Swedish In-Service Testing Programme on Emissions from Passenger Cars and Light-Duty Trucks

Annual Report 2014

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by

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Contents

1. List of Abbreviations

A4 / A5 / A6	4-speed / 5-speed / 6-speed automatic gearbox
CADC	Common Artemis Driving Cycle
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of production
CPC	Condensation Particle Counter
CVS	Constant Volume Sampler; exhaust emission sampling system
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)
Euro 5, Euro 6	Type approval test in accordance with Directive 715/2007/EC
FC	Fuel consumption
FTP 75	Federal Test Procedure 75 = US American driving cycle, defined in 1975
GTR	General Technical Regulation
HC	Hydro carbons; see THC
KBA	Kraftfahrtbundesamt – German Federal Motor Transport Authority
M1	Vehicles for passenger transportation with a capacity of max. 8 seats excluding the driver and a maximum total vehicle mass of 3,500kg
M5 / M6	5-speed / 6-speed manual gearbox
MK	Miljöklass; Swedish Environment Class
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 and 715/2007/EC
NO_X	Nitrogen oxides
OBD	On-Board Diagnosis
PEMS	Portable Emission Measurement System
PM	Particle Mass
PMP	Particle Measurement Programme
PN	Particle Number
RPA	Relative Positive Acceleration
SHED	Sealed Housing for Evaporative Emissions Determination
STA	Swedish Transport Agency
THC	Total Mass of hydro carbons emitted by a vehicle, given in C_1 equivalent
TSN	Type code number
UDC	Urban Driving Cycle; Part 1 of the New European Driving Cycle
UNECE	United Nations Economic Commission for Europe
WLTP	Worldwide harmonized Light vehicles Test Procedure

2. Summary

In this In-Service Conformity testing programme a total of 65 vehicles, spread over 5 vehicle types with positive ignition engine, within this 1 vehicle type with compressed natural gas and 8 vehicle types with compression ignition engine and particle filter were tested with respect to the exhaust emissions limited by law.

The measurements were carried out in the respective type approval cycle, the "New European Driving Cycle“ (NEDC) in accordance with Directive 98/69/EC and 715/2007/EC (Type I test). In addition to this, measurements according to the upcoming Worldwide Harmonized Light Duty Testing Cycle (WLTC) was conducted according to the latest version of the existing Procedure Draft and three vehicle types were tested with the Portable Emission Measurement System (PEMS) method on road and in real traffic.
Two vehicles of each type with compression ignition were tested at two cold temperatures (5°C and -7°C). In this way it was possible to cover the entire operational range relevant to exhaust emissions for vehicles. During the measurements on the chassis dynamometer, the exhaust emissions were measured and the fuel consumption was calculated from the emissions of the carbon-containing exhaust components. Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured of all vehicles with positive ignition engine. At two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. In addition on two vehicles per type with positive ignition engine, the exhaust emissions at low ambient temperatures (Type VI test) were measured. With the Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars was introduced. With Directive 715/2007/EC the Diagnose of Compression ignition engines becomes more important. During this programme the OBD-data were registered. Additional, some emission relevant failures were simulated to control the function of the OBD system of one vehicle per type.

One vehicle failed the Euro 5 limit for the Type VI test. All other tested gasoline vehicle types complied with the limits given by the type approval during Type I test and fulfilled the requirements for In-Service testing according to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC.

All diesel vehicle types tested were fitted with particle filter. None of the compression ignition vehicles tested during this programme exceeded the limit for particle mass and for nitric oxides. According to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC all compression ignition vehicle types complied with the requirements for In-Service testing. One of the compression ignition vehicle model was of Euro 6 emission standard.

During the Type I test on 13 vehicle types the measured and the average fuel consumption (and CO_2) was higher than the fuel consumption declared by the manufacturer for 12 vehicles. Average for diesel cars was + 5,4 percent and for gasoline cars + 7,3 percent.

Measuring exhaust emissions at idle speed during the Type II test no emission related problems were detected.

On all vehicle types with gasoline engine no crankcase emissions were emitted into the atmosphere at the Type III test.

During the exhaust emission test at low ambient temperatures (Type VI test), all vehicles complied with the limits according to Directive 98/69/EC and 715/2007/EC.

During this project the OBD-data were registered. In addition some emission relevant defects were simulated to control the function of the OBD system at one of the vehicles per type. All simulated failures were detected by the OBD systems.

Testing the vehicles on different test cycles showed the influence of driving behaviour and driving conditions on the exhaust emissions. Dynamic driving, high speed, high engine load and cold start conditions cause an increase of carbon monoxide and hydrocarbon emissions, especially on vehicles with positive ignition engine. The major environmental exposure caused by compression ignition vehicles is nitric oxide and particulate emissions. Increased NO_x was emitted by compression ignition vehicles especially during the WLTC cycle. This is due to the high temperature inside the combustion chamber at high engine load, combined with a surplus of oxygen within the cylinder. It became obvious that dynamic driving with strong accelerations on urban conditions gives the worst fuel consumption. Positive ignition engines suffer from cold start the most. Smoothly running traffic with moderate speed and acceleration gives the lowest fuel consumption.

3. Introduction

Well functioning transportation is vital for undertakings and citizens. Road transport dominates as it carries about 46 percent of freight and 83 percent of passenger traffic in Europe. The rise of the population causes a rise of the number of passenger cars. **Figure 3.1** shows the trend for the last 100 years.

The last December 2014 was Sweden's population 9,747,355 people. There is an increase of 102,491 people compared with the previous year. Population growth is the biggest ever recorded between two individual years. The main reason for this is a record high immigration of 126,966 people. The number of passenger cars in traffic was 4,585,519 December 31 2014.
The number of cars in traffic increased with 2,0 percent and the population with 1,6 percent from 2013 to 2014. The numbers of cars in traffic is just below 0.5 car per person (0,47) and seems to increase over time. 20 years back the number of cars per person was about 0.4 which means an increase of about 17 percent during the last 20 years.

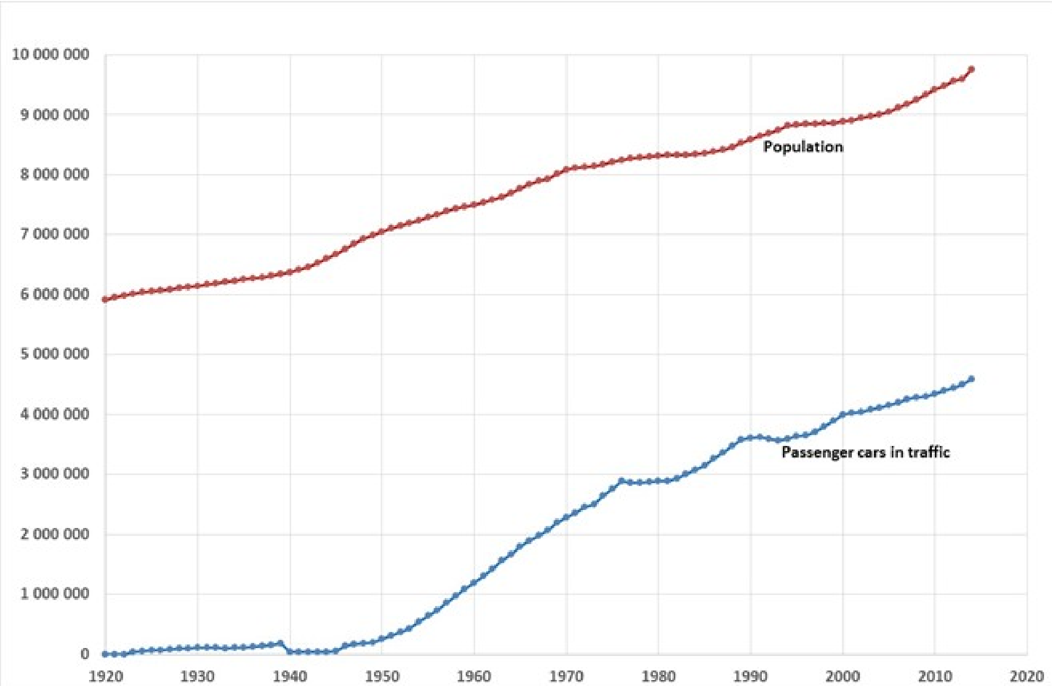

Figure 3.1 Number of population and passenger cars in Sweden

Within this rising number of passenger cars and population the pollution of the air by the emissions gets more and more important. Looking at the last seven years the number of sold passenger cars equipped with a compression ignition engine increases from 20percent in 2006 up to 60percent in 2013. **Figure 3.2** illustrates the increasing influence of compression ignition vehicles to the traffic in Sweden from 2006 to 2014.

Main changes 2014 compared with 2013

Number of sold passenger cars	+ 12,7 percent (303 948 sold cars)
percent sold diesel cars of total	59.3 percent
E85 cars	-16,7 percent
Gas cars	+ 32,2 percent
Electrical cars	+186 percent
Hybride cars	+ 83 percent

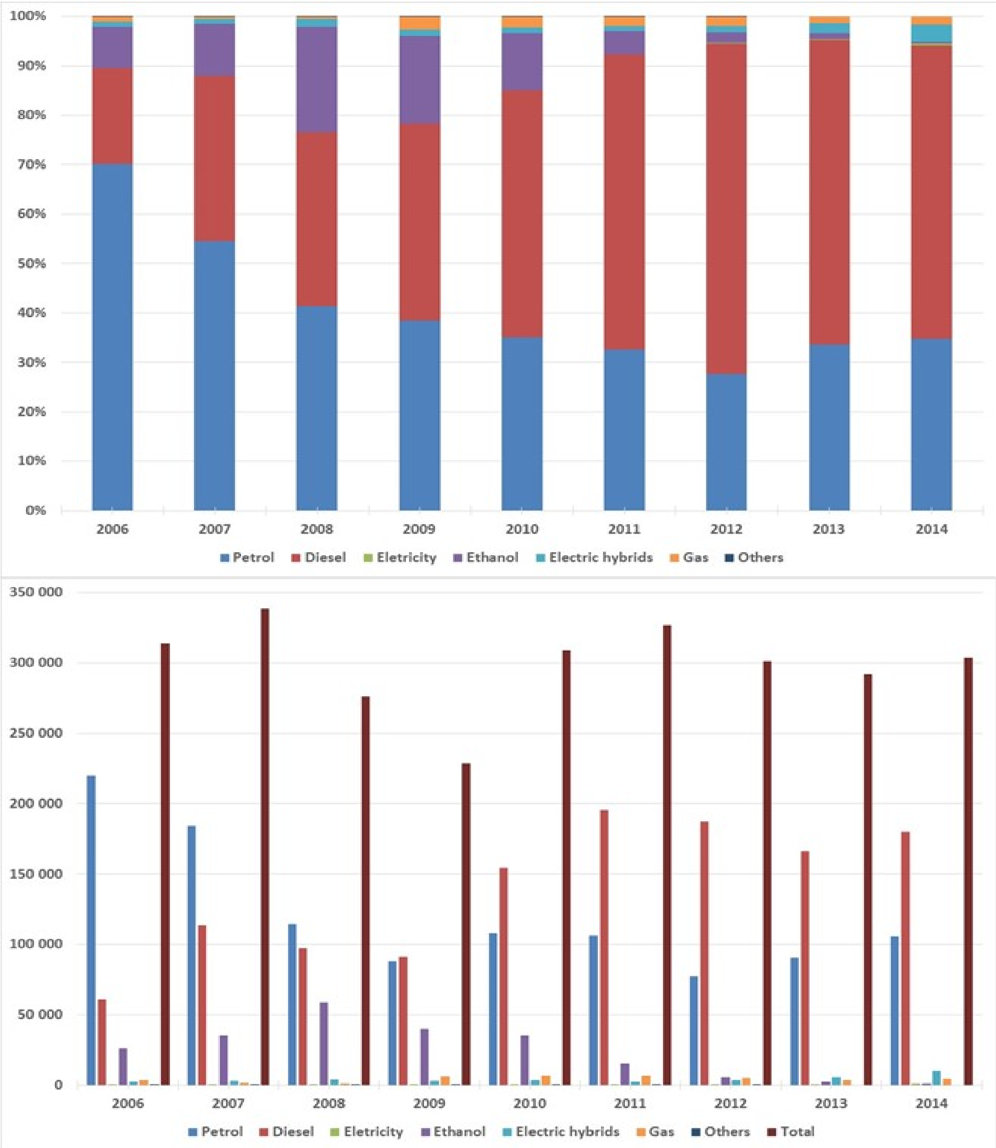

Figure 3.2: Use of different fuels and number of cars in Sweden; Statistiska Centralbyrån (SCB)

In addition the use of Ethanol (E85) decreased from the highest use of 20percent in 2008 down to about 0,5percent in 2014. Transport policies aim at ensuring clean, safe and efficient carriage of passengers and goods. Increasing the efficiency and reducing negative effects of road traffic on the environment is a major challenge. Road traffic is still the main source of air pollution from carbon monoxide, hydrocarbons and nitrogen oxides in Europe. In order to counter environmental pollution from motor vehicle emissions, exhaust legislation has been stepwise tightened over the past few decades. There is now an extensive package of measures available to reduce air pollution due to road traffic. This includes both control of new vehicles and testing of vehicles in-use. The control of new vehicles comprises type approval, durability testing and conformity of production (COP). The control of vehicles in-service includes an on-board diagnosis (OBD) system in the vehicles, the periodic inspection of all vehicles on the road, vehicle manufacturers' In-Service Conformity testing, plus enhanced requirements regarding fuel quality. **Table 3.1** shows various statutory measures taken to reduce exhaust emissions from motor vehicles.

The In-Service Conformity test of vehicles in operation on the roads was introduced in October 1998 with the Directive 98/69/EC and is resumed in directive 715/2007/EC in the member states of the EU. Here privately owned vehicles which have been licensed under Directive 98/69/EC or 715/2007/EC are examined after a statistical selection process in a complete test procedure according to the type approval cycle. It is the vehicle manufacturer who is responsible for this test. In addition to the manufacturer's own In-Service Conformity test some countries in the EU have parallel national programs for In-Service Conformity. On a regular basis this started in Sweden in 1991, first based on the national emission regulation and later on the harmonized european legislation..

In numerous programmes it has been shown that In-Service Conformity testing can reveal type-specific and design-related faults or inadequate maintenance regulations which, after an extended operating period of the vehicle, lead to an inadmissible increase in exhaust emissions.

Swedish Transport Agency (STA) is responsible for type-approval together with other obligations, for road vehicle emission controls. With that follows the obligation to carry out evaluations of the performance in-service. The STA has commissioned TÜV NORD (Germany) in collaboration with Ecotraffic (Sweden) to carry out the test programme on light dutyvehicles.

The objective of the Swedish test programme is to conduct screening tests on a number of vehicle models, picked out on a spot-check basis, to verify durability in the emission control concept. This is done in close collaboration with the vehicle manufacturers. This enables the manufacturers concerned to rectify any type-specific faults relevant to emissions of the vehicles on the road and serial production and to incorporate knowledge gained from the field monitoring in future developments. By proceeding in this way, this research programme contributes directly to lowering the environmental pollution from emissions caused by road traffic.

Besides In-Service Conformity testing it is also a minor objective of the programme to get information of emissions from vehicles during real world driving. These data will be used to update the European emission model HBEFA. HBEFA is used in Sweden for national emission inventories and as input to local air pollution calculations.

To get more information about real world driving the expert group of the European commission for Real Driving Emission on Light Duty Vehicles (RDE-LDV) declared the use of a Portable Emission Measurement System (PEMS) for type approval starting 2017. Up to now the RDE-LDV Group discusses how to proceed such measurements the right way. To update the database and to support the ongoing process three vehicle types of this program where tested with PEMS. The collected data were given to the Joint Research (JRC) Center of the European Commission.

	New Vehicles			Vehicles on the Road		
	Type Approval Test	**Durability Test**	**Conformity of Production**	**In-Use Compliance testing**	**Periodic Exhaust Inspection**	**On-Board Diagnosis**
Aim:	Verification of compliance with statutory specifications by the vehicle type	Verification of compliance with statutory specifications by the vehicle type	Statistical back-up for serial production	Detection of type-specific design-related defects or inadequate maintenance instructions	Detection of high-emission vehicles, servicing condition	Malfunction detection and indications for immediate repair
Area of Responsibility	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Owner	Vehicle Owner
Vehicle Selection	Prototypes	Prototypes or serial vehicles	Random sample from serial production	Random sample of vehicle fleet in the field	All vehicles on the road	All vehicles on the road
Test Interval	One-off	One-off	Sporadic	Regular	Regular	Permanent
Type of Test	Type test	Continuous run (AMA) or fixed deterioration factor	Type test	Type test	Idle test	Actual conditions according to manufacturer's application
Influence on Emission Reduction	Technology used	Durability under laboratory conditions	Technology used and implementation in production	Technology used and implementation in the field	Servicing condition	Durability and servicing condition in actual traffic
Statutory Basis	European Directives governing measures to prevent air pollution from motor vehicle emissions 98/69/EC ; 715/2007/EC			98/69/EC; 715/2007/EC	96/96/EC	98/69/EC; 715/2007/EC

Table 3.1: Approaches to the reduction of exhaust emissions from motor vehicles

4. Project Implementation

4.1. Investigation Programme

Within the framework of this programme a total of 5 vehicle types with positive ignition engine, within this 1 vehicle type with compressed natural gas (bifuel) on both potential fuels and 8 vehicle types with compression ignition engine and particle filter were tested with respect to the exhaust emissions limited by EU emission legislation.

