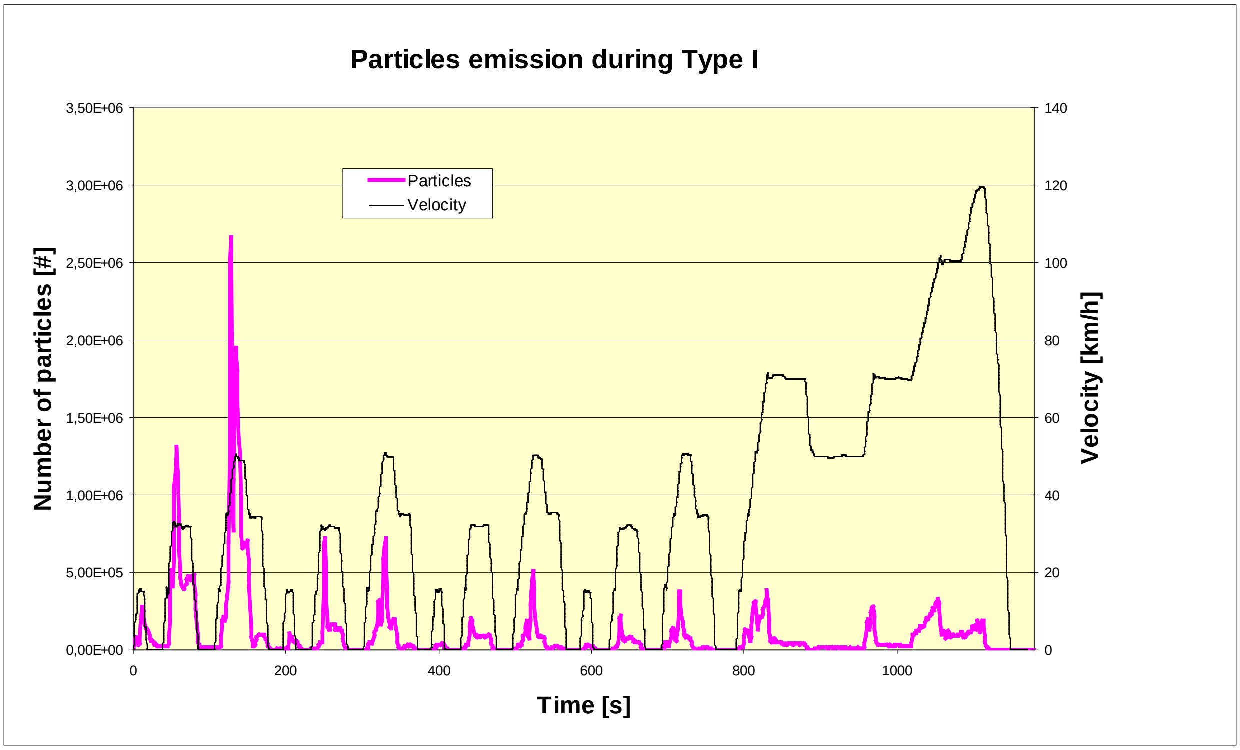


Figure 39: Particulate emissions of a Euro 4 M1 vehicle with CI-engine and DPF during Type I test (NEDC)

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 2010 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. All failures were registered and detected. All OBD-tested vehicles passed the tests according to the directive.

References

- Directive 70/220/EEC including all amendments
- Directive 80/1268/EEC including all amendments
- Euro 5/6 draft implementing legislation - Draft final version Published September 18, 2007
    - implementing and amending Regulation (EC) No 715/2007 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.

Gasoline fuel composition:

GASOLINE 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, as last amended by directive 99/100/EC, 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/dm³.
For the energy comparison the lower heating value 42.75 MJ/kg is used for the gasoline fuel.

CEC Legislative Gasoline 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 gasoline 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 gasoline fuel).

The same formula is used to calculate KH for the NO_X correction as in the gasoline 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) at A60 testing 2010:

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 guarantied 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

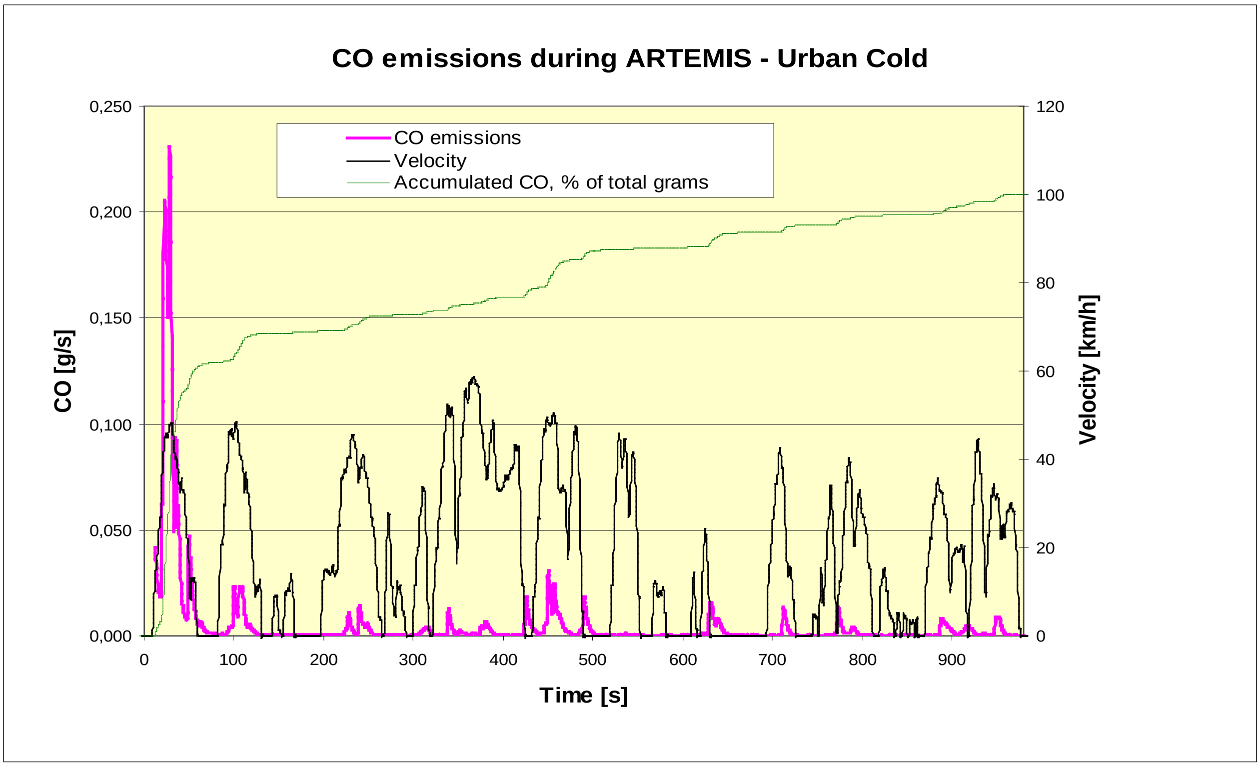


Figure 1: CO emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

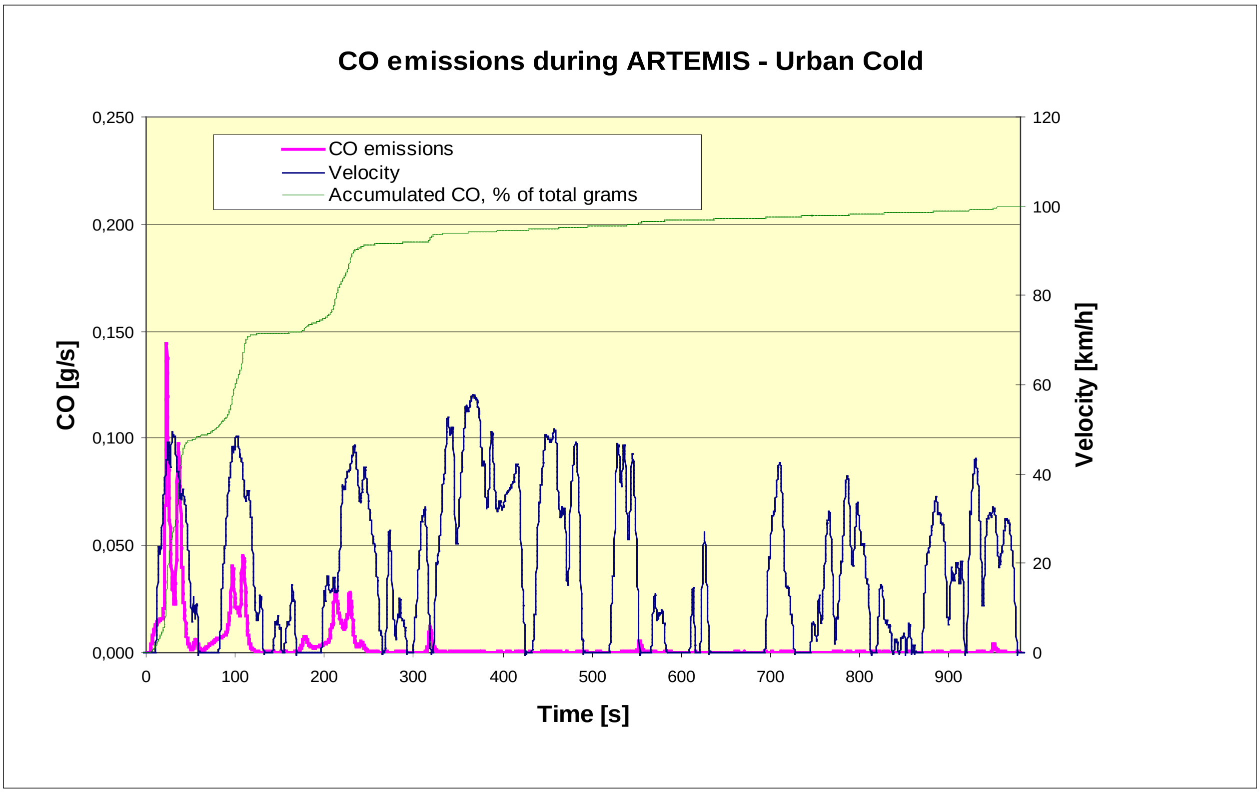


Figure 2: CO emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

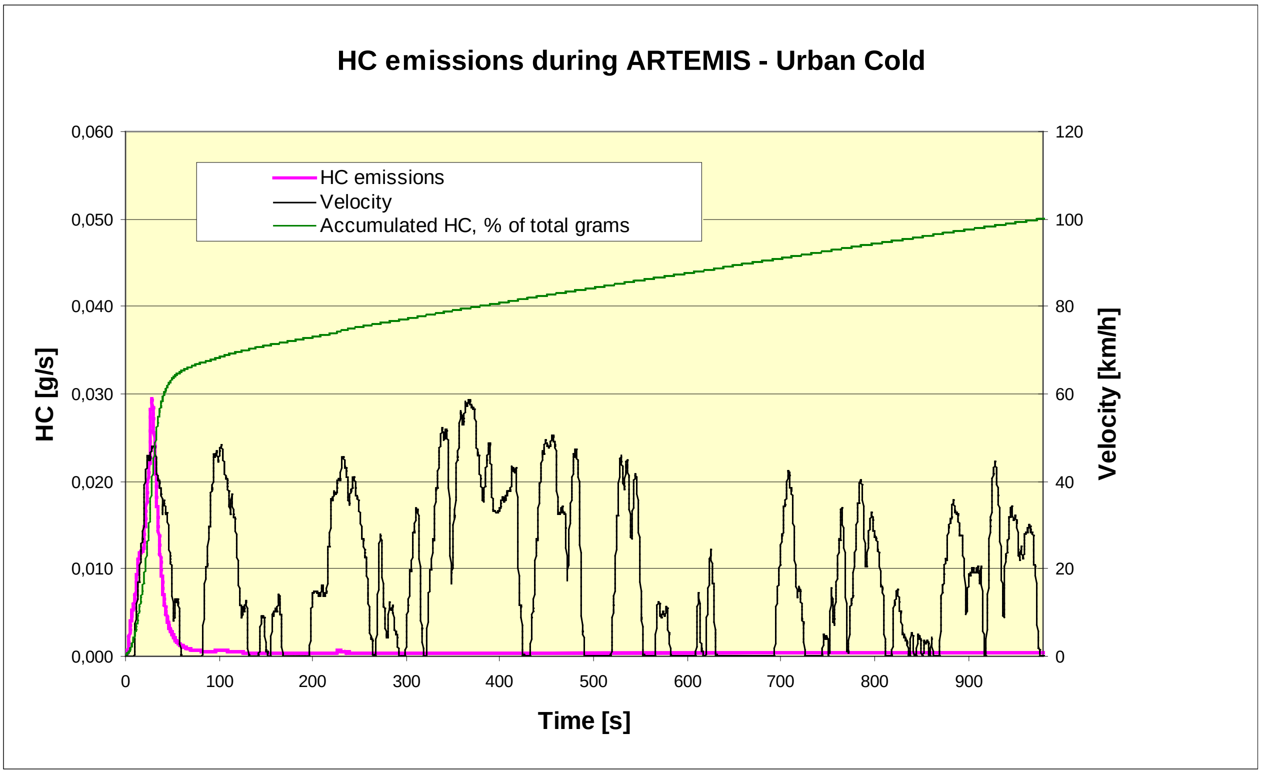


Figure 3: HC emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

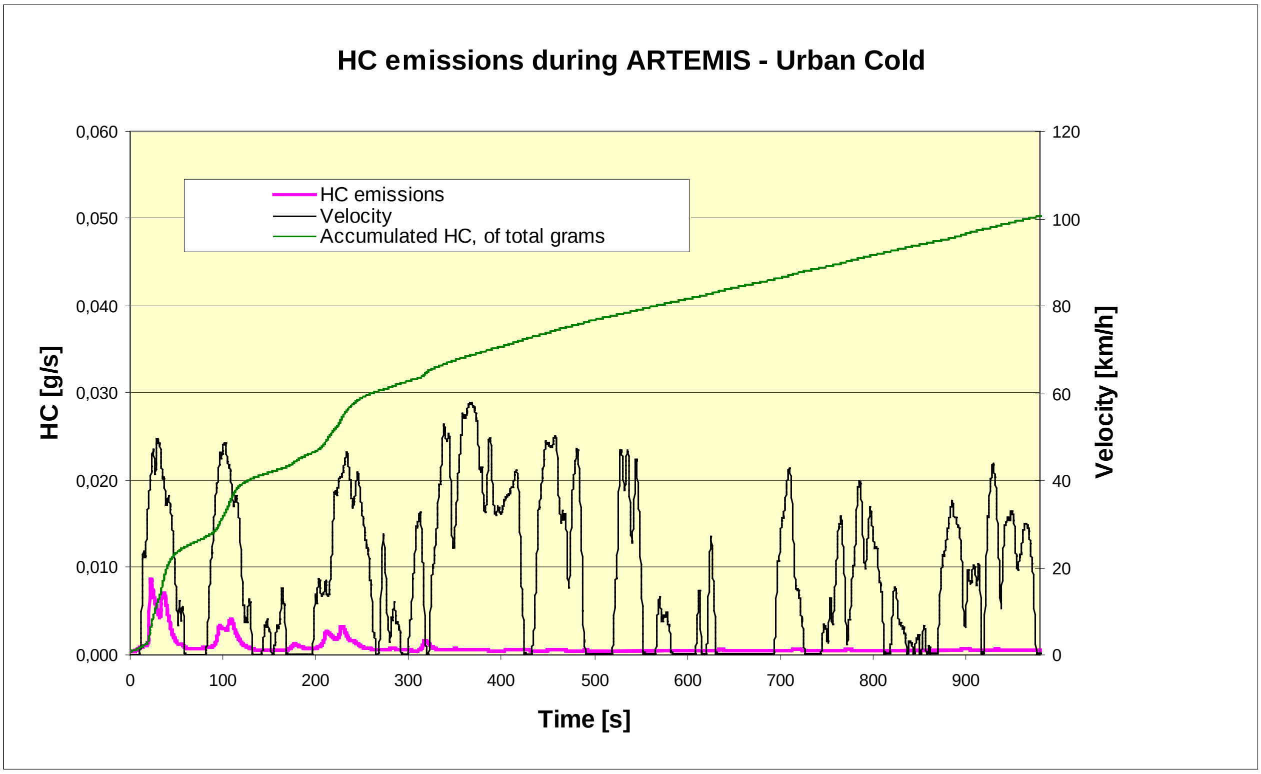


Figure 4: HC emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

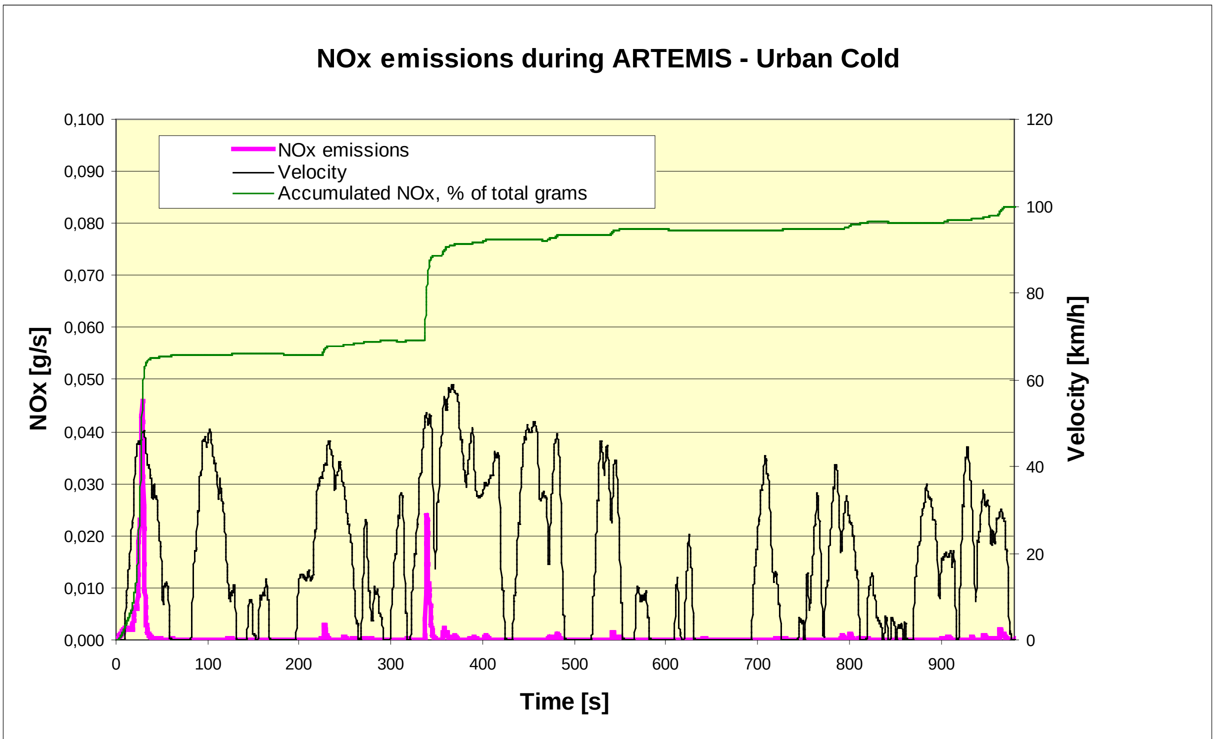


Figure 5: NO_X emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with SI-engine

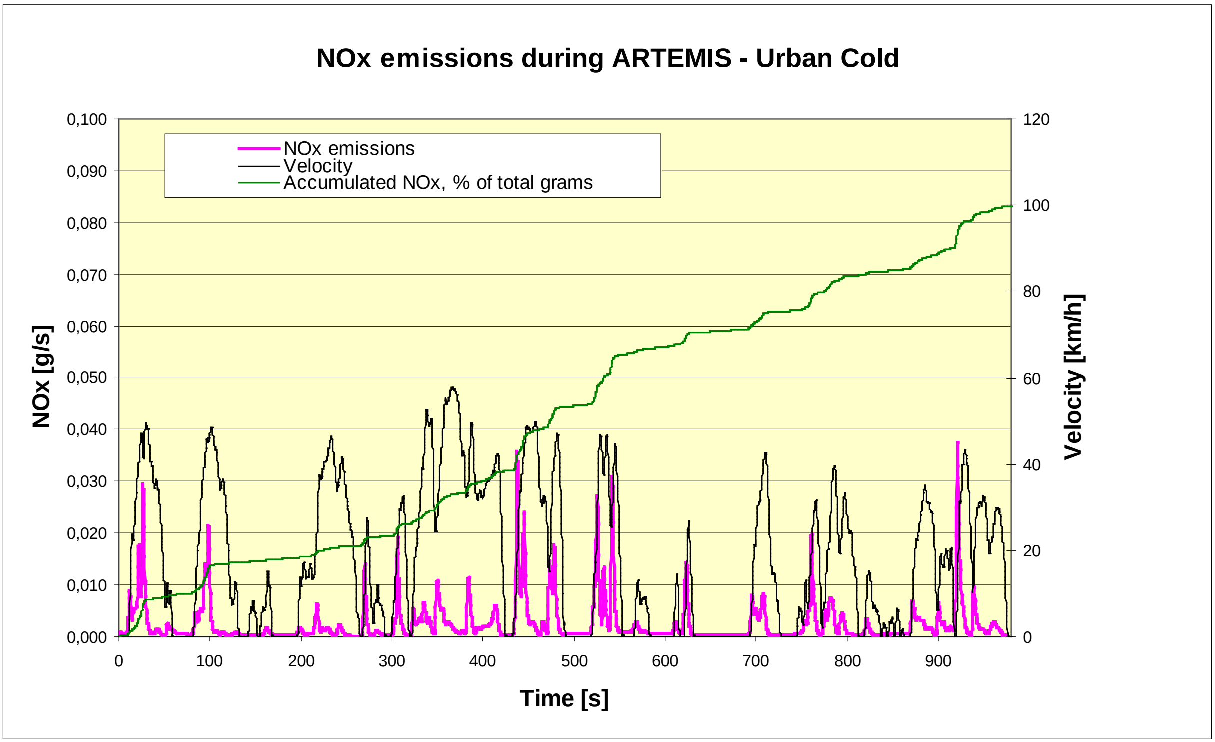


Figure 6: NO_X emissions during ARTEMIS Urban Cold cycle of a Euro 4 vehicle with CI-engine