The measurements were carried out in the respective type approval cycle, i.e. the "New European Driving Cycle"(NEDC) in accordance with Directive 98/69/EC and 715/2007/EC. In addition to this, measurements according to the upcoming Worldwide Harmonized Light Duty Testing Cycle (WLTC) was conducted according to the latest version of the existing Procedure Draft, results were given to the European working group that is responsible for the Correlation exercise between NEDC and WLTP. Three vehicle types were measured on road with PEMS. In this way it was possible to cover the entire operational range relevant to exhaust emissions for vehicles. The different driving cycles are shown in **section 4.3**.

During the measurements on the dynamometer, the emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X) and carbon dioxide (CO_2) were collected in bags in accordance with the regulations and the integral values were determined. For all vehicles particle mass was determined according to the current regulation. Parallel to this the exhaust emissions were recorded continuously every second (modal measurement). The results of the modal measurements serve as the basis for determining the functions of the emissions control system with which the exhaust emission behaviour can be shown in all relevant traffic situations.

In addition to exhaust emissions, fuel consumption was determined in the respective type approval cycle in accordance with Directive 715/2007/EC. The fuel consumption was calculated from the emissions of the carbon-containing exhaust components (CO_2, CO and HC).

Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured on all vehicles with positive ignition engine.

On two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. Exhaust emissions at low ambient temperatures (Type VI test) of two vehicles per type with positive ignition engine were measured.
With Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars and light-duty vehicles was introduced and is resumed in directive 715/2007/EC. During this programme the OBD-data were registered. In addition some emission relevant failures were simulated to control the function of the OBD system at one vehicle per type.
The test date was agreed upon with the car manufacturer or importer concerned to enable him to be present during the tests. Representatives of the respective vehicle manufacturer were present, having been invited to witness the implementation of the tests.

4.2. Vehicle Selection

It was intended that the selected vehicles should cover as wide a spectrum of manufacturers as possible, while maintaining a representative cross-section of the vehicle types registred in Sweden. Vehicle types from 10 different manufacturers were investigated in the programme. All selected vehicles were type approved according to directive 715/2007/EC.

Table 4.1 shows the exhaust emission limits valid for the type approval test of passenger cars and light duty vehicles. For passenger cars (M1) with a maximum mass bigger than 2,500 kg and light duty trucks (N1) separate limits can be applied according to the reference weight of the vehicle. The "New European Driving Cycle" is described in section 4.3.

Engine	Limit	Vehicle Class *)	Reference Mass (RM) [kg]	CO [mg/km]	HC [mg/km]	NMHC [mg/km]	NO_x [mg/km]	$HC+NO_x$ [mg/km]	PM [mg/km]	PN [#/km]
Gasoline	Euro5	M1 ≤ 2500kg	All	1000	100	-	80	-	-	-
		N1 class I	RM ≤ 1305	1000	100	-	80	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	-	100	-	-	-
		N1 class III	1760 < RM	2270	160	-	110	-	-	-
	Euro6	M1 ≤ 2500kg	All	1000	100	68	60	-	-	-
		N1 class I	RM ≤ 1305	1000	100	68	60	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	90	75	-	-	-
		N1 class III	1760 < RM	2270	160	108	82	-	-	-
Diesel	Euro5	M1 ≤ 2500kg	All	640	-	-	500	560	50	-
		N1 class I	RM ≤ 1305	640	-	-	500	560	50	-
		N1 class II	1305< RM ≤1760	800	-	-	650	720	70	-
		N1 class III	1760 < RM	950	-	-	780	860	100	-
	Euro6	M1 ≤ 2500kg	All	500	-	-	180	230	4,5	$6,0*10^{11}$
		N1 class I	RM ≤ 1305	500	-	-	180	230	4,5	$6,0*10^{11}$
		N1 class II	1305< RM ≤1760	630	-	-	235	295	4,5	$6,0*10^{11}$
		N1 class III	1760 < RM	740	-	-	280	350	4,5	$6,0*10^{11}$

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

Table 4.1: Emission limits for passenger cars and light-duty vehicles, valid for the Type I test (NEDC)

The vehicle selection was done in cooperation with local dealers to guarantee a good maintenance condition of the vehicles. Further criteria such as kilometre reading and date of first registration were taken into consideration. When the vehicles were taken over for the programme, additional data regarding repairs carried out on the vehicles as well as deviations from the series production condition was noted. The components which are relevant for exhaust emissions were checked for directly recognisable damage. OBD information was read to ensure that no emission relevant fault code was stored.

The following criteria were used as a basis when selecting individual vehicles:

- same type approval for vehicles of one type
- Kilometre reading between 15,000 km (alternatively at least 6 months in traffic) and 100,000 km,
- regular servicing according to manufacturer’s advice
- vehicle is unmodified series production model
- no mechanical damage to components

The vehicle types which were investigated are shown in **Tables 4.2 and 4.3** along with the relevant technical data. All vehicles with compression ignition engine were equipped with particle filter.

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm³]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	Toyota	E15UT	Auris	1ZR-FAE	1598	97	EURO 5	37,041	62,142	2010-05-04 to 2011-12-13
2	Hyundai	PBT	i20	G4LA	1248	57	EURO 5	27,494	69,584	2010-08-06 to 2011-09-29
3	Renault	R	Clio	H4Bt 400	898	66	EURO 5	7,793	22,595	2013-01-25 to 2013-09-27
4	Skoda	5J	Fabia	CGPA	1198	51	EURO 5	34,856	60,452	2010-11-08 to 2011-08-12
5	Volvo	B	V70 Bifuel	B5254T10	2521	170	EURO 5	37,916	63,669	2011-04-28 to 2012-03-30

Table 4.2: Vehicle Types with positive ignition engine

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm³]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	Hyundai	FDH	i30 CW	D4FB	1582	85	EURO 5	31,593	54,103	2011-05-20 to 2011-07-14
2	BMW	5K	520d	N47N	1995	135	EURO 6	6,864	13,705	2013-09-12 to 2013-10-07
3	Citroen	NC9HR8	C4	2PS	1560	82	EURO 5	26,570	59,906	2010-08-06 to 2011-09-16
4	Skoda	1Z	Octavia	CAYC	1598	77	EURO 5	33,380	55,142	2011-05-27 to 2012-02-29
5	Volkswagen	AU	Golf	CLH	1598	77	EURO 5	24,586	52,391	2012-12-11 to 2013-06-03
6	Opel	P-J	Astra	A17DTR	1686	92	EURO 5	39,124	72,156	2011-01-18 to 2011-05-30
7	Ford	BA7	Mondeo	T1BB	1560	85	EURO 5	36,237	64,890	2011-05-27 to 2012-05-30
8	Volvo	BW84	V70	D4162T	1560	85	EURO 5	40,512	75,582	2012-04-13 to 2013-05-21

Table 4.3: Vehicle Types with compression ignition engine

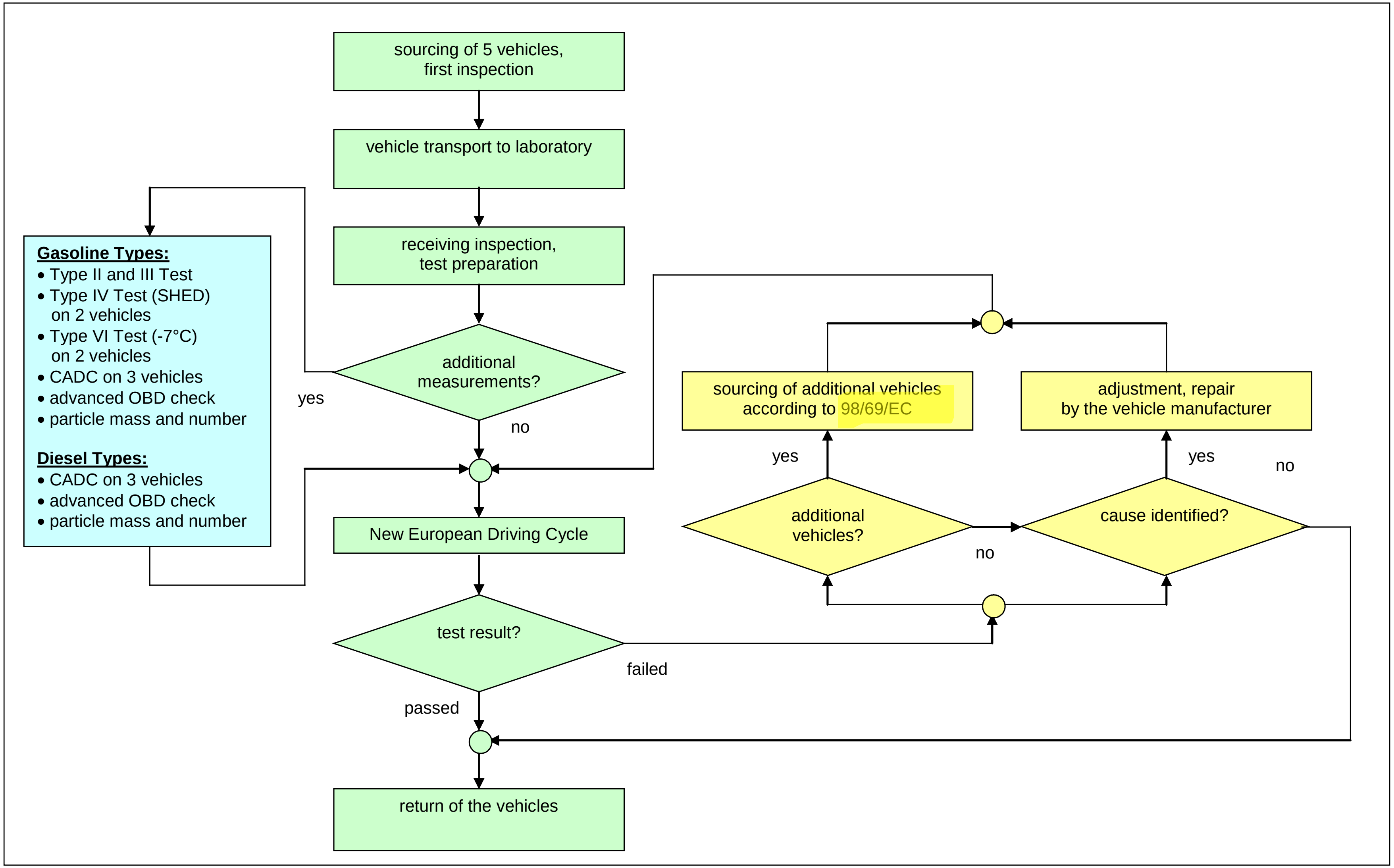

Figure 4.1: Simplified illustration of the In-Service Testing programme

4.3. Implementation of Tests

In **Table 4.4** the application of tests for type approval of passenger cars and light duty vehicles is illustrated.

Test	Description	Positive Ignition Vehicles	Compression Ignition Vehicles
Type I	tailpipe emissions after cold 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 devices	yes	yes
Type VI	low ambient temperature tailpipe emissions after a cold start	yes	-
OBD	On Board Diagnosis	yes	yes

Table 4.4: Application of tests for type approval

Within the framework of the programme 13 vehicle models were tested. The investigations were implemented with reference to Directive 98/69/EC and 715/2007/EC. In order to obtain a reliable assessment if type-specific defects are present on a vehicle type, initially five vehicles per type were measured with respect to exhaust emissions.

The vehicles were selected in cooperation with authorized dealers to be sure that the vehicles were maintained according to the manufacturer’s requirements. All vehicles were checked and the OBD information was read to ensure that no emission relevant fault code was detected. Before sending the chosen vehicles to the exhaust emission laboratory they were driven 50km for conditioning.

After the vehicles had been received at the laboratory, a check was made as to whether the specified maintenance intervals had been observed and that the vehicles were in a proper condition. Proof was provided by means of the service record manual. Before commencement of the measurements on the chassis dynamometer, the vehicles were checked with respect to the tightness of the exhaust system.

For dynamometer setting the same inertia weight and coast down values were chosen as for the type approval test. A deterioration factor was not used for evaluating the Type I test results. The vehicle types were assessed in accordance with Directive 98/69/EC and 715/2007/EC.

The vehicles were tested in a measuring programme which not only includes the tests applied for type approval, but also covers other test cycles like Common Artemis Driving Cycle to determine exhaust emission factors. Figure 4.1 gives a simplified illustration of the programme. It does not show the different tests in the order operated during the programme.

The WLTP was driven according the GTR in the beginning of the test-program to implement an additional conditioning of the vehicles before starting the tests according to the directive. On the afternoon of the day before running the Type I tests, all vehicles were conditioned (NEDC for vehicles with positive ignition, 3 Extra Urban Driving Cycles (EUDC) for vehicles with compression ignition).

Type II and III tests on vehicles with positive ignition engine were carried out immediately after the Type I test. The OBD check was done at the end of the test procedure to make sure that the simulation of emission relevant failures could not affect the results of the other tests. **Table 4.5** displays the procedure of the different tests during the programme.

Step	Item	Positive Ignition Type	Compression Ignition Type
1	WLTP (according GTR)	3 vehicles per type	3 vehicles per type
2	Conditioning	5 vehicles per type (NEDC)	5 vehicles per type (3 x EUDC)
3	Type I test	5 vehicles per type	5 vehicles per type
4	NEDC at 5°C	not relevant	2 vehicles per type (incl. Conditioning)
5	NEDC at -7°C	not relevant	2 vehicles per type (incl. Conditioning)
6	Type II test	5 vehicles per type	not relevant
7	Type III test	5 vehicles per type	not relevant
8	Type IV test	2 vehicles per type	not relevant
9	Type VI test	2 vehicles per type (incl. Conditioning)	not relevant
10	OBD check	1 vehicle per type	1 vehicle per type
11	PEMS	3 vehicles per 2 types	3 vehicles per 1 type

Table 4.5: Test programme

The different driving cycles are illustrated in the following section.

New European Driving Cycle (NEDC)

After conditioning the vehicle for at least 6 hours at an ambient temperature of 20 °C up to 30 °C the New European Driving Cycle (NEDC) begins with a cold start. The Urban Driving Cycle (UDC) has duration of 780 seconds, a driving distance of 4.1 km, an average speed of 19 km/h and a maximum velocity of 50 km/h. It is followed by an Extra Urban Driving Cycle (EUDC) with a duration of 400 seconds, a driving distance of 6.9 km, an average speed of 62.6 km/h and a maximum velocity of 120 km/h. Exhaust emissions of both UDC and EUDC are combined to get a total test result.

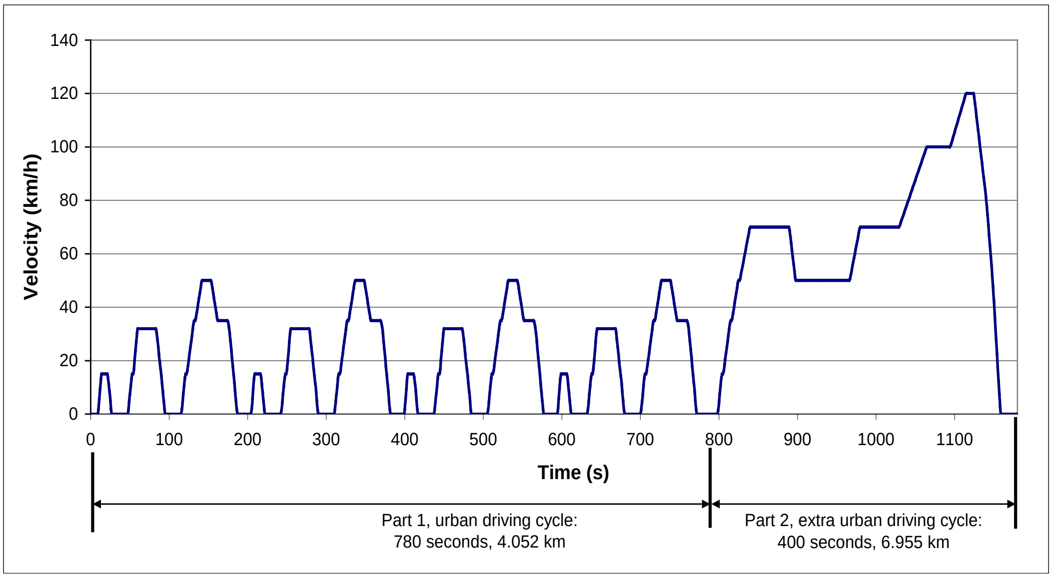

Figure 4.2: New European Driving Cycle

Worldwide light-duty test cycle (WLTC)

The Worldwide light-duty test cycle is part of the Worldwide light-duty testing procedure (WTLP). The WLTC (class 3) consists of four Phases:

- Phase Low, duration 589 seconds
- Phase Medium, duration 433 seconds
- Phase High, duration 455 seconds
- Phase Extra High, duration 323 seconds

The following figures show the different Phases.