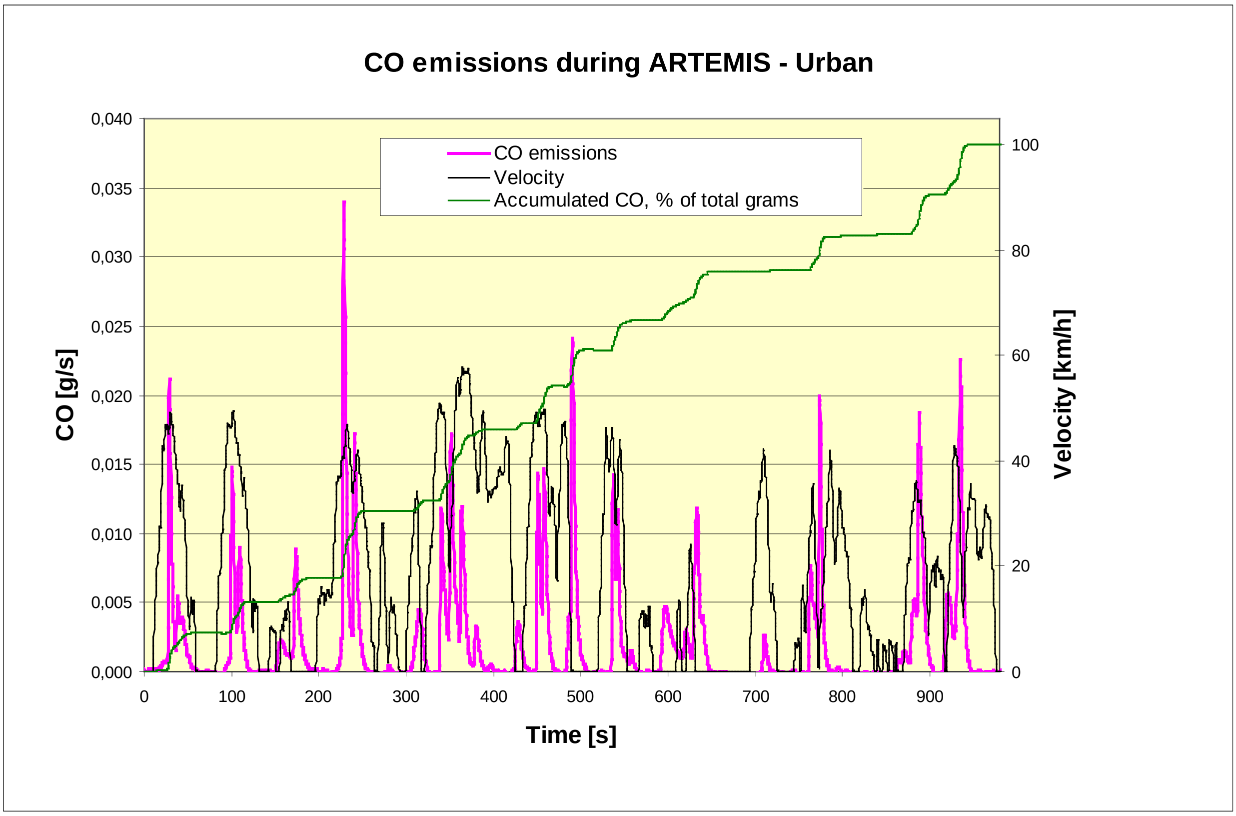


Figure 7: CO emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

In figure 8 the emissions of CO shows a peak in the middle of the cycle.

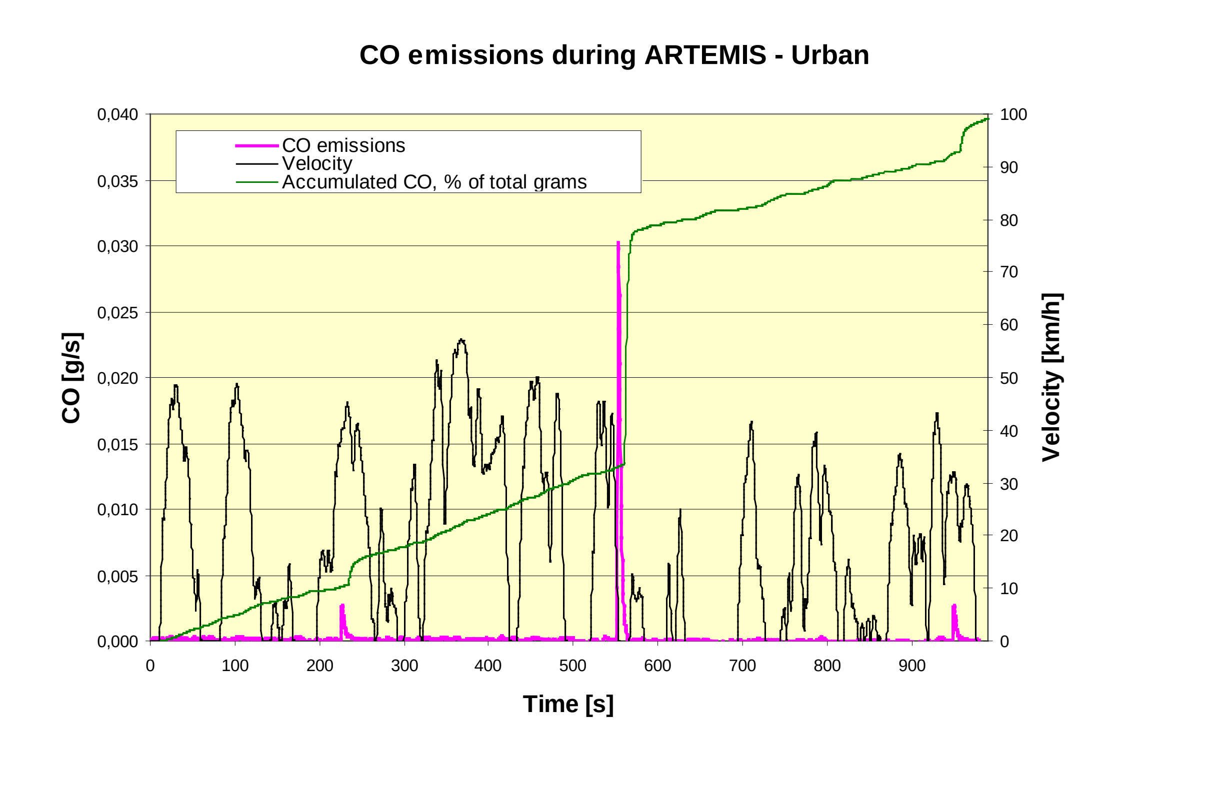


Figure 8: CO emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

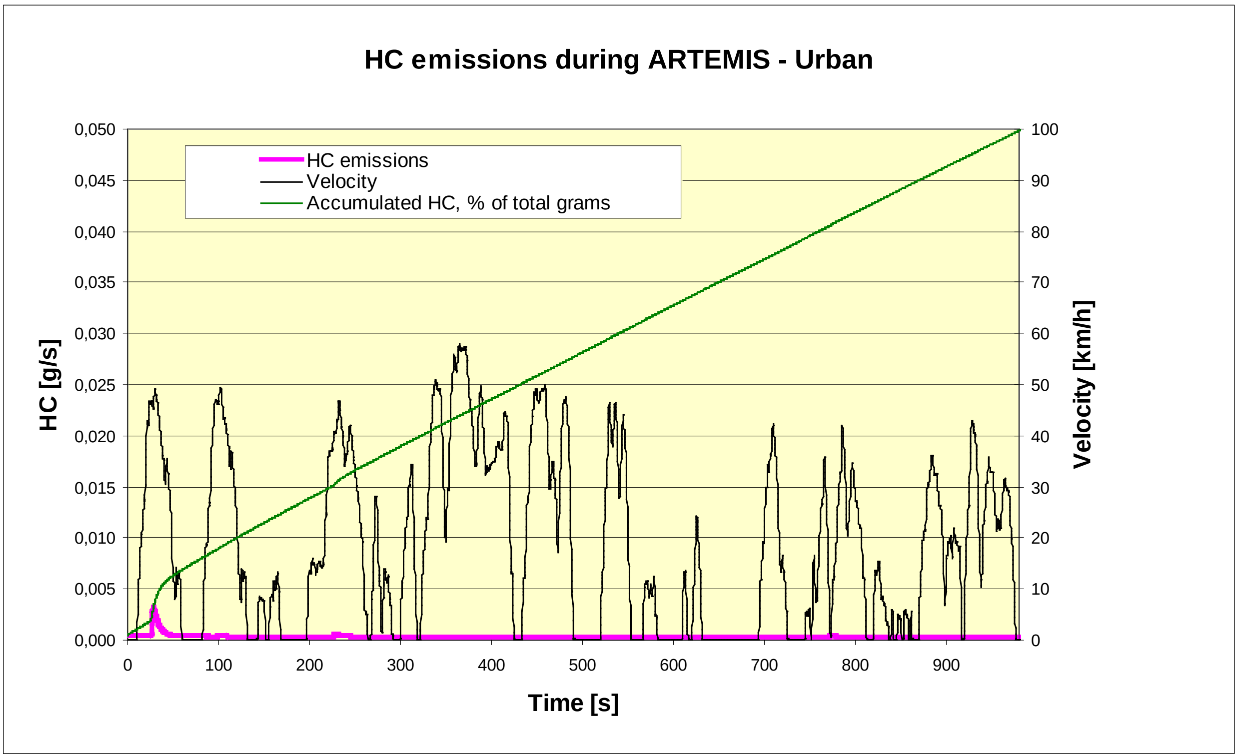


Figure 9: HC emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

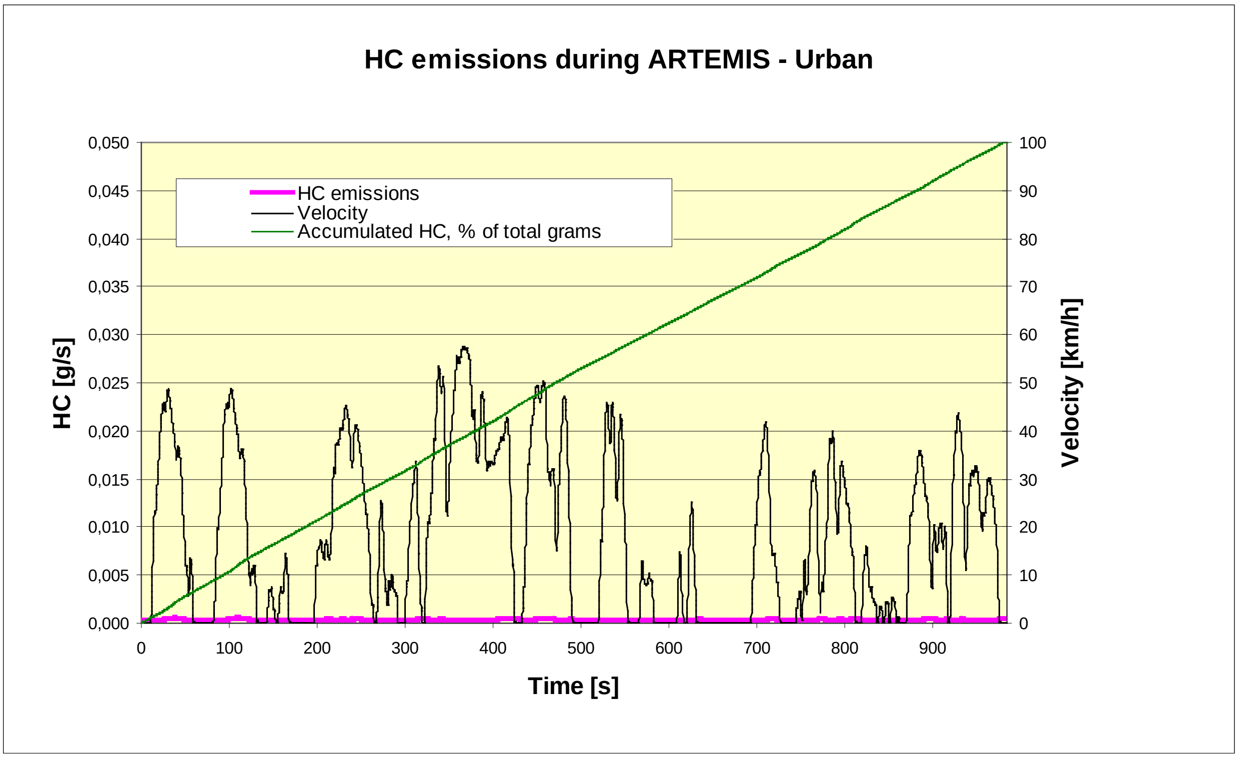


Figure 10: HC emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

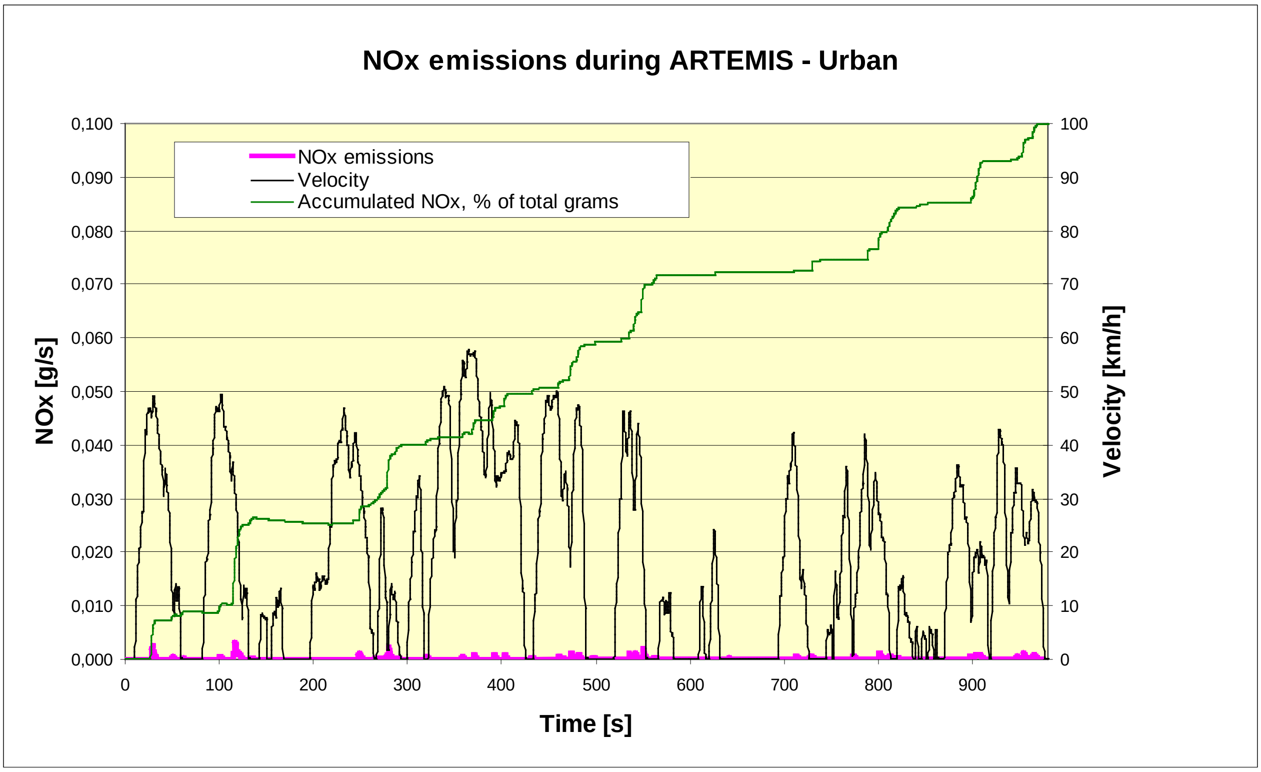


Figure 11: NOx emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with SI-engine

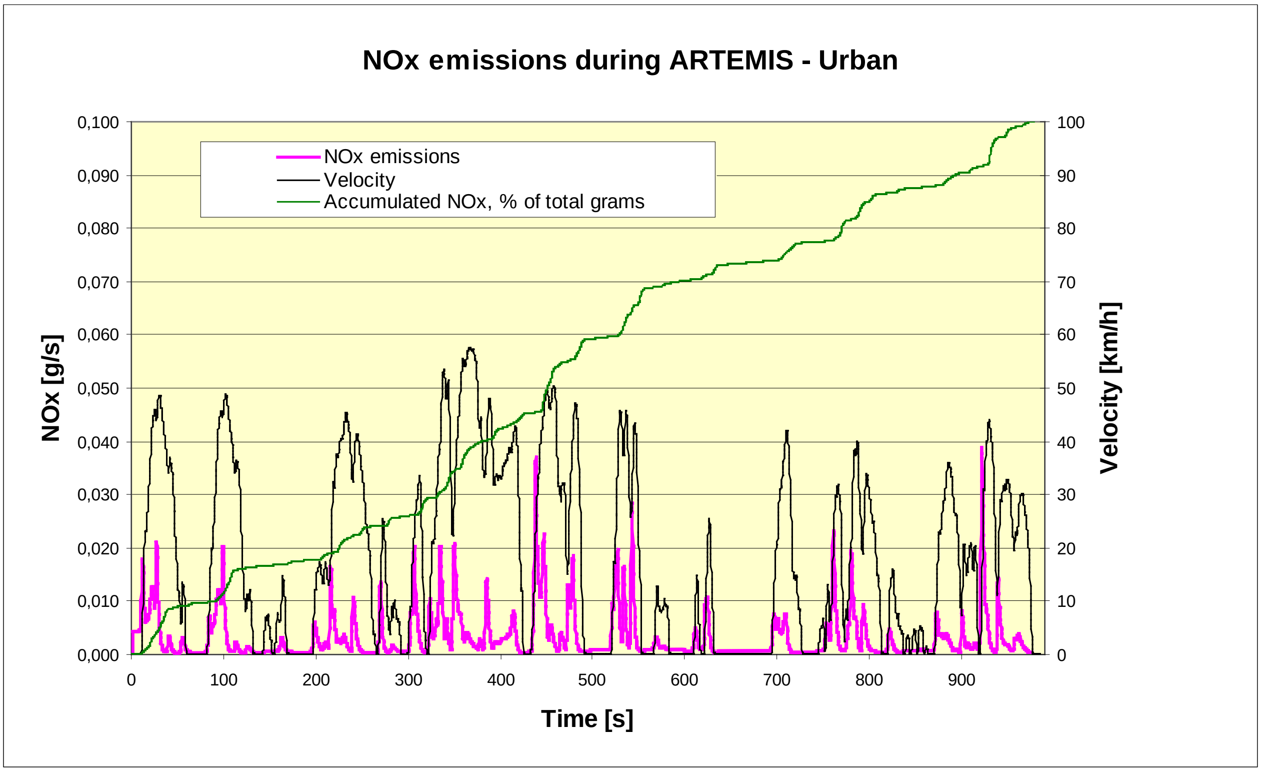


Figure 12: NOx emissions during ARTEMIS Urban cycle of a Euro 4 vehicle with CI-engine