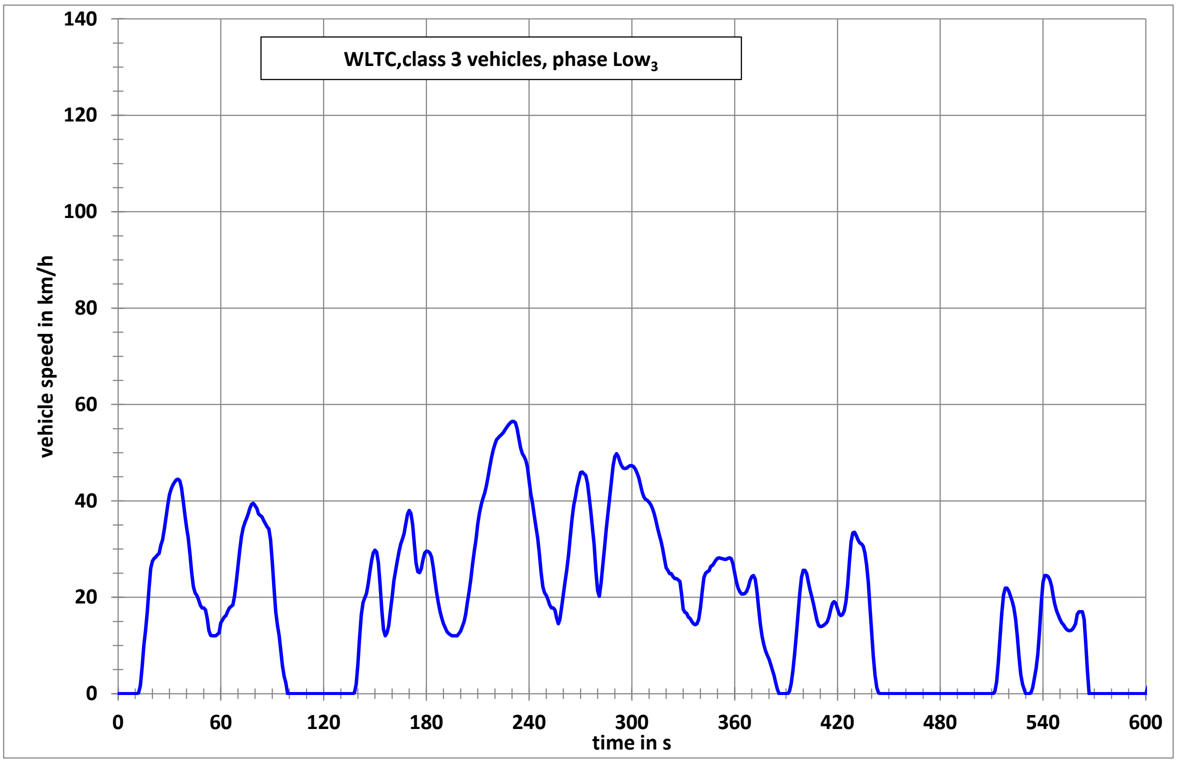

Figure 4.3: Phase Low

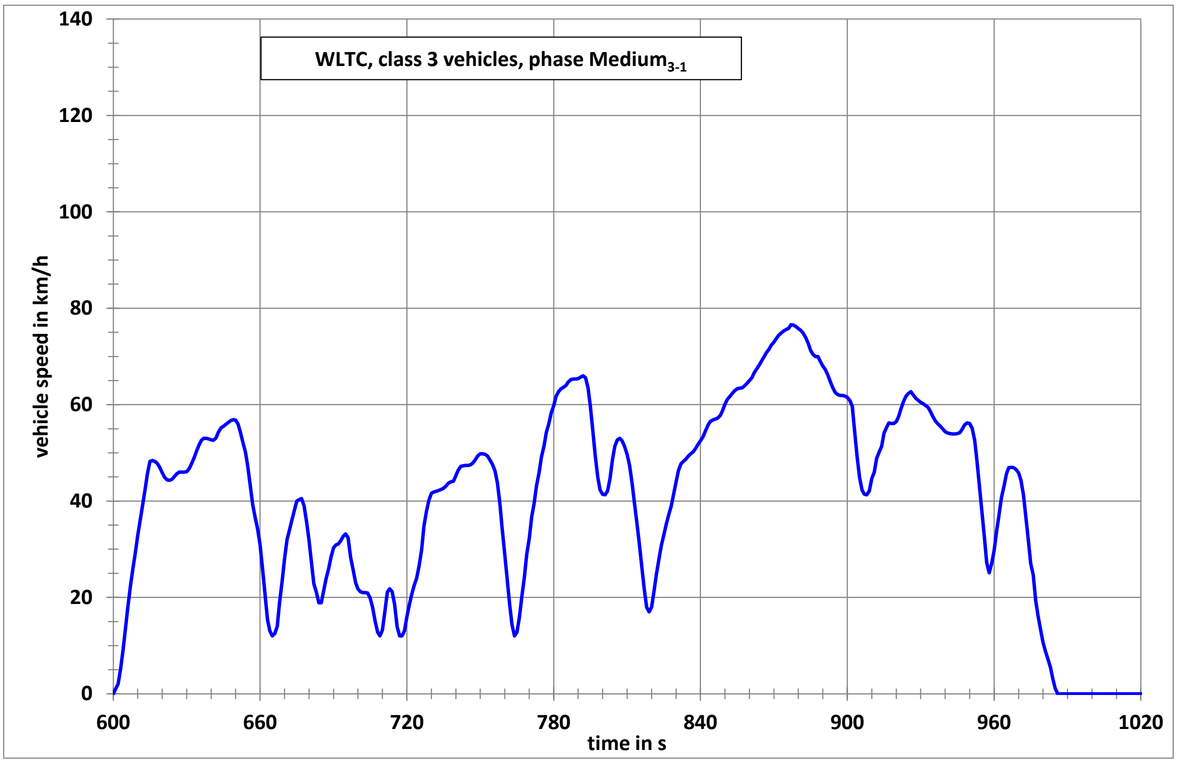

Figure 4.4: Phase Medium

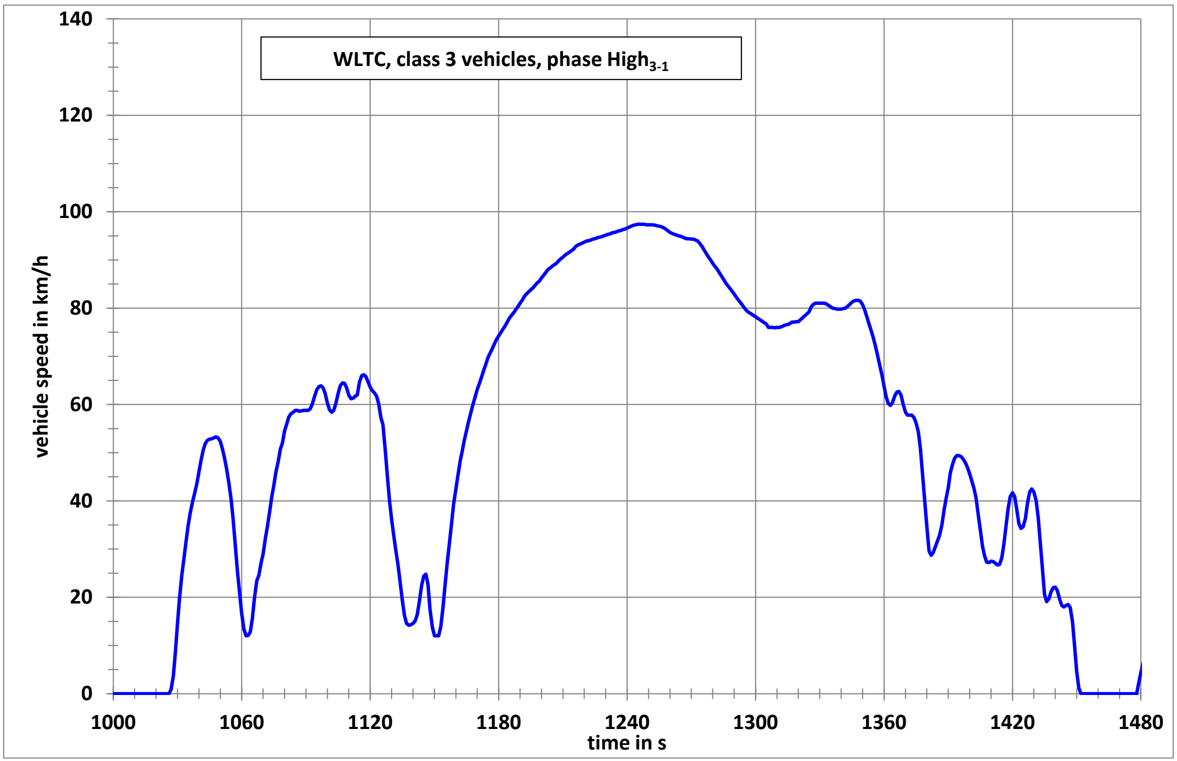

Figure 4.5: Phase High

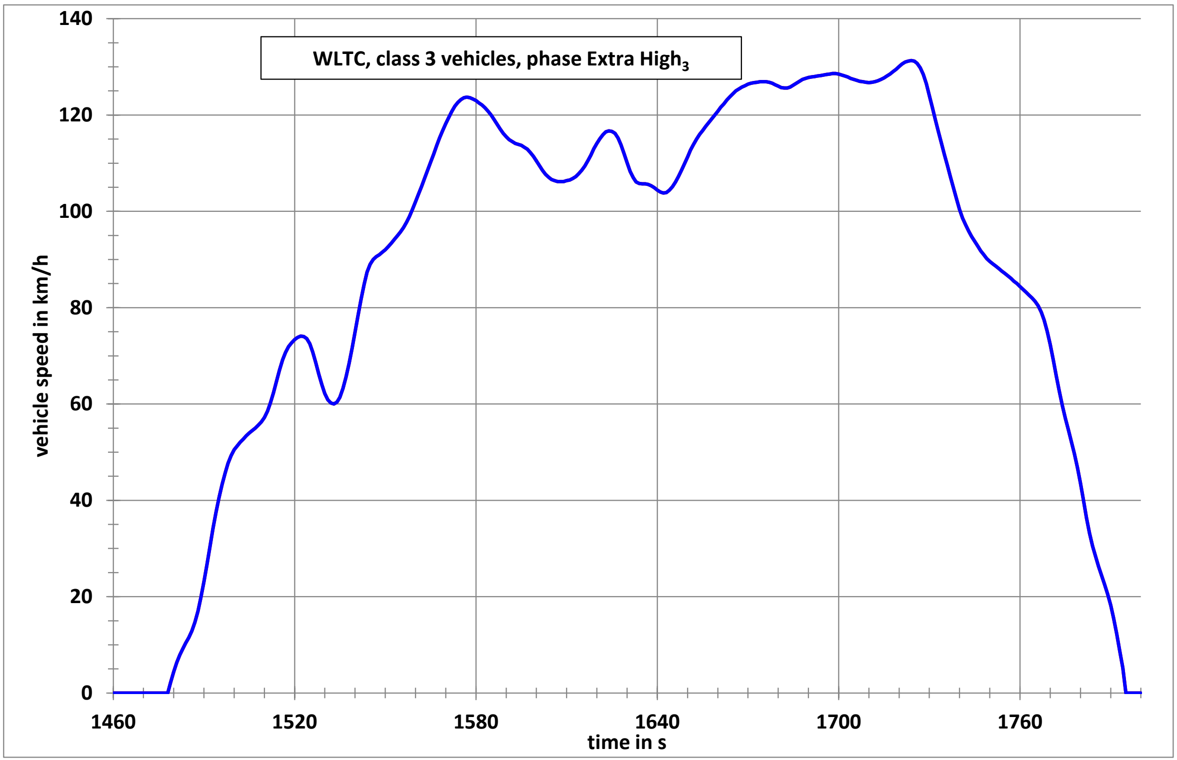

Figure 4.6: Phase Extra High

A comparison of the sub-cycles of NEDC and WLTC is given in **Table 4.6.** The average speed of UDC is comparable to WLTC LOW. The same is valid for EUDC and WLTC HIGH. However the WLTC cycles are much more dynamic as can be seen from the Relative Positive Acceleration (RPA). The gear shifting points are determined in accordance with the vehicle's weight, engine power and engine revolutions.

Driving cycle	**NEDC**		**WLTC – class 3**			
	UDC	**EUDC**	**LOW**	**MEDIUM**	**HIGH**	**EXT-HIGH**
Distance [km]	4.1	7.0	3,1	4,8	7,2	8,3
Average Speed [km/h]	19	63	19	40	57	92
RPA [m/s^2]	0.13	0.09	1,5	1,6	1,6	1,6

Table 4.6: Comparison of driving cycles

Gaseous emissions in all driving cycles were measured integrally and in parallel continuously every second (modal measurement). The results of the modal measurements may serve as the basis for determining the behaviour of the exhaust emission emission control system in all relevant traffic situations.

Portable Emission Measurement System (PEMS)

During the measurements on road the Measurement System is equipped in the car. The emissions are measured second by second at the end of exhaust pipe. In addition to the Gaseous emissions (THC, NOx, CO, CO2) the particulate mass was measured by a soot sensor. Figure 4.6 shows the most important information about the driving route used.

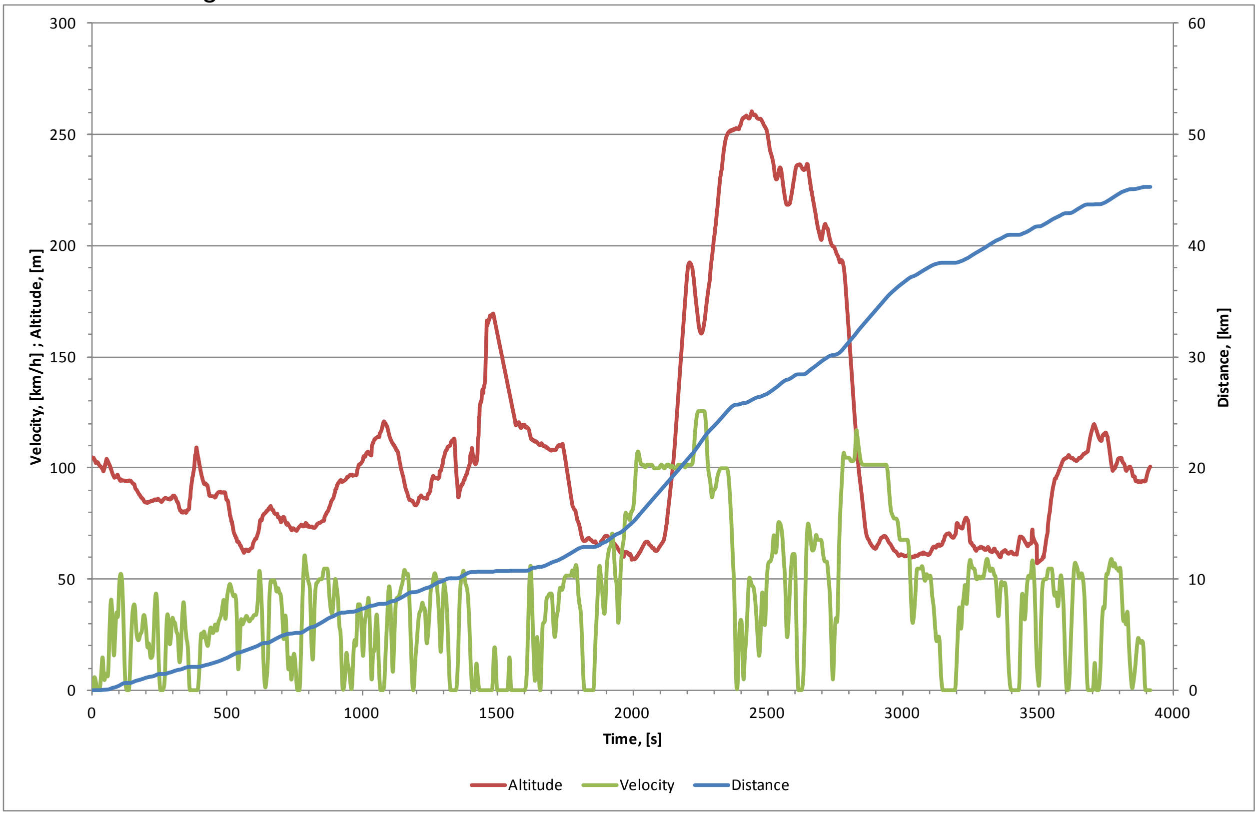

Figure 4.6: PEMS route

The results of the PEMS measurements carried out within this program were given to the Joint Research Centre of the European Commission. Up to now the evaluation of the data is not pointed out and there are different solutions in discussion. After the Evaluation of the Data defined an extra report for the PEMS measurements will be published.

5. Presentation of Results

5.1. Exhaust Emissions (Type I test)

In the following sections the values for exhaust emissions and fuel consumption of the various vehicles in the respective approval cycle are examined. **Figures 5.1 to 5.3** give examples for the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of a Euro 5 vehicle with positive ignition engine during Type I test.

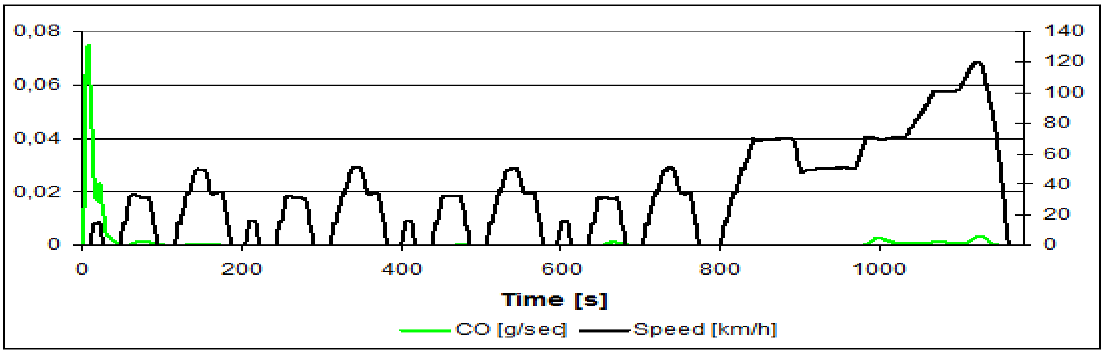

Figure 5.1: CO emitted by a positive ignition vehicle during NEDC

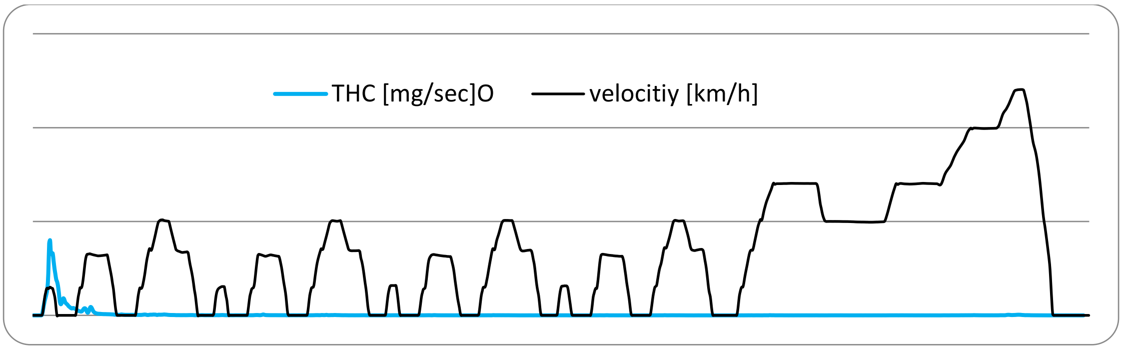

Figure 5.2: THC emitted by a positive ignition vehicle during NEDC

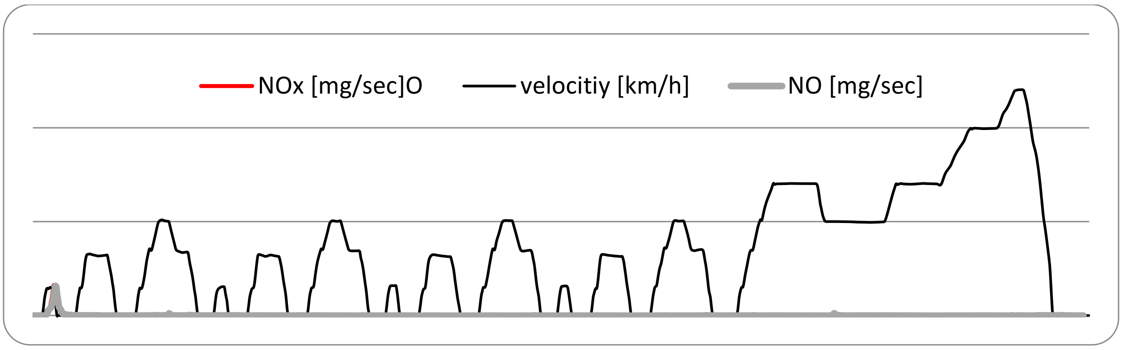

Figure 5.3: NOx and NO emitted by a positive ignition vehicle during NEDC

The major fraction of the CO, the THC and NOx emissions occurs at cold start conditions in the beginning of the driving cycle. As soon as the catalyst has reached its light off temperature of about 250°C carbon monoxide, hydrocarbons and nitric oxides are converted to carbon dioxide, water vapour and nitrogen.

Figures 5.4 to 5.6 show the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of a Euro 5 vehicle with compression ignition engine during Type I test.

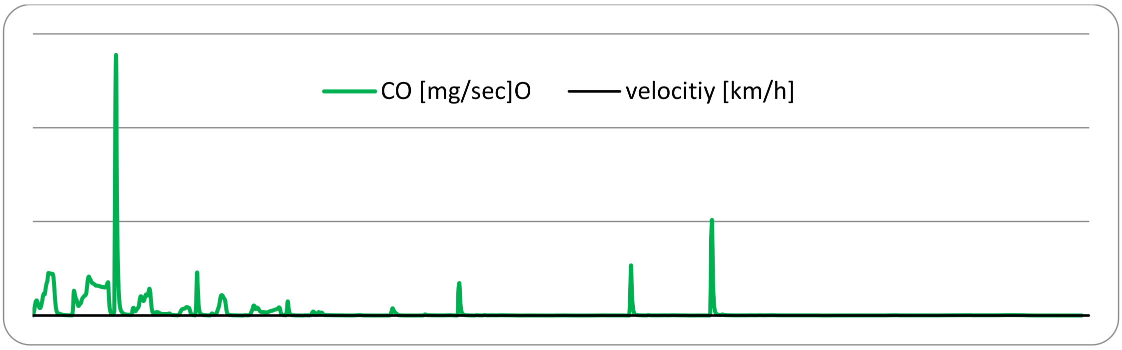

Figure 5.4: CO emitted by a compression ignition vehicle during NEDC

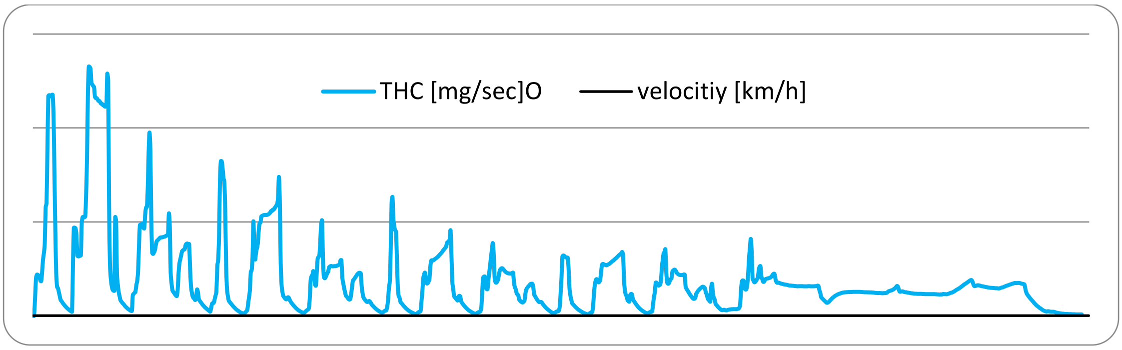

Figure 5.5: THC emitted by a compression ignition vehicle during NEDC

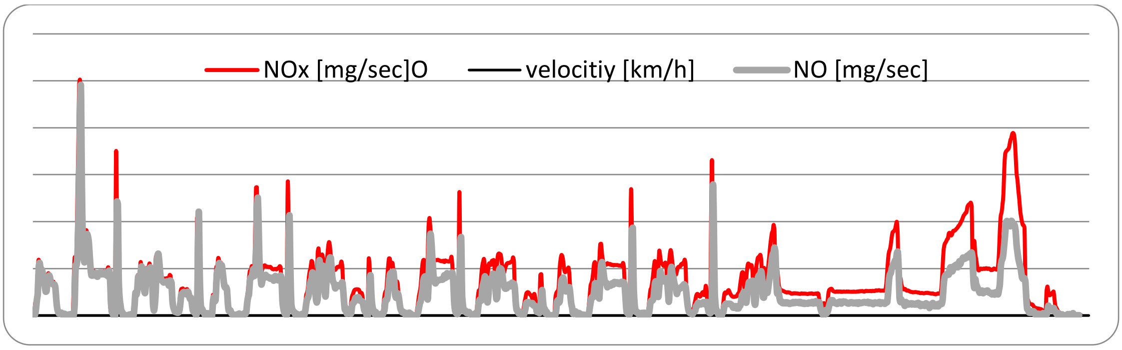

Figure 5.6: NOx and NO emitted by a compression ignition vehicle during NEDC

Carbon monoxide and total hydro carbon emissions of compression ignition vehicles show a graph similar to gasoline vehicles on a lower level. Due to cold start the major fraction of CO and THC are emitted during the first minutes of the test. As soon as the catalyst has reached its light off temperature, carbon monoxide and hydro carbons are oxidised. Because of the different combustion process, compression ignition engines generate higher nitric oxide emissions than positive ignition engines. High temperatures and a surplus of oxygen in the combustion chamber cause nitric oxide emissions. These conditions are found especially during accelerations. Due to an oxygen surplus within the exhaust gas these nitric oxides cannot be converted by a three-way catalytic converter on diesel cars.

In **Table 5.1** the average of the measured exhaust emissions for the different vehicle categories are compared to the type approval limits. The average emissions of all types tested complied with the limits given by the directive.

Category	Directive	Cycle	Average Exhaust Emissions						
			CO [mg/km]	HC [mg/km]	NMHC [mg/km]	NO_x [mg/km]	$HC+NO_x$ [mg/km]	PM [mg/km]	PN [#/km]
Compression ignition	Euro 6	UDC	32,3	14,4	9,4	9,8	24,2	-	-
	Euro 6	EUDC	17,3	53,1	17,1	10,4	63,5	-	-
	Euro 6	NEDC	22,8	39,1	14,3	10,2	49,3	0,07	$9{,}1*10^{9}$
Limit	**Euro 6**	**NEDC**	**500**	**-**	**-**	**80**	**170**	**4,5**	**$6{,}0x10^{11}$**
Positive ignition	Euro 5	UDC	838	101	93	34	135	-	-
	Euro 5	EUDC	99	1,5	1,4	6,6	8,1	-	-
	Euro 5	NEDC	372	38	35	17	55	0,78	$6{,}5*10^{11}$
Limit	**Euro 5**	**NEDC**	**1000**	**100**	**68**	**60**	**-**	**4,5**	**-**
Compression ignition	Euro 5	UDC	371	41	31	191	232	-	-
	Euro 5	EUDC	4,0	4,4	2,5	121	125	-	-
	Euro 5	NEDC	139	18	13,1	147	165	0,22	$4{,}9*10^{11}$
Limit	**Euro 5**	**NEDC**	**500**	**-**	**-**	**180**	**230**	**4,5**	**$6{,}0x10^{11}$**

Table 5.1: Average exhaust emissions during Type I test

Figure 5.7 presents the carbon monoxide emissions and the hydrocarbon emissions of positive ignition vehicles during Type I test. One of the gasoline vehicle types tested exceeded the Euro 5 limits for carbon monoxide and hydro carbons during Type I test.

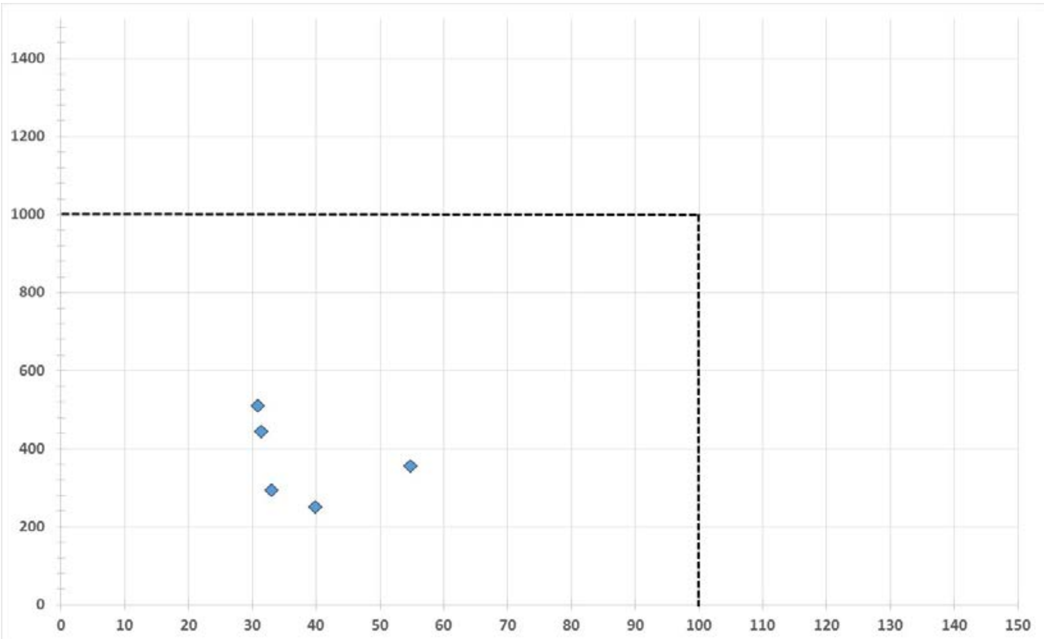

Figure 5.7: Average CO and HC emissions of vehicles with positive ignition during Type I test, [mg/km]

Particle mass emissions and nitric oxide emissions of positive ignition vehicles during Type I test are shown in **Figure 5.8.**

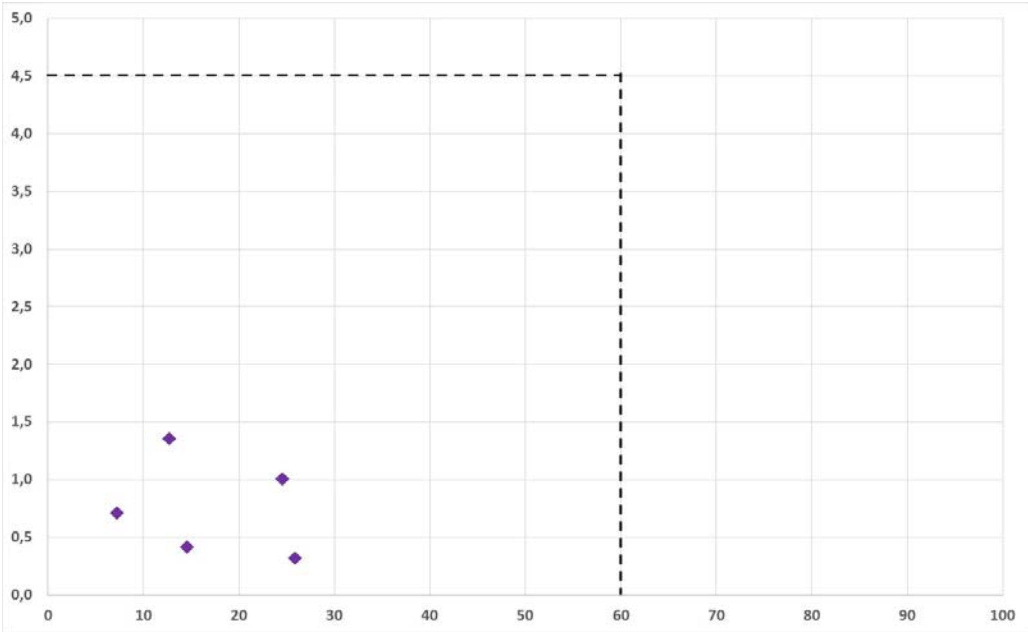

Figure 5.8: Average PM and NOx emissions of vehicles with positive ignition during Type I test, [mg/km]

All five tested gasoline vehicle types complied with the Euro 5 limits during Type I test and fulfilled the requirements for In-Service testing according to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC.

Figure 5.9 shows particle mass and nitric oxides emitted by one Euro 6 (green) and seven Euro 5 vehicles with compression ignition engine and particle filter during the Type I test.

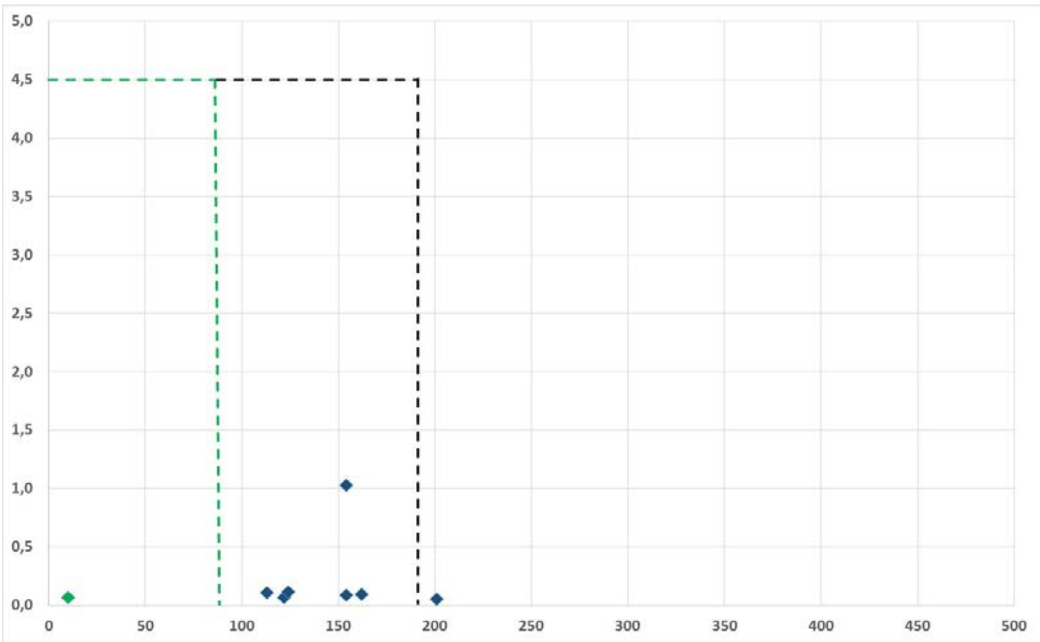

Figure 5.9: Average particle mass and NOx emissions of Euro 5 and 6 vehicles with compression ignition and particle filter during Type I test, [mg/km]

All tested vehicles with compression ignition were equipped with a periodically regenerating particulate trap. During type approval a factor (Ki) is used to consider the emissions during filter regeneration. The values given in this report do not consider the Ki factor. Considering the emission during filter regeneration by adding the Ki factor all Euro 5 and Euro 6 compression ignition vehicle types with particle filter complied with the limit for particulate mass given in directive 715/2007/EC, except of one single vehicle that failed the given limit for NOx-Emissions.