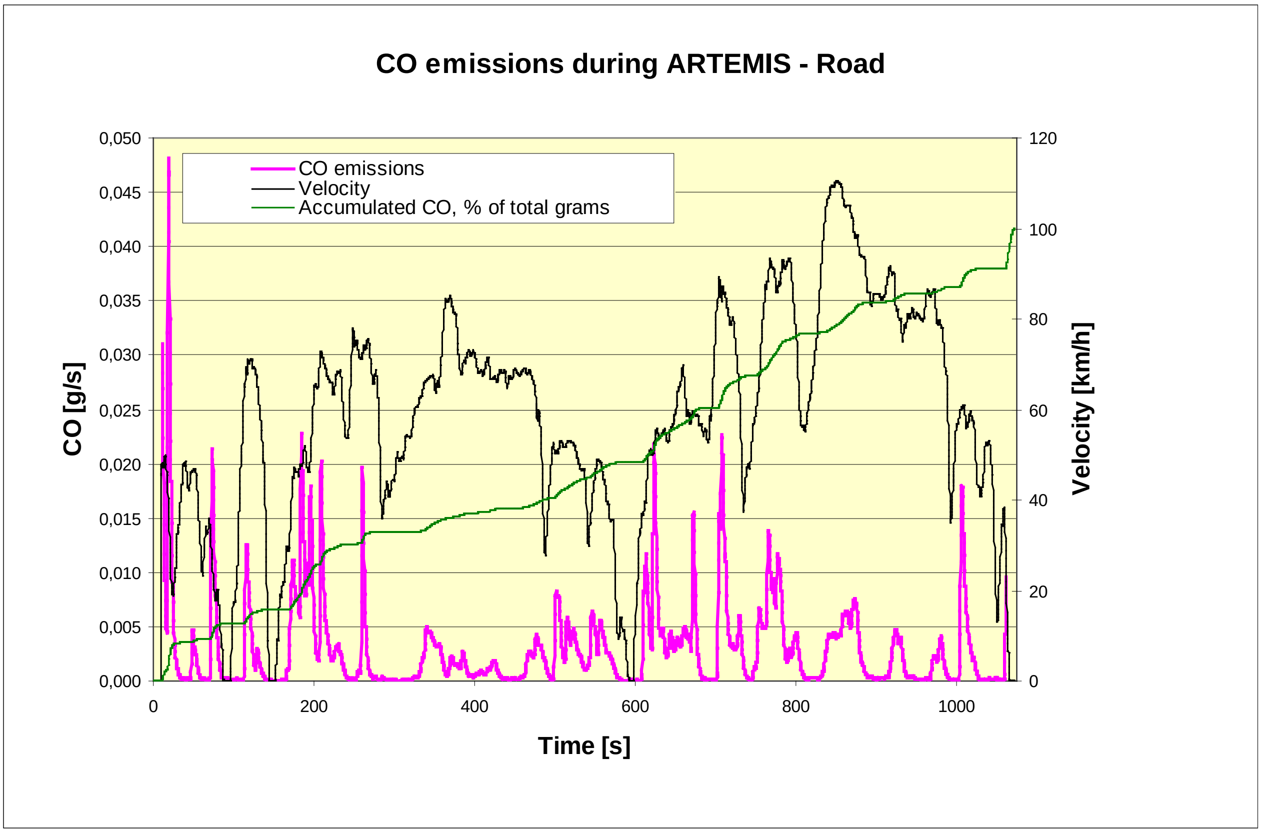


Figure 13: CO emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

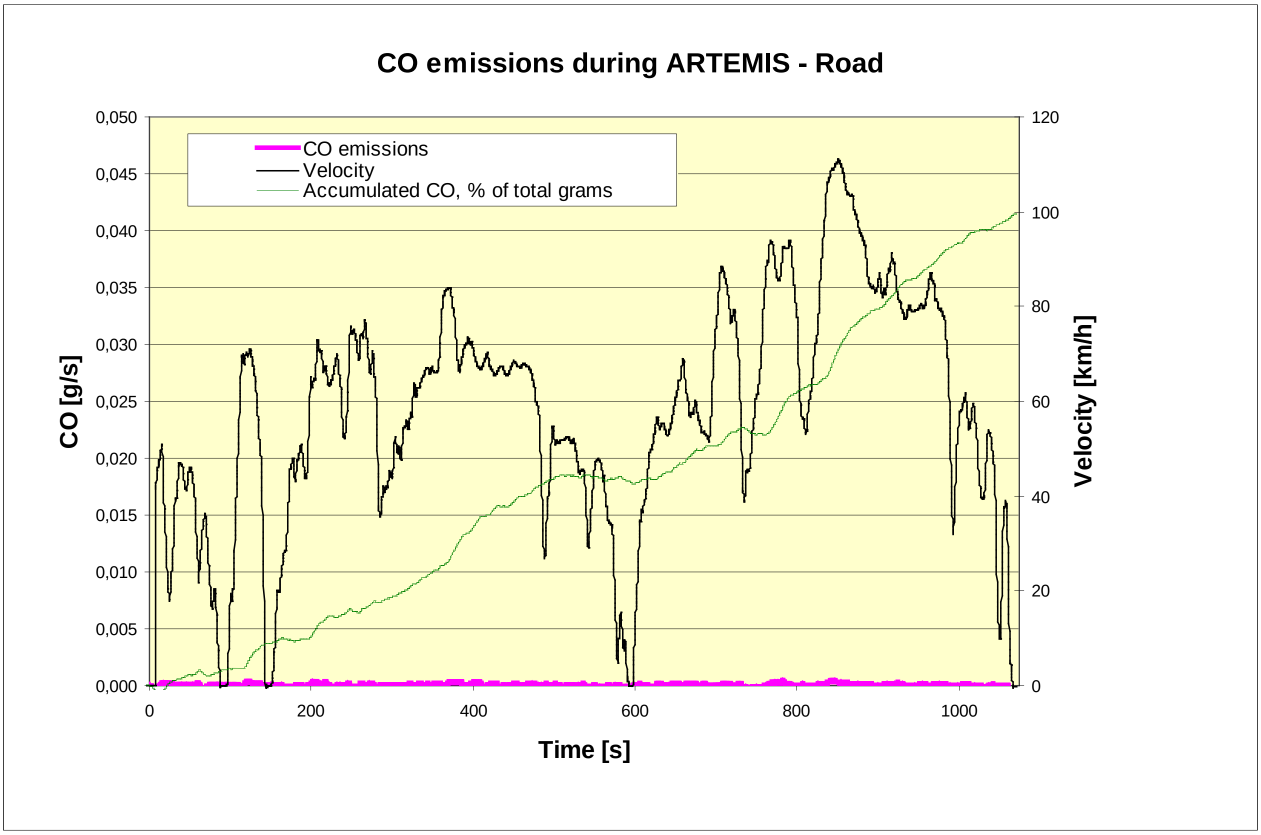


Figure 14: CO emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

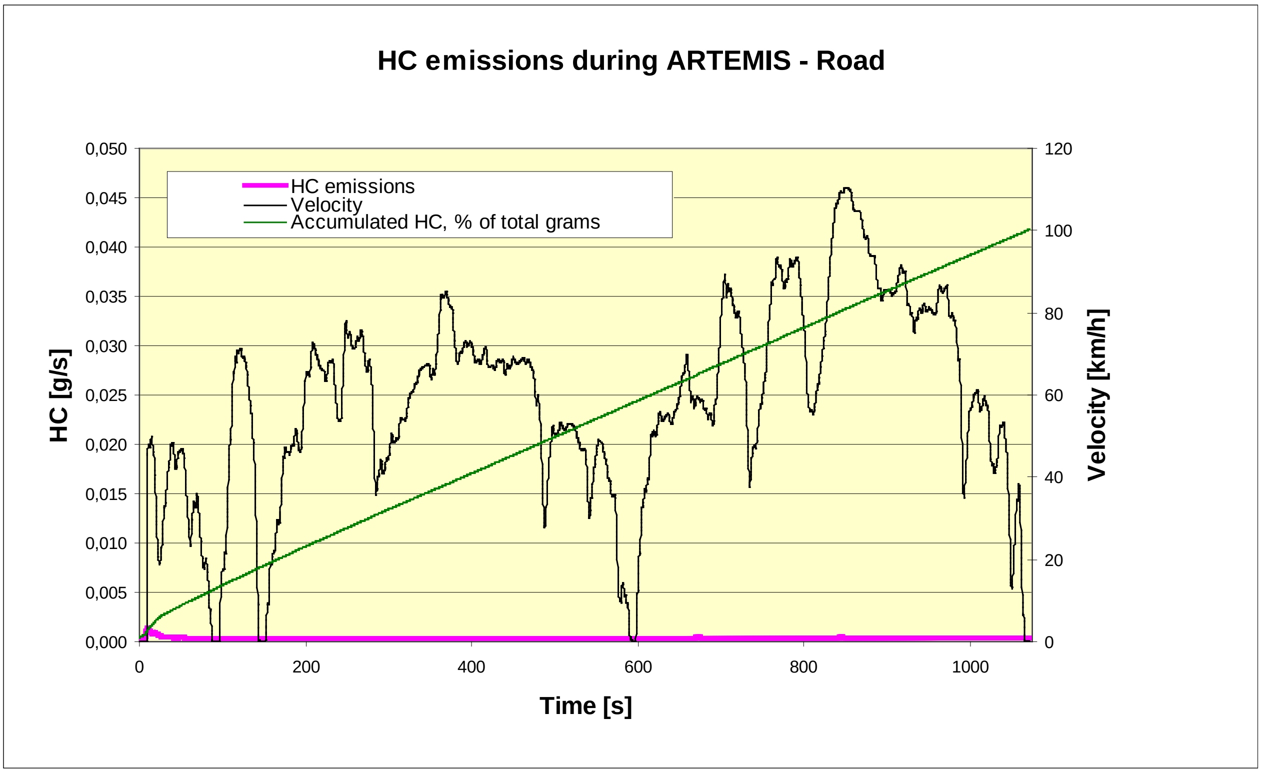


Figure 15: HC emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