5.2. Categorisation of Carbon Dioxide Emissions and Fuel Consumption

Carbon dioxide is an important greenhouse gas because it transmits sunlight and strongly absorbs the infrared radiation reflected by earth. Combustion of fossil fuels increases the concentration of carbon dioxide in the atmosphere. Road traffic is a major source for man-made carbon dioxide emissions. Traffic of passenger cars contributes to 12percent of man-made CO_2 in Europe, according to 2004, EU-25 figures from the European Commission.

According to Directive 80/1268/EEC, the member states are not permitted to refuse grant of the EC type approval or conformity of production with national validity for a vehicle type for reasons which are related to the emission of carbon dioxide and fuel consumption if the CO_2 emission and fuel consumption are determined in accordance with Annex I of the Directive. These values are therefore a part of the type approval. However, there are no limit values at the moment. The CO_2 and consumption declarations are for consumer information and in many EU countries used as a basis for vehicle related taxes. The Directive requires that the values are contained in a document which is supplied to the owner by the manufacturer when the vehicle is purchased. If the CO_2 and consumption values are considerably exceeded, the buyer could apply warranty claims in the legal sense. The CO_2 figures will with the future CO_2 and cars regulation be even more important, when the manufactures have to fulfil 130 g/km as an average for their sold vehicles within EU.

The CO_2 emissions are measured in the "New European Driving Cycle". The fuel consumption is calculated using the measured CO_2 emissions and the other carbon-containing emissions (CO and HC). The test vehicle must be presented in good mechanical condition. For type approval it must be run-in and it must have been driven for at least 3,000 km, but for less than 15,000 km.

In **Figure 5.12** the average fuel consumption determined during the Type I test for the various vehicle types is compared to the value declared by the manufacturers.

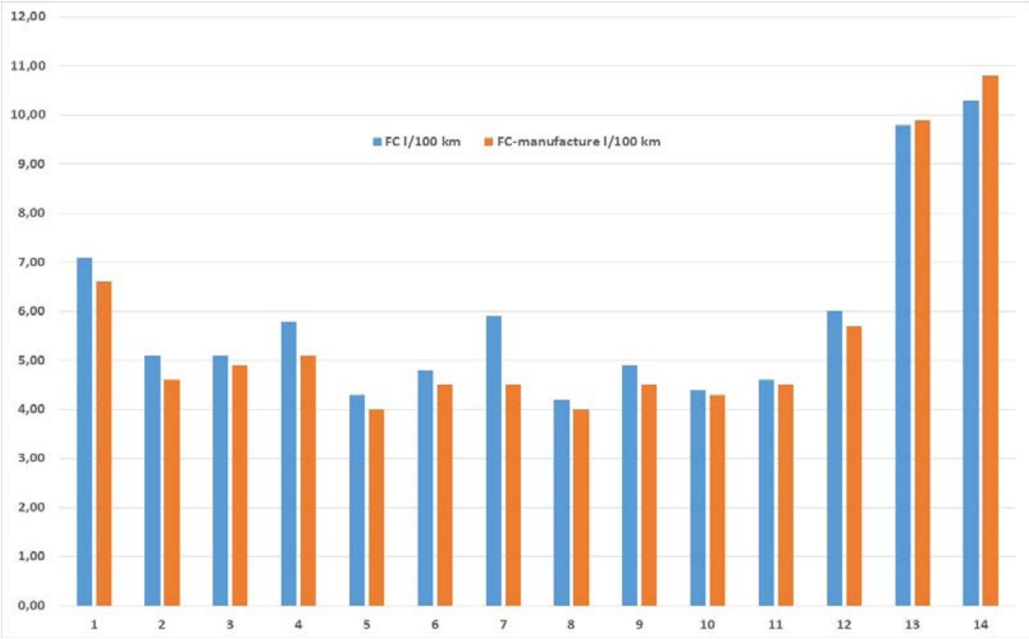

Figure 5.12: Average fuel consumption during Type I test for the different vehicle types

During the Type I test on 14 vehicles the measured average fuel consumption was higher than the fuel consumption declared by the manufacturer for 12 vehicle models. For one vehicle type the deviation from the values given by the manufacturer was 24 percent on fuel consumption. For two types the determined average fuel consumption was lower than the manufacturer's declaration.

The average carbon dioxide emissions determined during the Type I test for the various vehicle types compared to the values declared by the manufacturers are given in **Figure 5.13 and 5.14.**

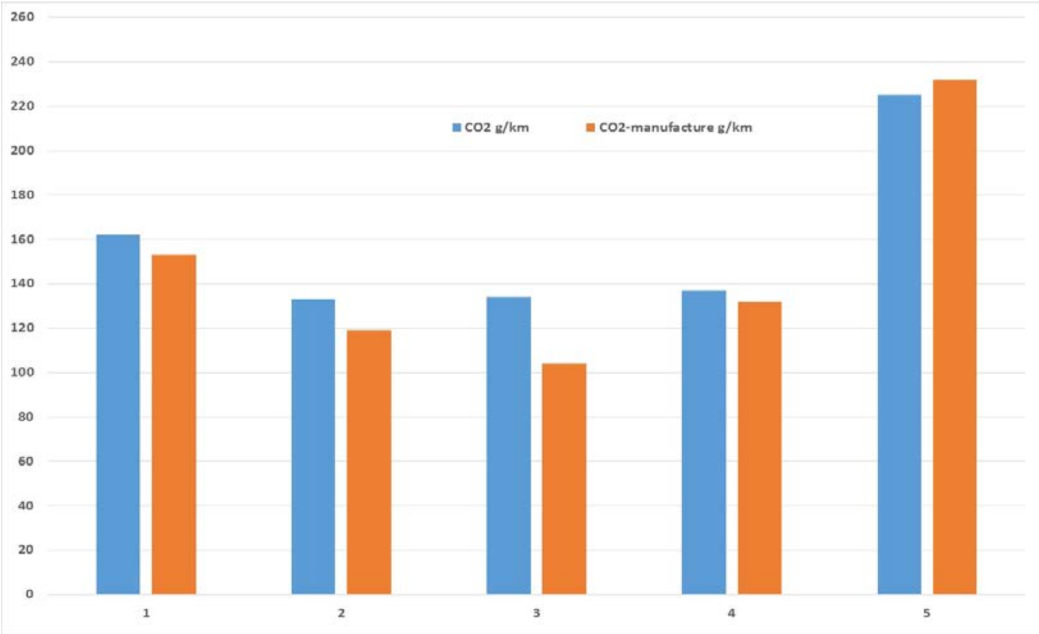

Figure 5.13: Average CO_2 emissions during Type I test for the different vehicle types with gasoline engine

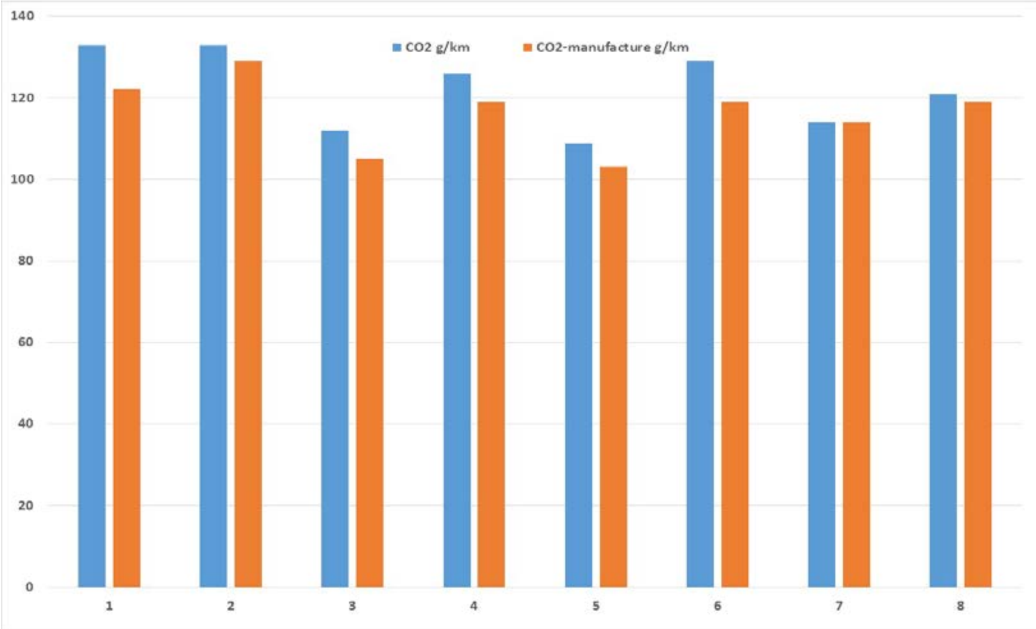

Figure 5.14: Average CO_2 emissions during Type I test for the different vehicle types with diesel engine

Figure 5.15 shows the relative deviation of the carbon dioxide emissions measured during Type I test to the value declared by the manufacturers.

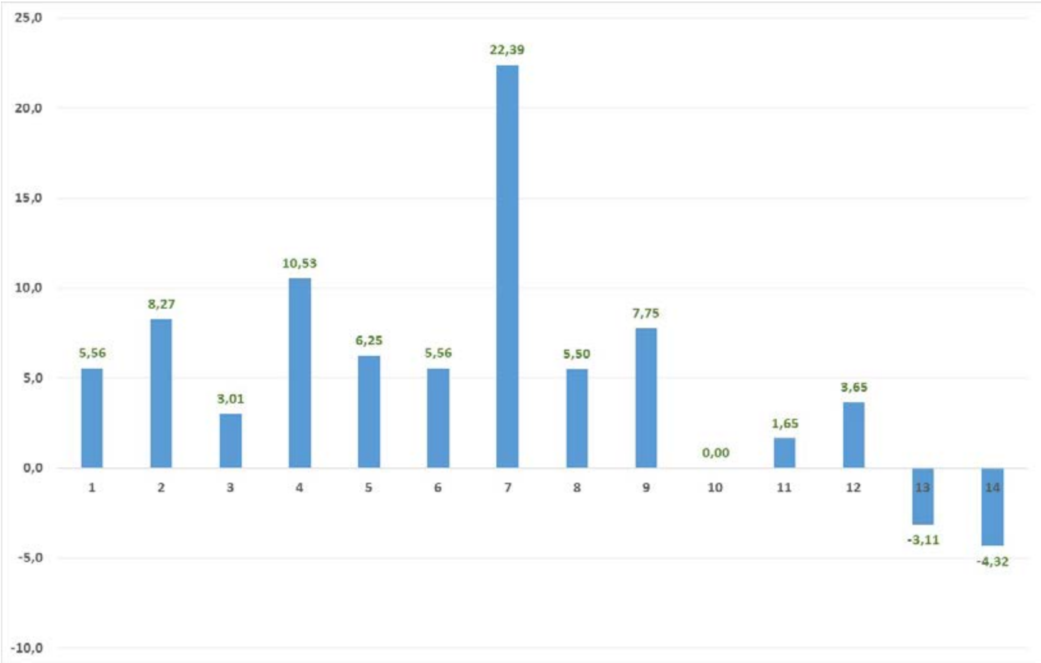

Figure 5.15: Relative deviation (percent) of the CO_2 emissions to the manufacturer's values during Type I test for the different vehicle types

For 8 types the average CO_2 emissions measured during Type I test were higher than 5percent above the manufacturer's declaration. Two vehicle types showed lower carbon dioxide emissions than declared by the manufacturers.

5.3. Idle Test (Type II test)

On vehicles with positive ignition engine exhaust gas concentrations are measured at idle speed. For this test the engine must be warmed up. The exhaust emissions measured at idle speed and at about 2,500 rpm are displayed in **Table 5.2**. The lambda value is calculated using the concentrations of CO, HC, CO_2 and O_2.

		Idle			
	CO [percentvol.]	**HC [ppm]**	**CO_2 [percentvol.]**	**O_2 [percentvol.]**	**λ**
Average gasoline	0,0036	0,44	14,60	0,010	0,999
Limits	3.5	-	-		-
		High idle (ca. 2,500 rpm)			
	CO [percentvol.]	**HC [ppm]**	**CO_2 [percentvol.]**	**O_2 [percentvol.]**	**Λ**
Average gasoline	0,0074	0,16	14,94	0,037	1,0006
Limits	-	-	-		-

Table 5.2: Average exhaust emissions during Type II test

During the Type II test no emission related problems were detected on the vehicles with positive ignition engine.

The Type II test is not relevant for vehicles with compression ignition engine.

5.4. Crankcase Emissions (Type III test)

Exhaust gases passing by the piston rings could cause environmental pollution. Therefore vehicles with positive ignition engine are equipped with a crankcase ventilation system. The crankcase gases are routed to the intake manifold and are combusted in the engine. The crankcase ventilation system is tested by measuring the pressure within the system at idle speed and at 50 km/h on the dynamometer with two different load settings. The pressure measured in the crankcase may not exceed the atmospheric pressure at different load conditions.

No crankcase emissions were emitted into the atmosphere at the Type III test on all tested vehicle types with positive ignition engine.

Measuring the crankcase emissions is not relevant for vehicles with compression ignition engine.

5.5. Evaporative Emissions (Type IV test)

If the fuel located in the fuel system is heated up, hydrocarbons evaporate. These vapours escaping into the environment cause considerable pollution. For this reason, modern vehicles with positive ignition engine are equipped with a system for retaining such fuel vapours.

For type approval testing, in addition to exhaust emissions in the driving cycle, the amount of evaporative hydrocarbon emissions escaping mainly from the vehicle fuel system is measured. For this Type IV test a Sealed Housing for Evaporative Emissions Determination (SHED) is used. The Type IV test is designed to determine hydrocarbon evaporative emissions caused by hot soaks during parking and by diurnal temperatures variation. The measurement of evaporative emissions according to Directive 98/69/EC and 715/2007/EC includes three phases:

- test preparation including a driving cycle
- hot soak loss determination
- diurnal loss determination

For measuring the hot soak emissions, the test vehicle is placed in a SHED for one hour directly after having finished a driving cycle. During the diurnal test the vehicle is placed in the SHED for 24 hours to determine the fuel-system and tank ventilation losses. The vehicle is exposed to an ambient temperature cycle which simulates the temperature profile for a summer day while the hydrocarbons released are measured. In this way, hydrocarbon emissions due to permeation and micro-leaks in the whole fuel-bearing system are considered. The results of the hot soak test and of the diurnal test are summated to a total result. The statutory limit value for the total evaporative emissions is 2 g hydrocarbons per test.

Figure 5.16 gives a detailed outline of the Type IV test procedure according directive 98/69/EC and 715/2007/EC. During this programme the vehicles were refilled with reference fuel and driven within the Common Artemis Driving Cycle before starting the SHED-procedure. On all tested vehicles the washer fluid canister was drained, purged and refilled with clear water.