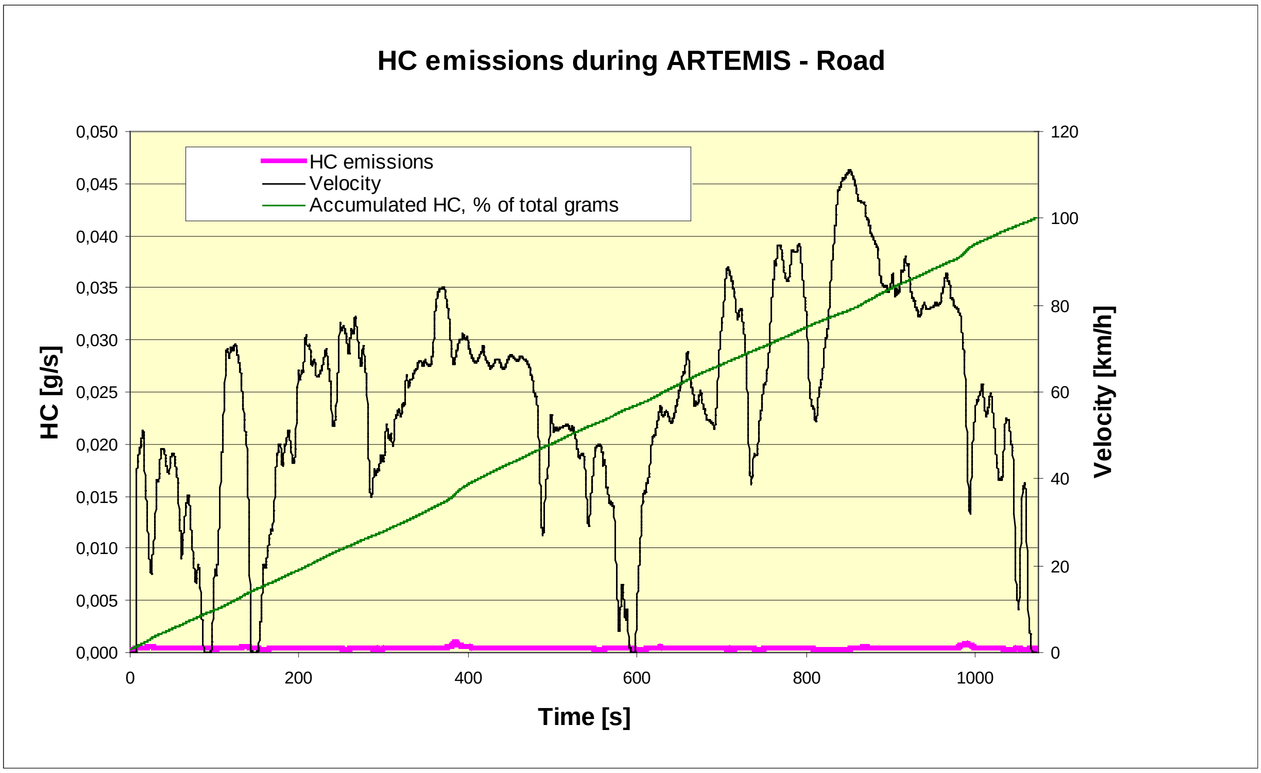


Figure 16: HC emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

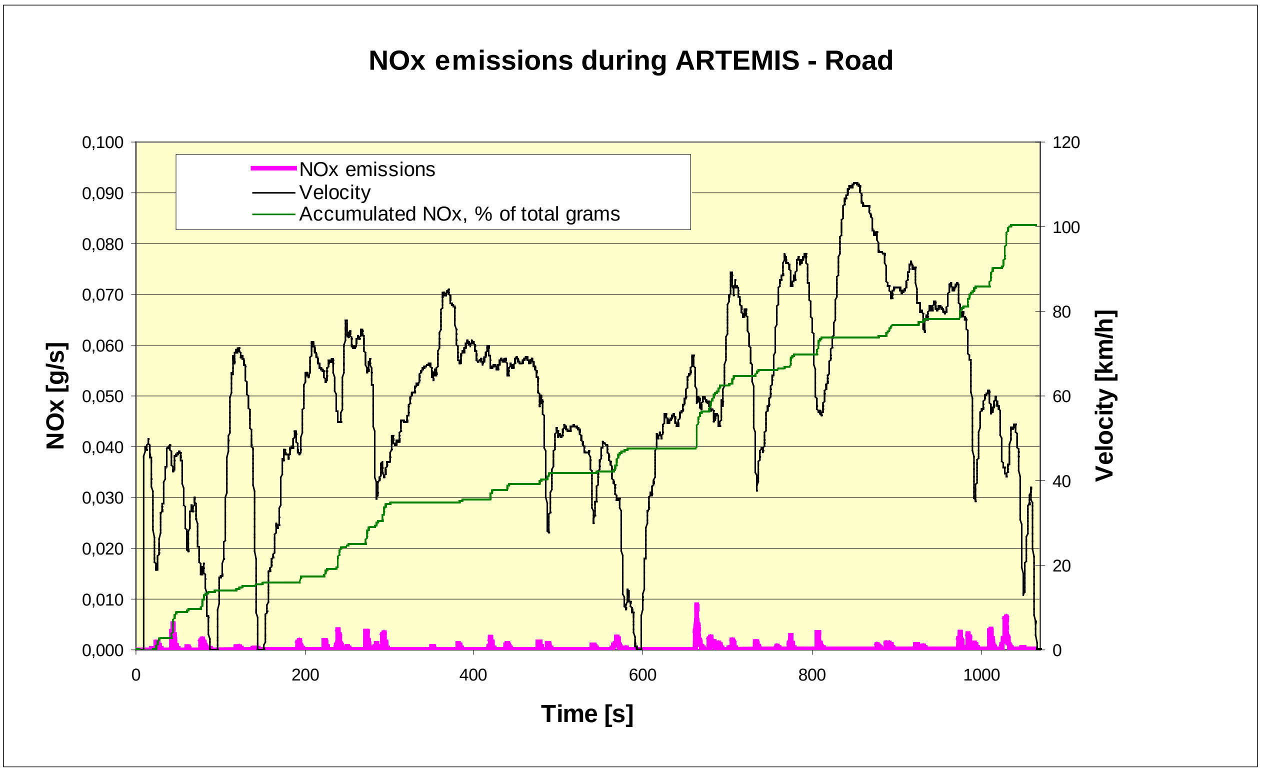


Figure 17: NOx emissions during ARTEMIS Road cycle of a Euro 4 vehicle with SI-engine

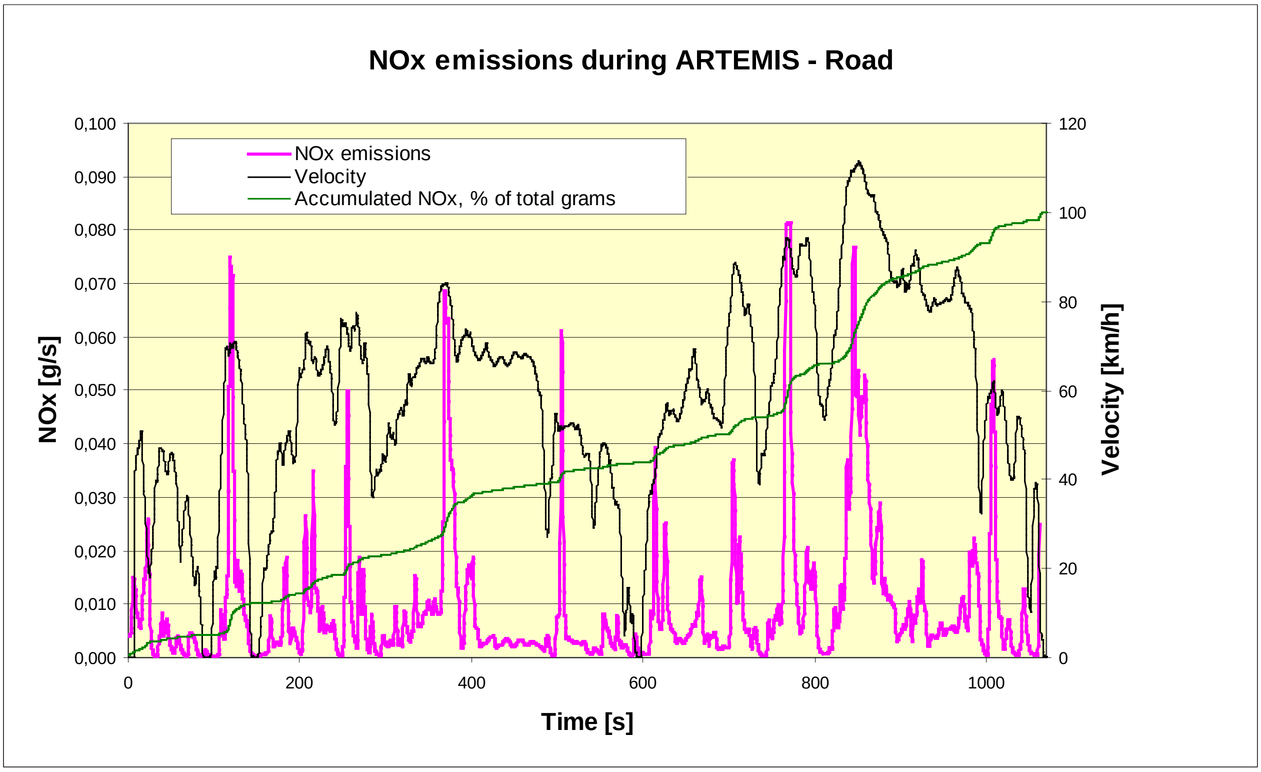


Figure 18: NOx emissions during ARTEMIS Road cycle of a Euro 4 vehicle with CI-engine