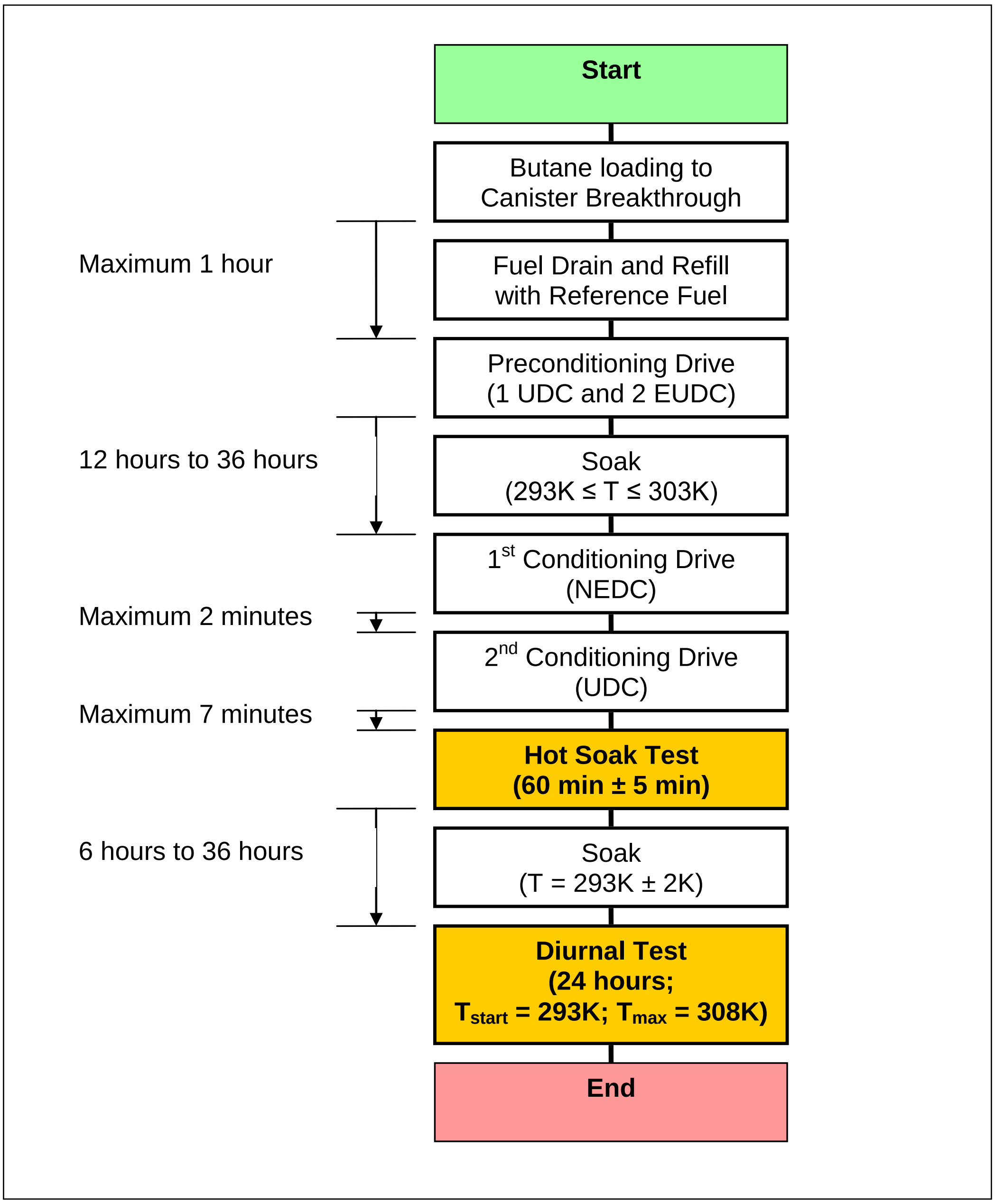

Figure 5.16: Type IV test procedure

During this In-Service Conformity testing programme, measurement of the evaporative emissions was carried out on two vehicles per model with positive ignition engine in addition to the exhaust emission measurement. The results of these measurements are summarised in **Figure 5.17**.

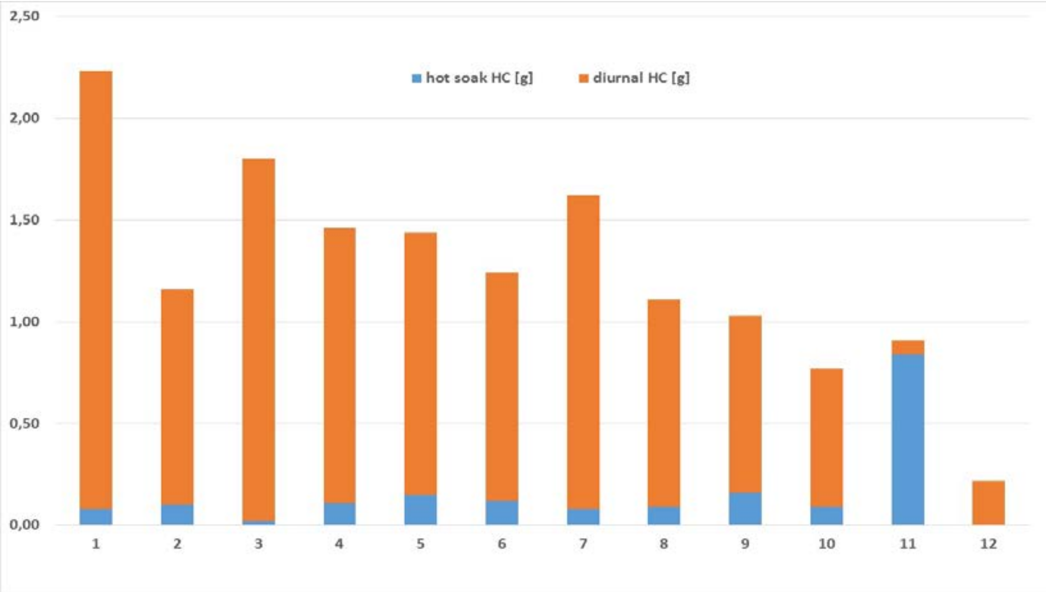

Figure 5.17: Evaporative emissions

One of the 12 tested vehicles exceeded the limit for evaporative emissions according to Directive 98/69/EC and 715/2007/EC.

Vehicle No.	Evaporative emissions [g HC]		
	Hot Soak	Diurnal	Total
1	0,08	2,15	2,23
2	0,10	1,06	1,17
3	0,02	1,78	1,80
4	0,11	1,35	1,46
5	0,15	1,29	1,44
6	0,12	1,12	1,25
7	0,08	1,54	1,62
8	0,09	1,02	1,12
9	0,16	0,87	1,03
10	0,09	0,68	0,77
11	0,84	0,07	0,91
12	0,00	0,22	0,22
Average			
	0,15	**1,10**	**1,25**
Limit			
	-	**-**	**2.00**

Table 5.3: Evaporative emissions

Results presented in **Table 5.3** show that evaporative emissions during the diurnal test generate the major fraction of the total result.

5.6. Emissions at low Temperatures (Type VI test)

Directive 98/69/EC introduced an exhaust emission test at low ambient temperatures for vehicles with positive ignition engine. Also in directive 715/2007/EC the test at low temperature is mandatory. The test includes a cold start at -7°C and the urban part of the NEDC. The purpose of this Type VI test is the adaptation of type approval testing to realistic driving conditions. Carbon monoxide and hydrocarbon emissions are limited by the Directive. During this In-Service Conformity testing programme, two vehicles per type with positive ignition engine were tested at low ambient temperatures.

Table 5.4 show the Type VI test results compared to the Type I test results of the positive ignition vehicles tested at low ambient temperatures.

Vehicles with positive ignition engine		**Exhaust Emissions**			
Test	**Driving Cycle**	**CO [mg/km]**	**HC [mg/km]**	**NOx [mg/km]**	**CO_2 [mg/km]**
Type I test	UDC	838	101	34,9	213
	EUDC	99,6	1,51	6.61	127
	NEDC	371	38,0	17,0	158
Limit	**NEDC**	**1000**	**100**	**60**	**-**
Type VI test	UDC	5361	1044	92,6	256
Limit	**UDC**	**15000**	**1800**	**-**	**-**

Table 5.4: Exhaust emissions during Type VI and Type I of vehicles with positive ignition engine and EURO 5 emissions standard tested at -7°C

Figure 5.20 shows the exhaust emissions measured during Type VI test. During the exhaust emission test at low ambient temperatures, all tested vehicles complied with the limits according to Directive 98/69/EC / 715/2007/EC.

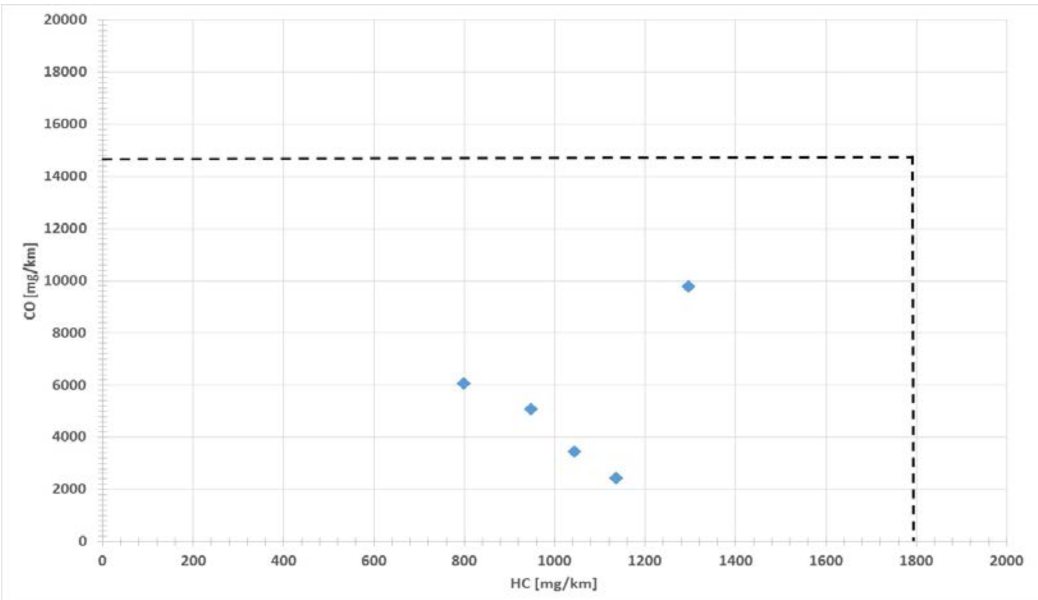

Figure 5.20: Average exhaust emissions at low ambient temperatures

Figure 5.21 illustrates the HC emissions during Type I test and Type VI test.

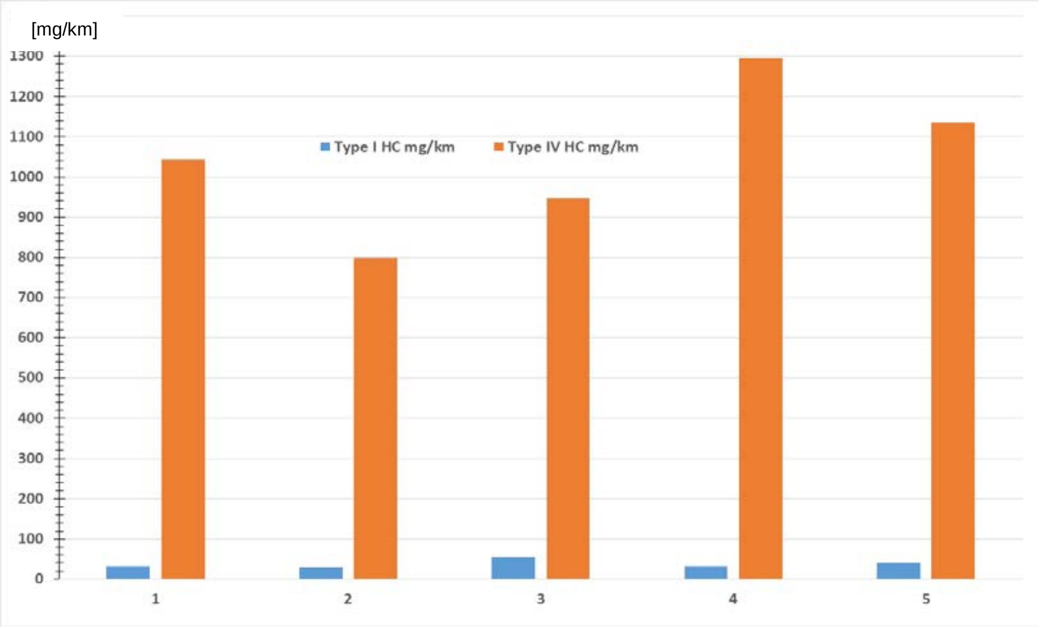

Figure 5.21 : Hydrocarbon emissions during Type I and Type VI test

Hydrocarbon emissions during UDC at low ambient temperature (-7°C) exceeded the exhaust emissions at 'normal' ambient temperature (20°C up to 30°C according to the directive) by a factor of 10.

5.7. OBD System

With the Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars was introduced and resumed by directive 715/2007/EC. The aim of introducing the OBD system was to achieve a significant upgrade in emission performance over the useful lifetime of vehicles in service. The OBD is an electronic system designed to detect failures of anti-pollution devices immediately, monitor critical functions of the engine and emission control systems, store additional information about deviations and assist during maintenance with fault diagnosis and fault rectification. OBD is required for vehicles with positive ignition engine registered since the 1. January 2001 and for vehicles with compression ignition engine registered since the 1. January 2004.

During this project the OBD-data were registered. In addition, some emission relevant defects were simulated to control the function of the OBD system at one of the vehicles per model. Different failures like electrical disconnection of intake air pressure sensor, disconnection of throttle position sensor, misfire, electrical disconnection of injector, disconnection of oxygen sensor (before and after catalyst) were implemented depending on the power train of the vehicles tested.

All simulated failures were detected by the OBD system.

5.8. Exhaust Emissions during the Worldwide harmonized Light vehicles Test Procedure (WLTP)

“The Commission should keep under review the need to revise the New European Drive Cycle as the test procedure that provides the basis of EC type approval emissions regulations. Updating or replacement of the test cycles may be required to reflect changes in vehicle specification and driver behavior.”
This quotation taken from the Framework directive 715/2007 leads to the establishment of the Informal Working group with the mandate to develop a new test procedure for exhaust emissions. The figures below present the emission behavior measured during the progam. All test carried out according the Global Technical Regulation (GTR) No. 15.

In **Figures 5.22 to 5.25** the average gaseous exhaust emissions of all vehicles tested during WLTP are illustrated.

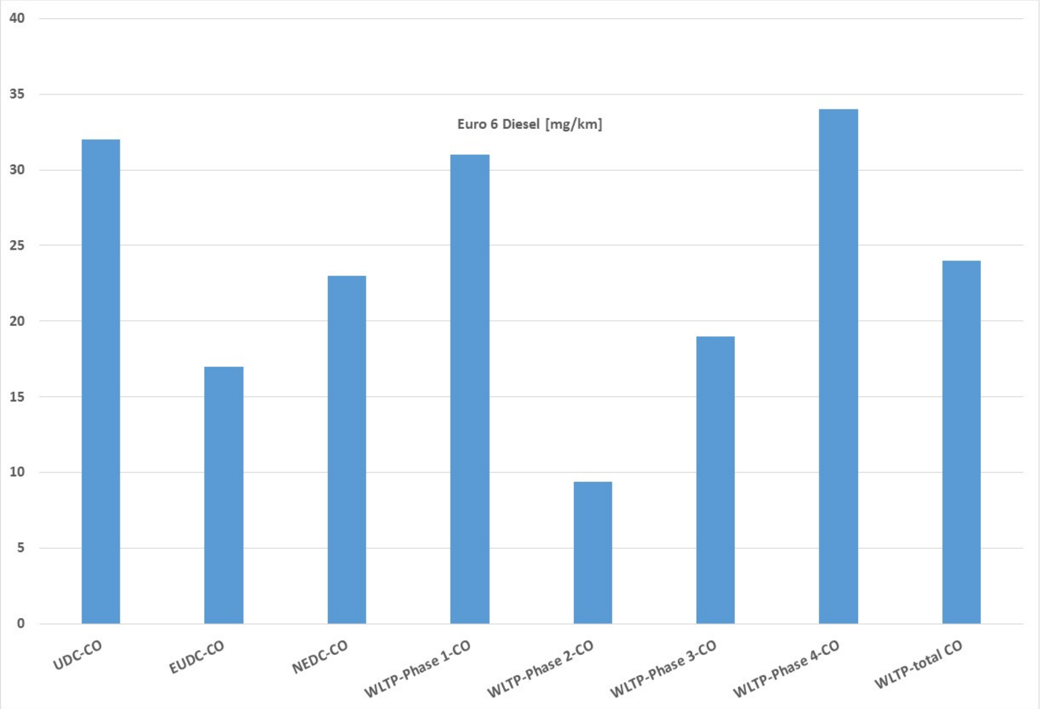

Figure 5.22: CO emissions under different driving conditions EURO 6 vehicle

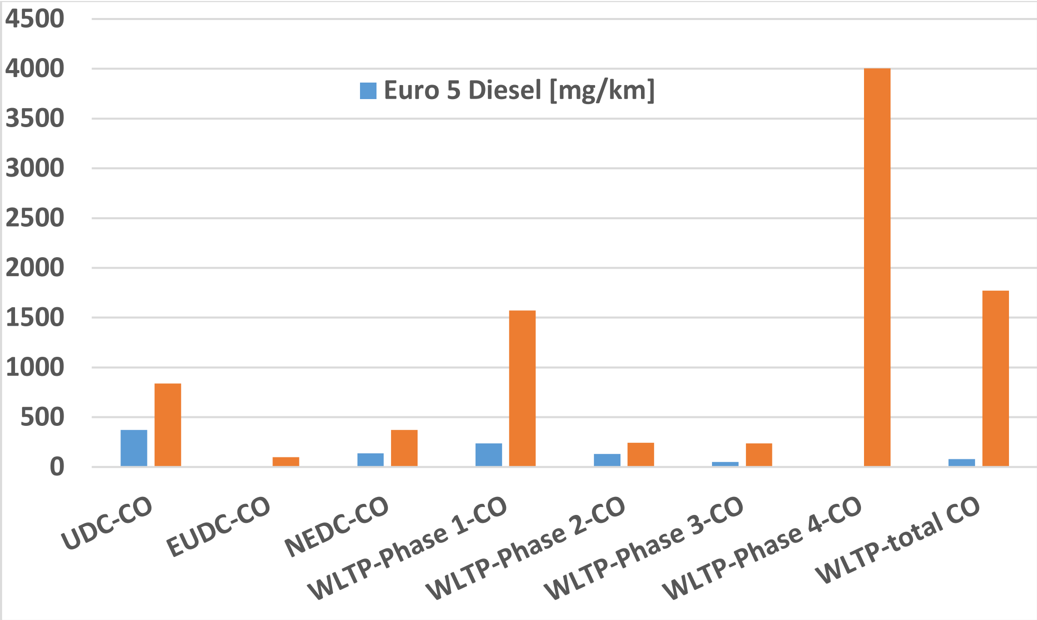

Figure 5.23: Average CO emissions under different driving conditions EURO 5 vehicles

The figures demonstrate that the major fraction of CO and HC within the New European Driving Cycle is emitted during the Urban Driving Cycle including cold start. High load and high speed during the WLTP cause increasing carbon monoxide emissions on positive ignition engine vehicles. The high average CO emissions during WLTP phase 4 of positive ignition vehicles were caused by a few cars with small engines that showed extremely high emissions.