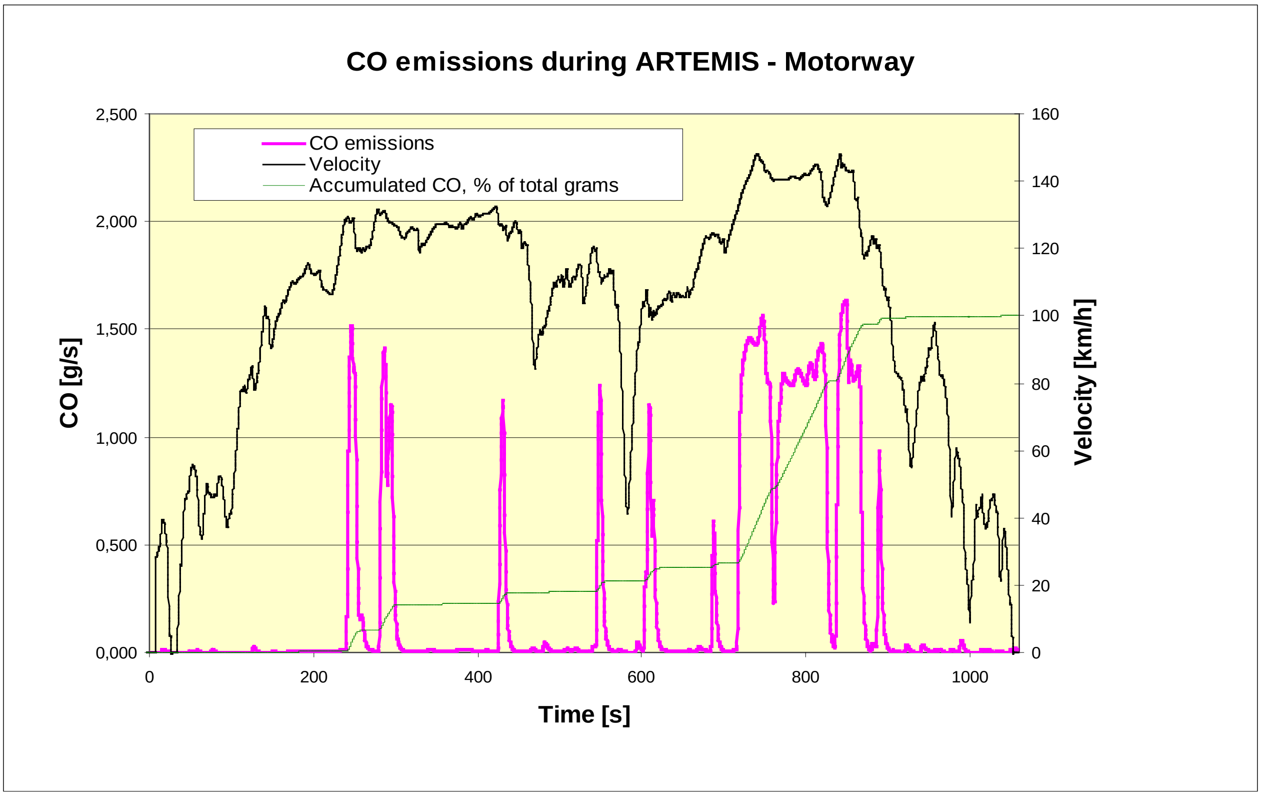


Figure 19: CO emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

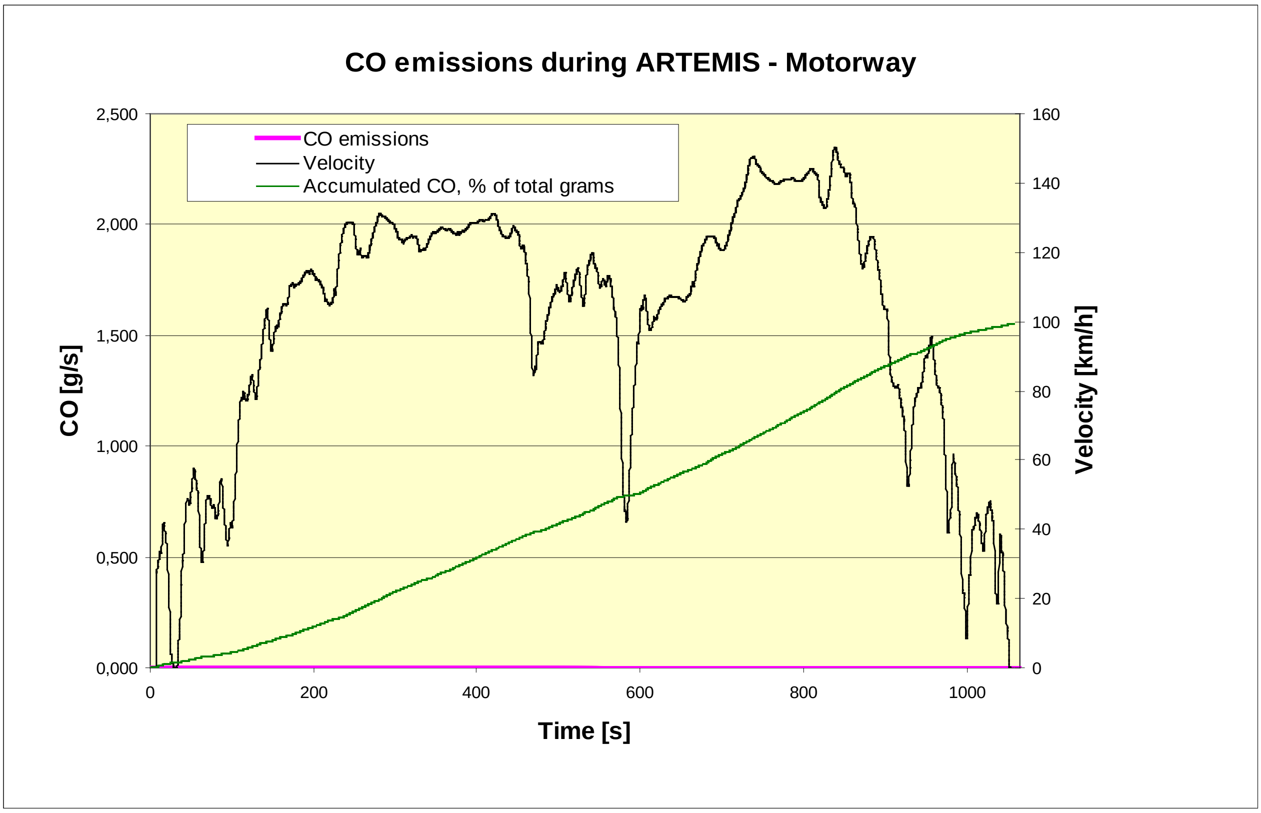


Figure 20: CO emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI- engine

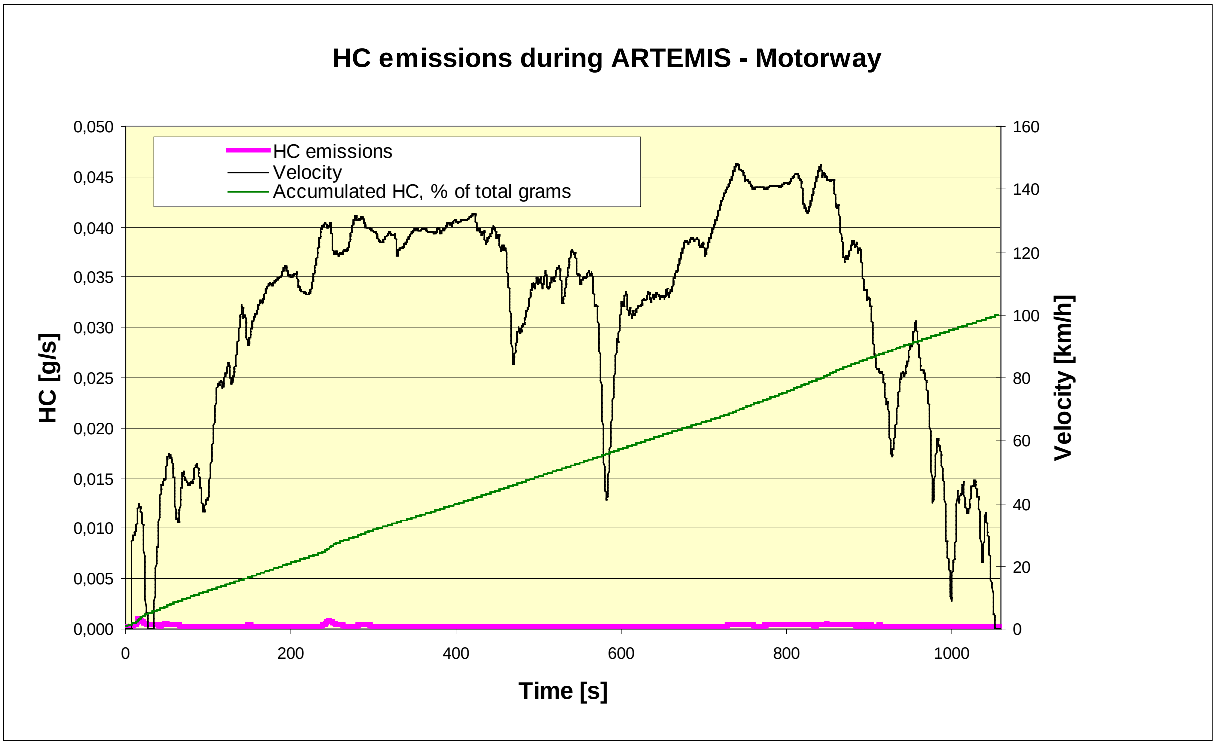


Figure 21: HC emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

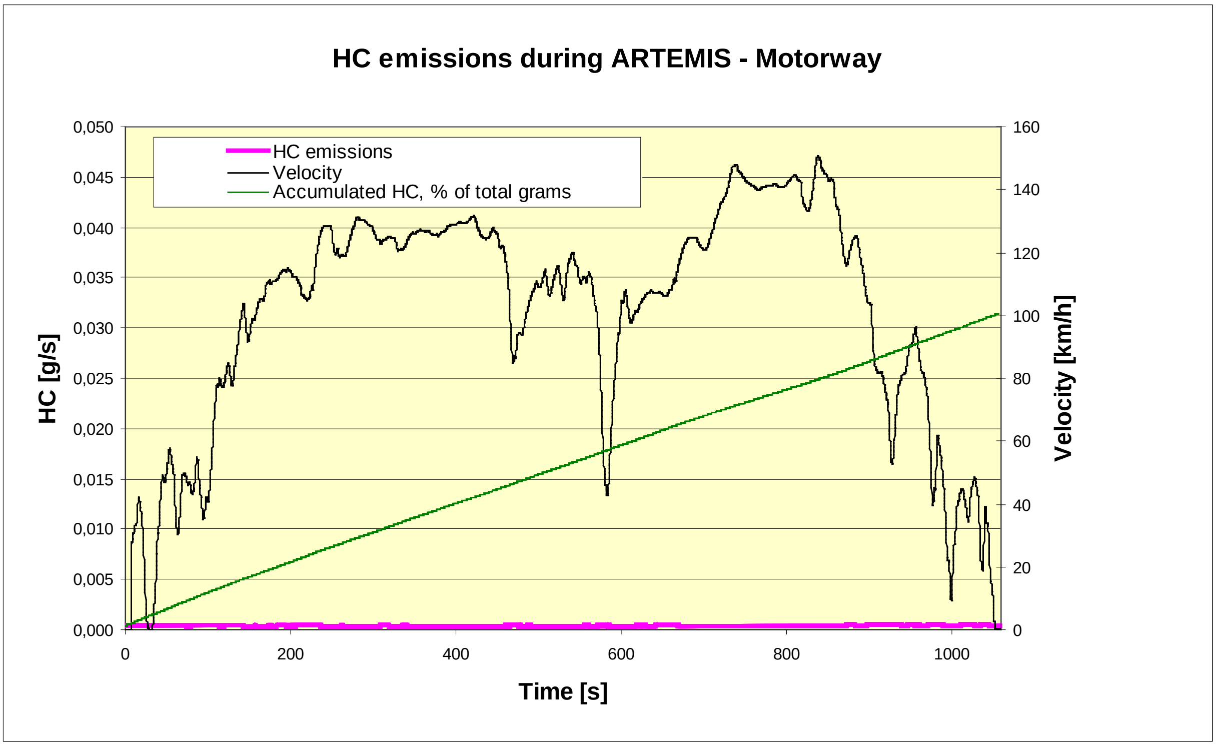


Figure 22: HC emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI-engine

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.