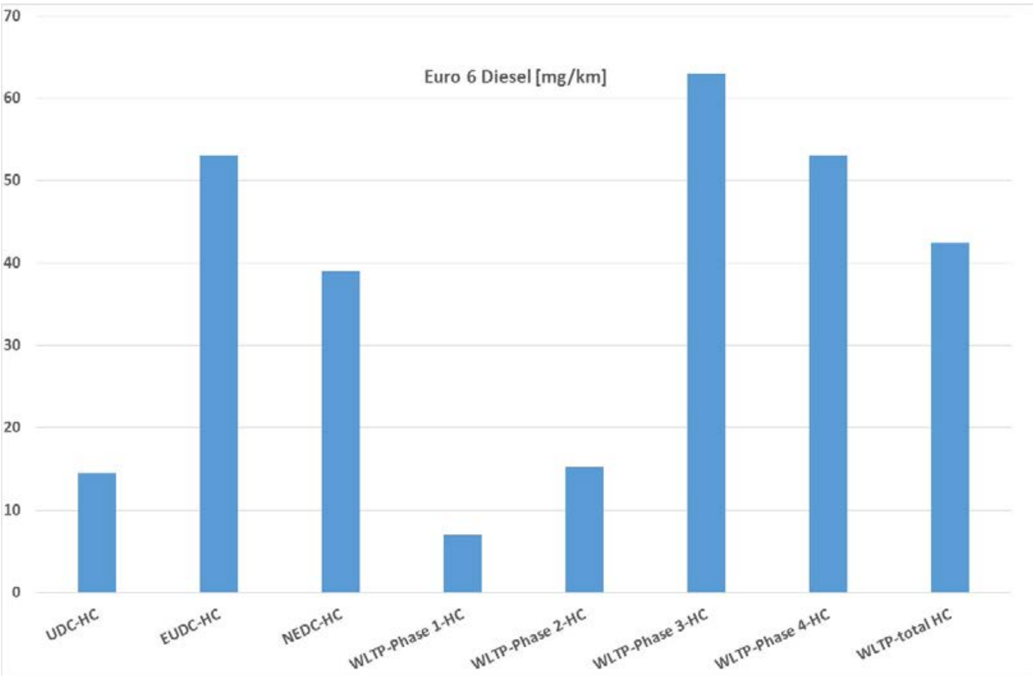

Figure 5.24: HC emissions under different driving conditions EURO 6 vehicle

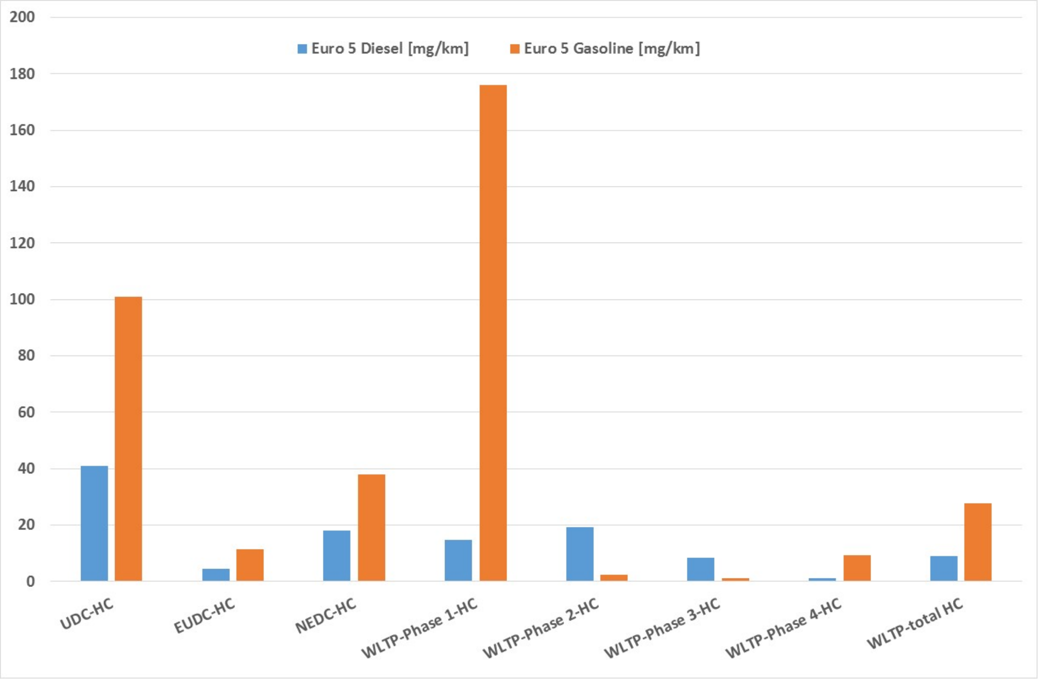

Figure 5.25: Average HC emissions under different driving conditions EURO 5 vehicles

Both carbon monoxide and hydro carbon emissions are products of incomplete combustion. Therefore CO and HC are emitted at the same driving conditions. Especially at cold start conditions before the catalyst has reached its light-off-temperature and at high load with a rich air fuel ratio carbon monoxide and hydro carbons are emitted because they cannot be converted. Due to a surplus of oxygen in the air fuel mixture, carbon monoxide and hydrocarbon emissions of vehicles with compression ignition engine are lower than of vehicles with positive ignition during all different test cycles.

Figures 5.26 and 5.27 demonstrate the different behaviour of compression- and positive-ignition with respect to NOx emissions.

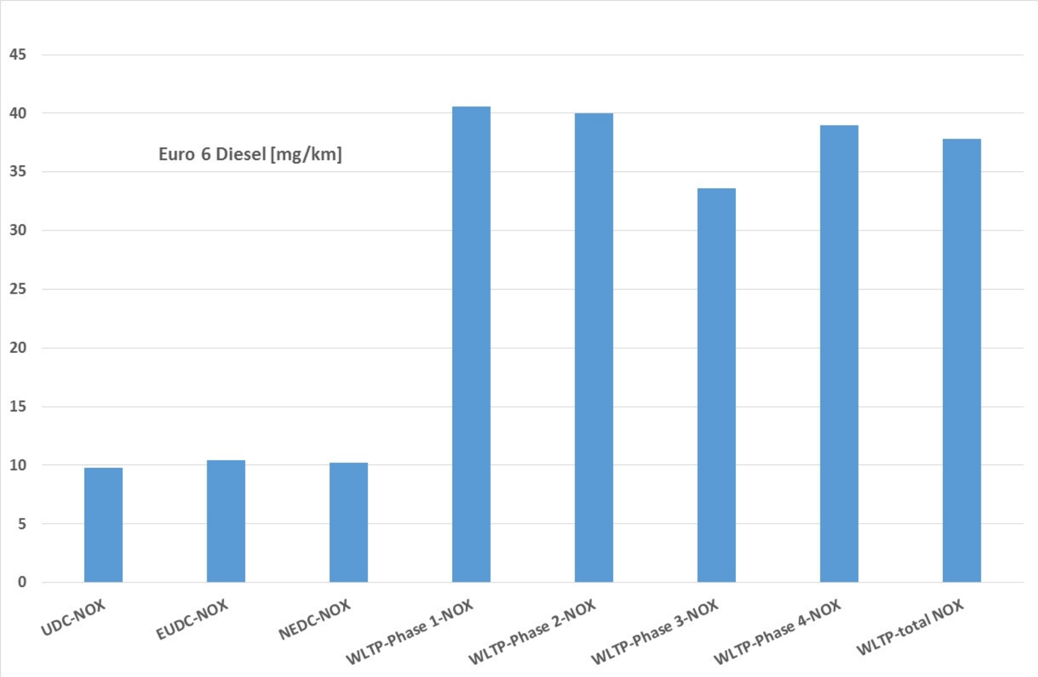

Figure 5.26: Average NOx emissions under different driving conditions EURO 6 vehicle

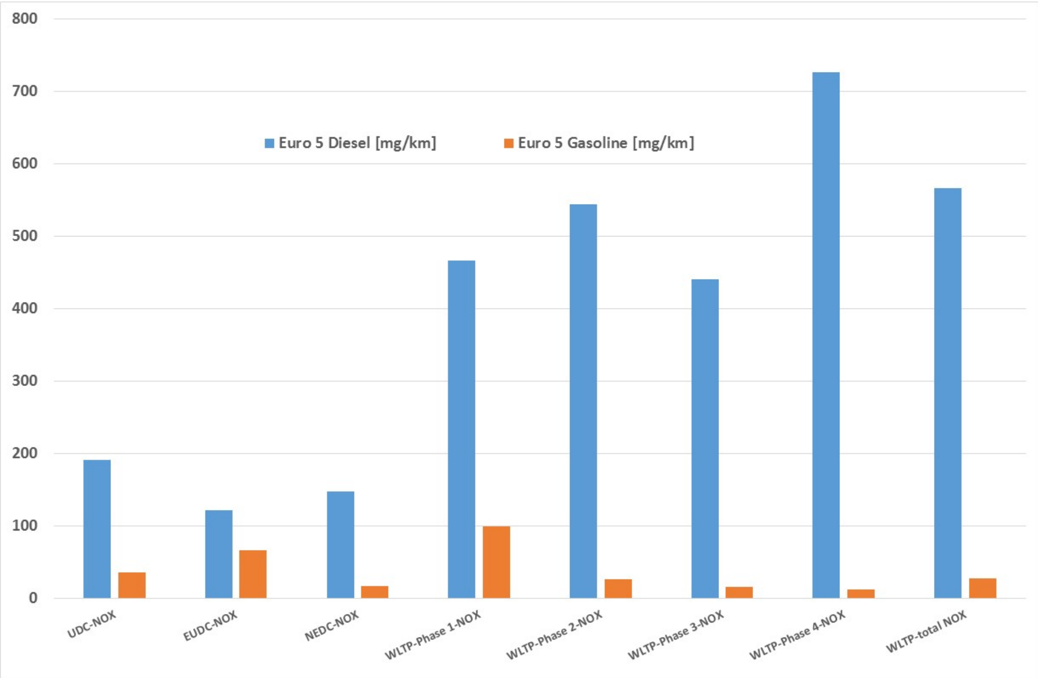

Figure 5.27: Average NOx emissions under different driving conditions EURO 5 vehicles

The major environmental exposure caused by compression ignition vehicles is nitric oxide and particulate emissions. Figures 5.26 and 5.27 illustrate that NO_x is emitted by compression ignition vehicles especially during the WLTP phase 4 cycle. This is due to the high temperature inside the combustion chamber at high engine load combined with a surplus of oxygen within the cylinder.

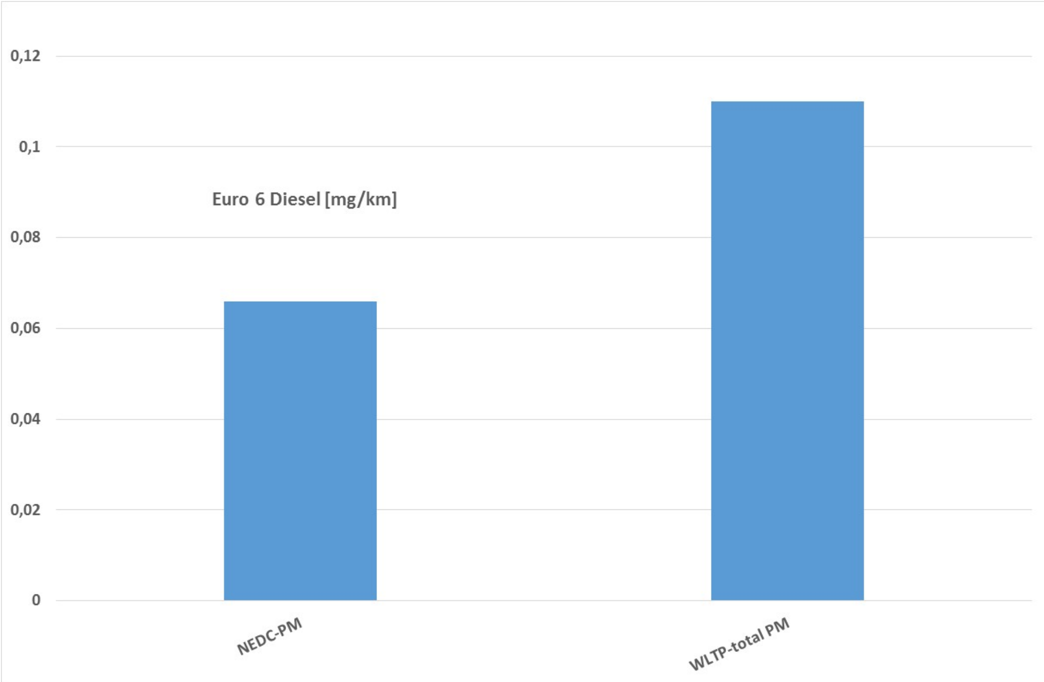

Figure 5.28: Particle mass in NEDC vs WLTP, EURO 6 vehicle

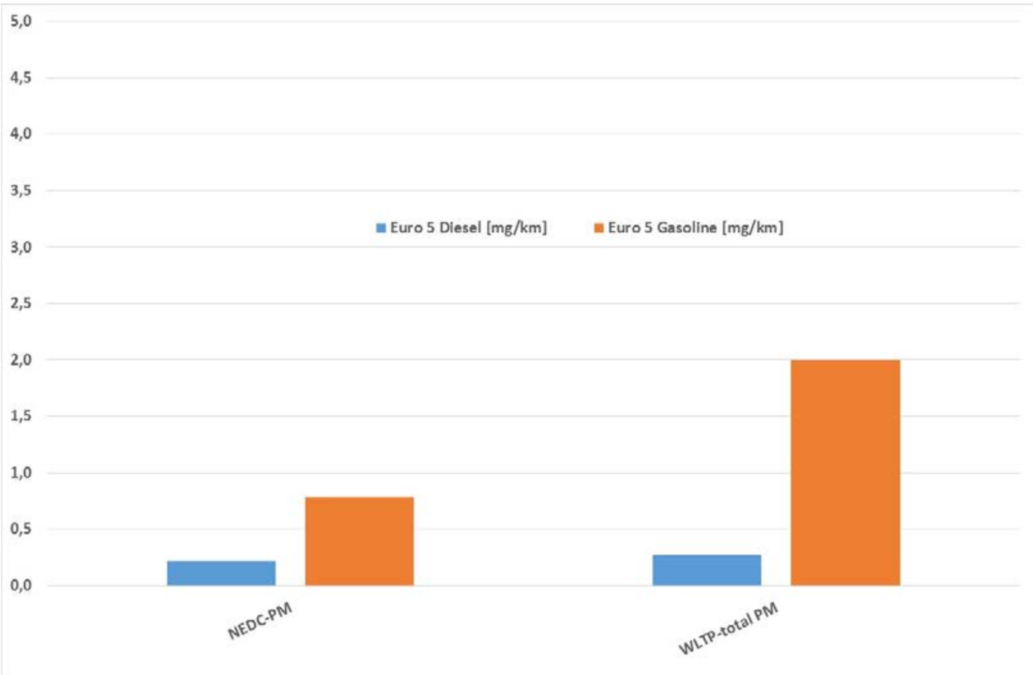

Figure 5.29: Average particle mass NEDC vs WLTP, EURO 5 vehicles

During this programme particle emissions were measured both on diesel and on gasoline vehicles. In **Figures 5.28 and 5.29** demonstrated that particle mass on positive ignition vehicles is higher compared with compression ignition vehicles with particle filters. It has to be considered that due to the measurement technique especially on positive ignition vehicles beside particles, condensed volatile hydrocarbons might have been collected on the filter pads which could have affected the test results. More detailed information concerning particle emissions is given in chapter 5.9.

Figures 5.30 and 5.31 illustrate the fuel consumption measured at different driving conditions. The average fuel consumption is given for all positive ignition and compression ignition vehicles tested during WLTP.