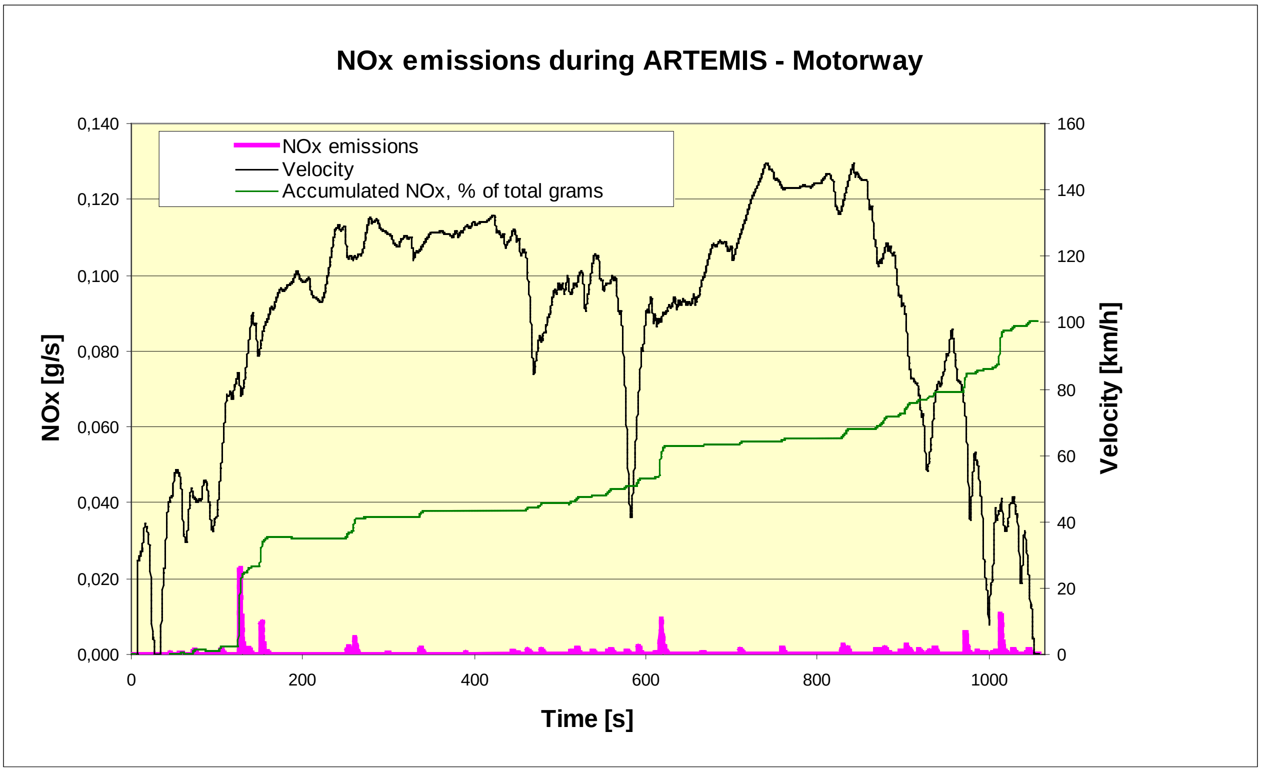


Figure 23: NO_X emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with SI-engine

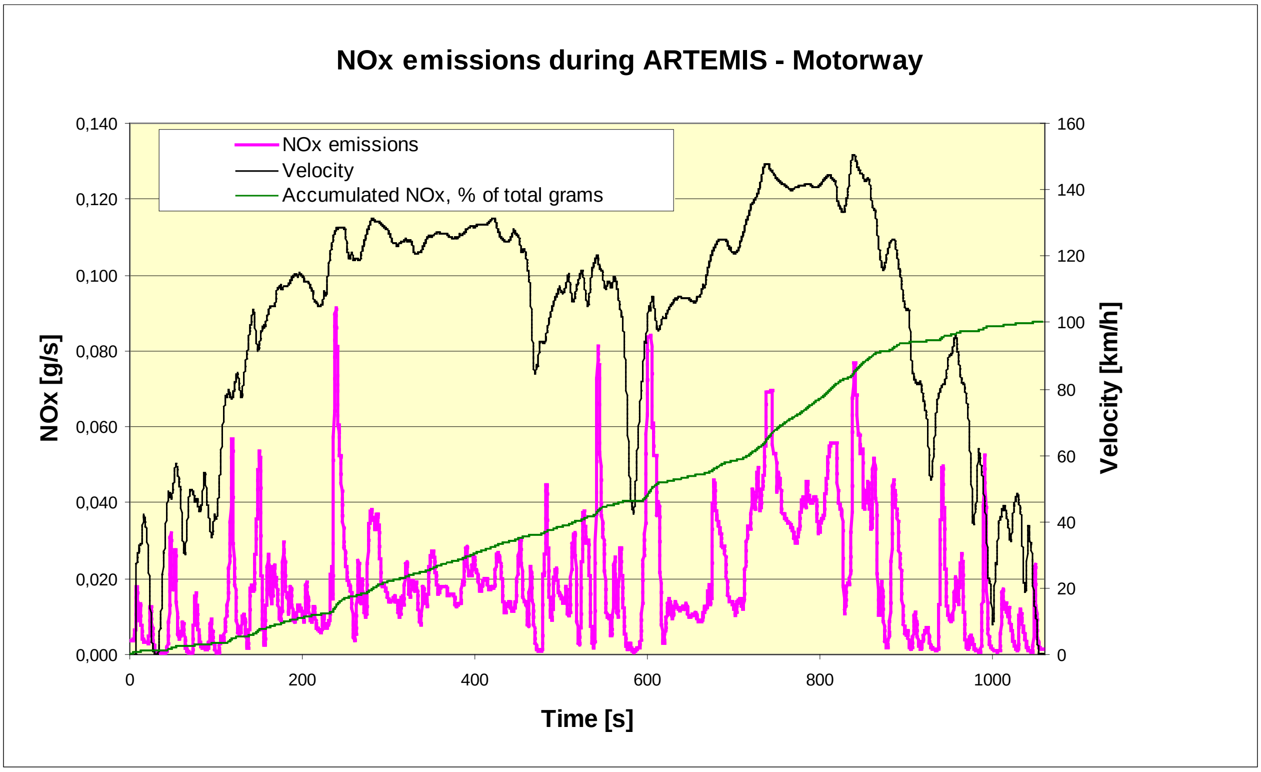


Figure 24: NO_X emissions during ARTEMIS Motorway cycle of a Euro 4 vehicle with CI-engine

Appendix 3

On-road testing - PEMS

PEMS - Subaru Legacy Outback

In Table 2, section “Test Programme Vehicles” on page 10, all tested cars with SI-engines are presented. These vehicles were tested on chassis dynamometer according to Directive 70/220/EEC as amended by 2003/76/EC. In addition, vehicle family no 7, Subaru Legacy Outback (SI-engine vehicle, see figure 1), 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, gasoline 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: Subaru Legacy 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 route used for the Subaru Legacy was a part of 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)	1200
Trip distance (km)	13,9
Average speed (km/h)	42

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

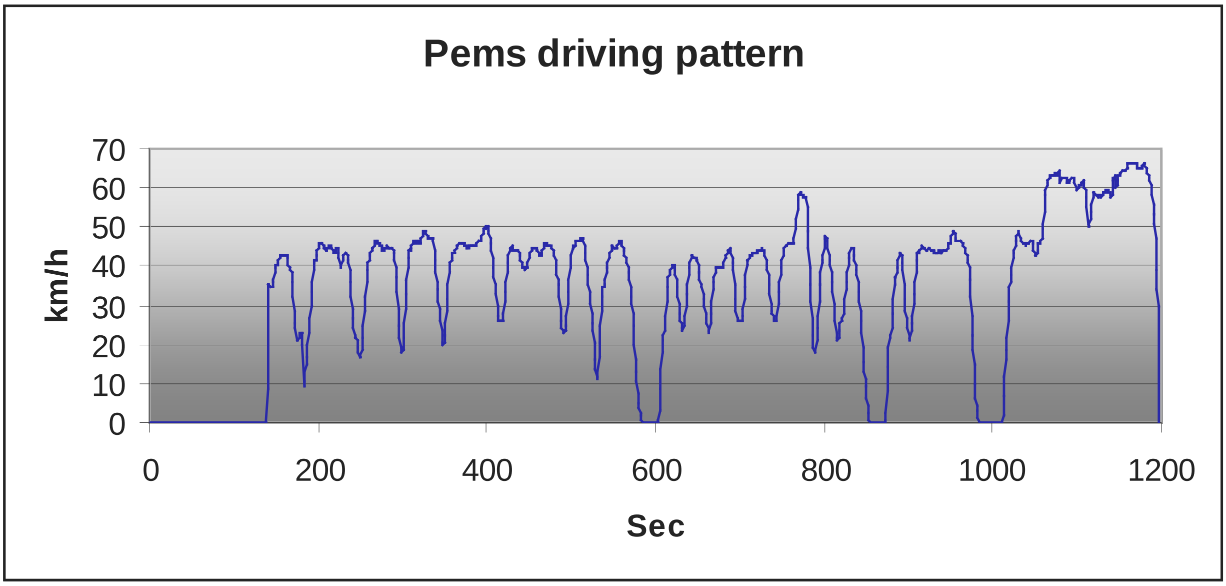


Figure 2: The light duty PEMS test route

In order to compare the PEMS route results with chassis dynamometer testing, emissions from 20 minutes of driving were calculated i.e., the same duration as NEDC.

Prior testing, the vehicles were prepared and soaked according to the standard test procedure i.e. 22 ^{o}C. The test route was carried out at an ambient temperature of 18 °C.

Results

From the results in Table 2 it can be seen that the emission results when comparing the CO and HC emissions from chassis dynamometer testing and on road measurements differs in the rage of 30 to 40% except vehicle no 3, with 6 timers higher emissions of CO and 9 times higher for HC. However, the PEMS results for HC are close to the detection limit and may thus be not significant. Regarding the NO_X emission, vehicle 1 and 2 differs 4 and 3 times respectively. There is no difference when comparing the chassis dynamometer and PEMS tests for vehicle 3. The fuel consumption is less than 10 % higher on chassis dynamometer compared with the PEMS test.

	CO g/km	**HC g/km**	**NO_X g/km**	**FC l/100km**
Subaru 1 CD	0,22	0,06	0,061	9,3
Subaru 1 PEMS	0,16	0,02	0,016	8,8
Subaru 2 CD	0,18	0,5	0,015	9,2
Subaru 2 PEMS	0,29	0,03	0,044	8,8
Subaru 3 CD	0,25	0,09	0,017	9,1
Subaru 3 PEMS	0,04	0,01	0,015	8,1
Euro 4 Limit	**1**	**0,1**	**0,08**	**-**

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