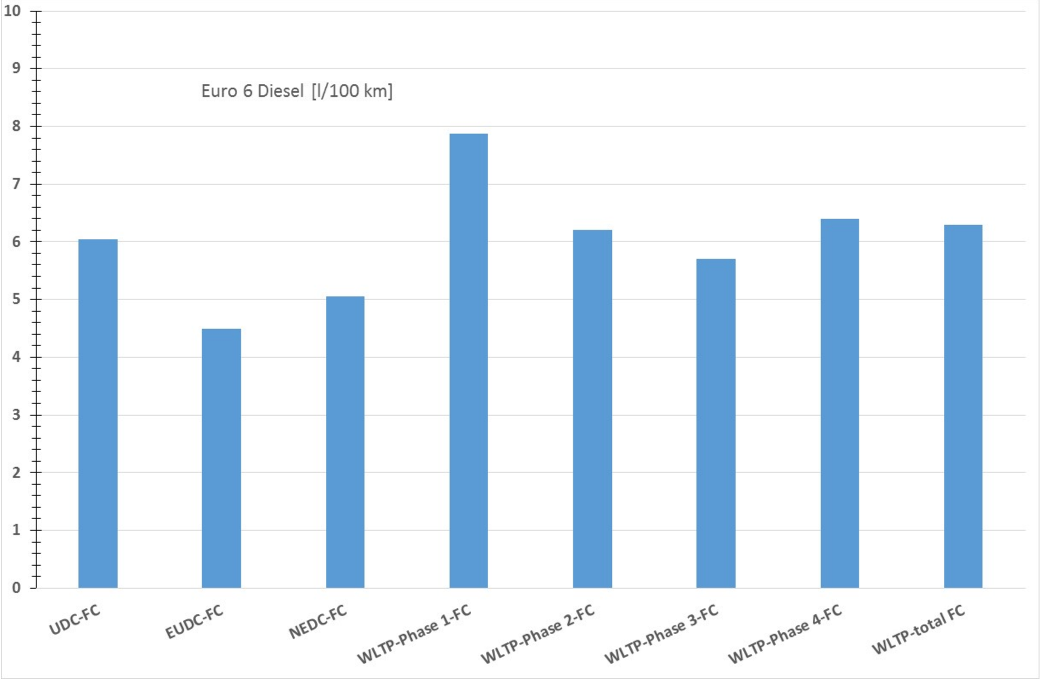

Figure 5.30: Fuel consumption under different driving conditions compared EURO 6 vehicle

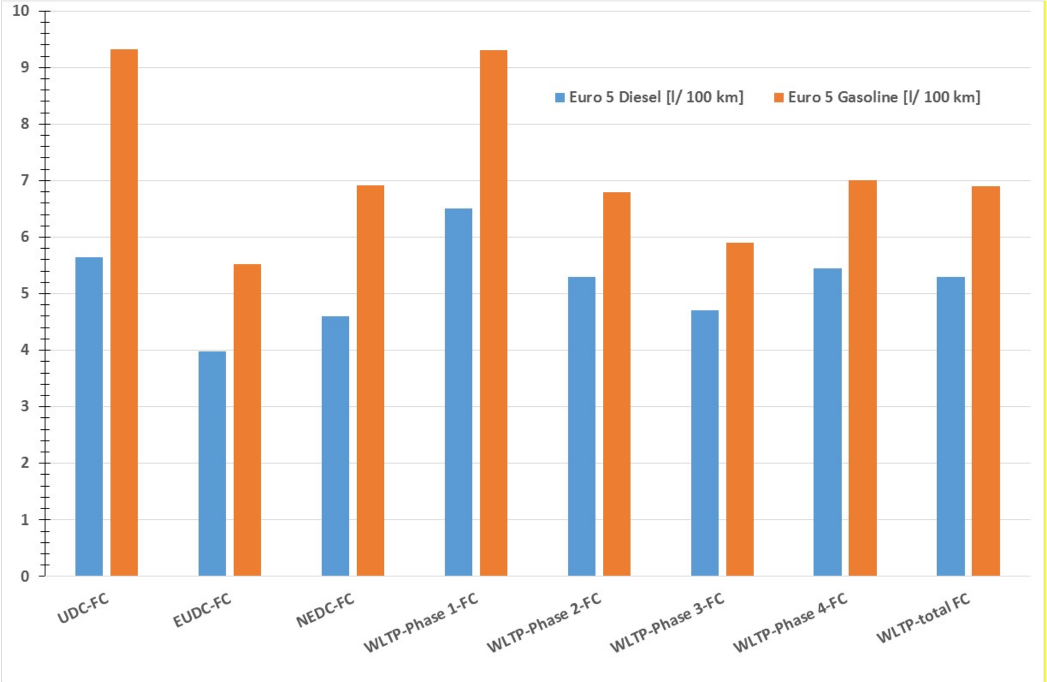

Figure 5.31: Average fuel consumption under different driving conditions value EURO 5 vehicles

Figures 5.30 and 5.31 demonstrate the influence of driving conditions and driving behaviour on the fuel consumption of different engine concepts. It is obvious that dynamic driving with strong accelerations at urban conditions gives the worst fuel consumption for vehicles with combustion engines. Positive ignition engines suffer from cold start more than compression ignition engines. Smoothly running traffic with moderate speed and acceleration gives the lowest fuel consumption. Under road conditions, the tested compression ignition engine showed the best results compared to the NEDC.

5.9. Particulate Measurement

Particulate emissions from vehicles with compression ignition engine are suspected of causing diseases of the respiratory tract and cancer. Therefore, the EU Commission proposed an update of European exhaust emission legislation. The Euro 5 particulate limit for type approval of passenger cars and light duty vehicles shall be 5 mg/km. This means an 80 percent reduction of the Euro 4 limit, which has been applicable for the type approval procedure since 1. January 2005.

According to current exhaust emission legislation, the particles emitted during the Type I test are collected on filters and the particulate mass (PM) is determined by weighing these filters. For detecting low emissions expected from future diesel vehicles, an adaptation of the measurement technique is necessary. In 2001 the United Nations Economic Commission for Europe (UNECE) installed a working group to establish a new method of measuring particulate emissions. During the Particle Measurement Programme (PMP) several different techniques were tested. The conclusion of the PMP members was to modify the existing particle mass detection and to add a particle number determination.

Accuracy of particulate mass measurement shall be improved by several provisions like a high-performance inlet filter for the dilution air of the CVS system, upgraded sampling system including cyclone separator, constant sampling temperature, optimisation of the procedures for avoiding electrostatic charging and 99.9percent efficiency filter pads.

In order to minimize the influence of the background emissions from the dilution air the dilution tunnel of the exhaust gas laboratory in Essen was already equipped with an HEPA filter. This High Efficiency Particulate Air Filter is intended to achieve a particle separation rate of 99.97percent.

Council Directive 98/69/EC specifies the use of filters for collecting particles whose surface consist of material which is hydrophobic and inert in relation to the exhaust gas constituents. The filters must be made of fluorocarbon-coated glass fibres or equivalent material. In most exhaust gas laboratories, T60A20 filters from the company Pallflex are used to determine the particulate mass. According to the manufacturer these heat-resistant filters of fluorocarbon-coated borosilicate glass fibres exhibit a typical filter effectiveness of 96.4percent. With the exhaust gas measurement during the driving cycle two filters arranged in series (collecting filter and back-up filter) are used in order to capture the largest possible quantity of particles. Pallflex provides filters of borosilicate micro-fibres which are reinforced with a glass fibre fabric and are bonded with PTFE. These TX40HI20 filters should, according to the manufacturer, achieve a typical aerosol separation rate of 99.9percent. In view of the high filtering effect, a back-up filter can be abandoned if such filters are used.

To improve the accuracy of particle mass determination the ambient conditions for filter conditioning is regulated more stringent than in the current directive. To observe a temperature of 22°C ± 3 and a humidity of 45percent ± 8 a new weighing chamber was installed. The dewpoint in the chamber is maintained at 9.5 °C ± 3 °C. In addition a balance with higher accuracy according to PMP suggestion was used.

In **Table 5.5** essential elements of the particle measurement equipment according directive 98/69/EC are compared to the new directive 715/2007/EC

PM according to 98/69/EC	PM according to 715/2007/EC
- (HEPA filter also used during this programme)	HEPA Filter with 99.97percent efficiency for dilution air
Probe with ‚China Hat‘	Probe with ‚China Hat‘ or Probe without ‚China Hat‘ combined with a cyclone
TA filters with 96.4percent efficiency: one filter + backup filter per phase	TX filters with 99.9percent efficiency: single filter without backup filter for both phases
Balance with 5 µg accuracy and 1 µg resolution (new balance used also during this programme)	Balance with 2 µg accuracy and 1 µg resolution
Filter conditioning at constant temperature and humidity (new weighing chamber also used during this programme)	Weighing chamber conditioning at temperature: 22°C ± 3 humidity: 45percent ± 8 dewpoint: 9.5 °C ± 3 °C

Table 5.5: Particle mass determination according to directive 98/69/EC and to the current status of PMP discussion

For particle number detection directive 715/2007/EC specifies the Condensation Particle Counter (CPC). The CPC determines the number concentration of particles contained in the exhaust emissions. The particles are enlarged by condensation and counted by the method of light scattering. For particle number (PN) detection, a complex sampling system is used. The particles are preclassified by a cyclone. The pre-classifier 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm. For counting particles, the sample has to be diluted within two steps. To eliminate condensed volatile hydrocarbons the probe is heated to a temperature between 150°C up to 300°C and cooled down again for measuring. **Figure 5.32** illustrates the sampling system for particle number determination.

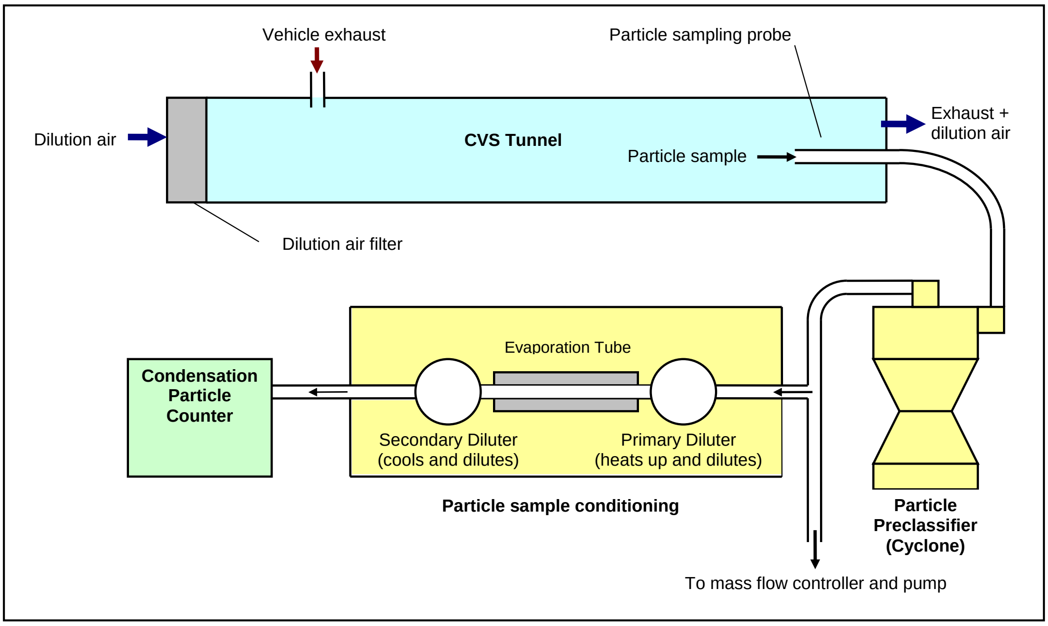

Figure 5.32: Sampling system for particle number detection

The update of European exhaust emission legislation proposes particle limits both for vehicles with compression ignition engine and vehicles with positive ignition engine and direct injection. The limits for particle emissions are given in **Table 5.6.**

Cate-gory	Reference Mass (RM) [kg]	Limits Euro 5 and Euro 6					
		Compression Ignition			Gasoline Direct Injection		
		PM [mg/km]	PM PMP [mg/km]	P-Num-ber [#/km]	PM [mg/km]	PM PMP [mg/km]	P-Number [#/km]
M1	All	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
N1	RM ≤1305	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
	1305<RM≤1760	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
	1760<RM	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
N2	All	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*

*) Particle Number Limit for Euro 5 measured according 98/69/EC (Two-filter-method)
**) Stepwise implementation 2013: 6,0E+12; 2014 6,0E+11

Table 5.6: Euro 5 and Euro 6 limits for particle emissions

Although determination of particle mass for vehicles with positive ignition engine according to directive 98/69/EC and 715/2007/EC is not relevant, it was done on both vehicles with compression ignition and positive ignition. The results are shown in Table **Table 5.7**.

		NEDC	WLTC phase 1	WLTC phase 2	WLTC phase 3	WLTC 4hase 4	WLTC total
Compression ignition Euro 6	PM [mg/km]	0,066	n.a	n.a	n.a	n.a	0,11
	PN [#/km]	9,2 E9	3,2 E11	3,78 E10	1,6 E9	9,1 E9	8,8 E9
Compression ignition Euro 5	PM [mg/km]	0,22	n.a	n.a	n.a	n.a	0,27
	PN [#/km]	4,9 E11	5,14 E11	1,2 E11	9,4 E10	2,0 E10	1,3 E11
Positive ignition Euro 5	PM [mg/km]	0,78	n.a	n.a	n.a	n.a	2,00
	PN [#/km]	6,6 E11	6,0 E12	5,5 E11	3,9 E11	1,1 E12	1,4 E12

Table 5.7: Average particle mass and number determined according to directive 715/2007/EC

Comparing the total results given in Table 5.7 for WLTC total illustrate two facts:

1. Compression ignition vehicles equipped with a particulate filter do also perform well during WLTP and stay below the given limit of 6,0 x 10^{11}.
2. Positive ignition vehicles – with direct injection (DI) as well as some multipoint injection (MPI) engines show higher emissions.

Up to now, the limit of 6,0 x 10^{11} is not valid for gasoline cars equipped with MPI engines. Figure 5.33 shows an example comparing the second by second emissions of a DI and a MPI car.

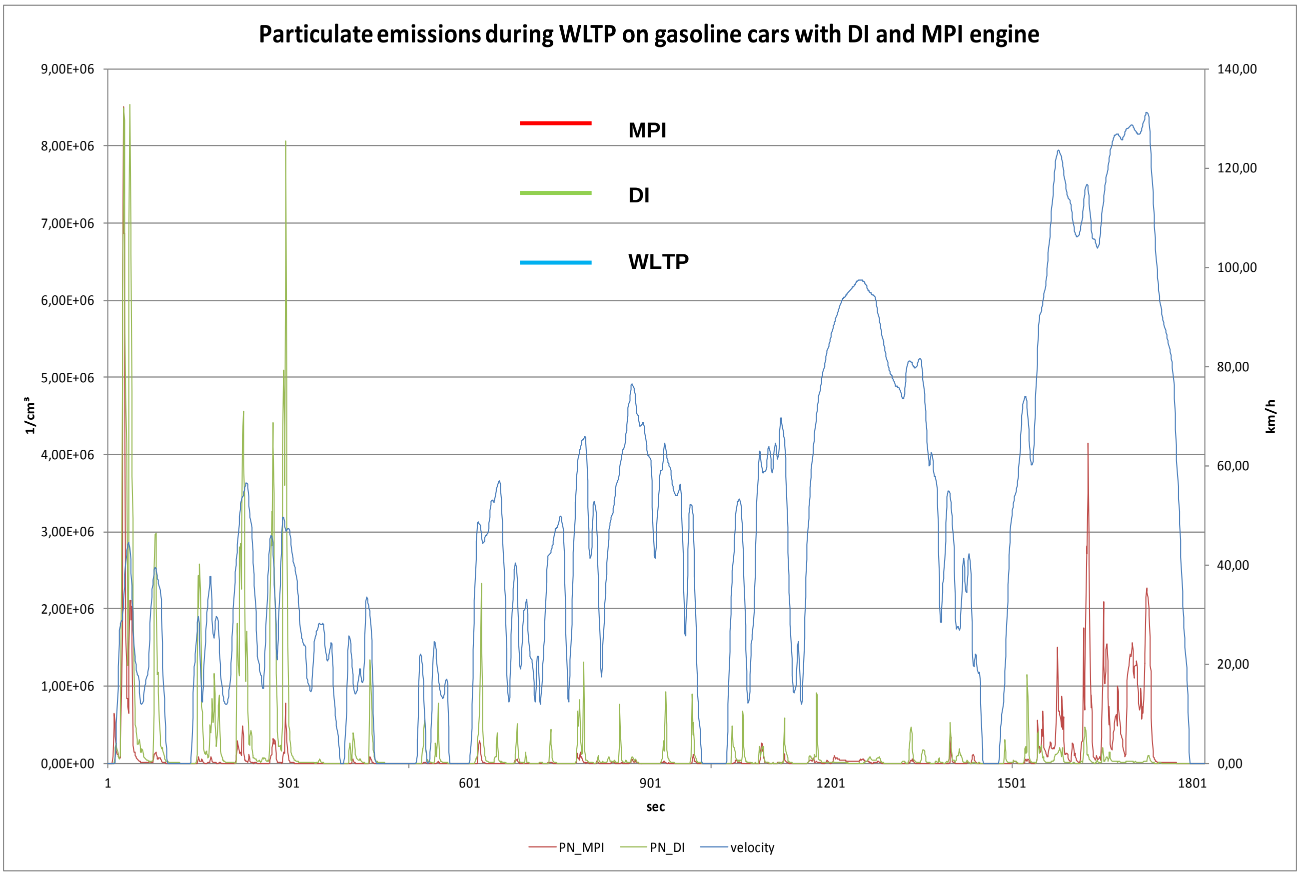

Figure 5.33: Particle emissions during WLTP of a vehicle with MPI and a vehicle with DI positive ignition engine, PN MPI: 1,66E+12 [#/km]; PN DI: 2,44E+12 [#/km]

Comparing the second by second data showed in Figure 5.33 the different behaviour of DI and MPI engines become clear. The overall level of DI engines is constantly higher, MPI engines emitting Particulate emissions during cold start and high load phases (as WLTP Phase extra high). This behaviour should be taken into account when implementing a particulate number limit for WLTP.

6. References

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