EMISSION EFFECTS FROM DIESEL FUELS AND ED95 – HEAVY DUTY VEHICLES

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AVL MTC 2013/12
REVISION 1 2015/01

A REPORT FOR

THE SWEDISH TRANSPORT ADMINISTRATION
AND
THE SWEDISH TRANSPORT AGENCY

Document information and revision history

Version	Action	Date
Revision 1	The following items have been revised: Page 10: Clarification of calculated fuel consumption. Page 24: Table 9. Page 25: Figure 10 and Table 10. Page 26: Figure 11. Page 27: Table 11 and Figure 12.	2015-01-16

SUMMARY

In order to reduce the climate impact from the transport sector, there is an ambition in the European Union to increase the share of alternative fuels. Since the transport sector is very diverse, there are multiple ways to deal with this. The vehicles can be dedicated towards a certain fuel, or accepting different types of fuel blends where at least part of the fuel consists of conventional types (i.e. diesel or petrol).

In recent years, new fuels and blends have been introduced on the market. In Europe, the Commission has presented a road map towards a low carbon economy 2050, a white paper on transport and a proposal for alternative fuel infrastructure. The main focus in these strategies is to reduce the oil dependency and the negative climate impact from the transport sector. In combination with the climate impact, it is important to also involve other aspects of new fuels, such as parameters affecting environment or health.

In this study vehicle tests have been performed with five different diesel fuels and the ethanol fuel ED95 used for compression ignited vehicles. Two heavy duty trucks have been used, one diesel truck and one dedicated for ED95, both of EEV emission standard. The tests have been performed on chassis dynamometer, where the vehicles have been driven according to the Worldwide Harmonized Vehicle Cycle (chassis dynamometer version of WHTC).

The following fuels were used – B7 (conventional diesel fuel), B7+HVO30, HVO100, synthetic diesel (GTL), B100 and ED95. The B7+HVO30, HVO100 and the synthetic diesel were so-called drop-in fuels, i.e. fuels that can be used in existing engines. The B100 can be used in existing vehicles with some adjustments, whereas the ED95 fuel can be used in dedicated vehicles.

The regulated components and CO2 have been measured. In addition, some unregulated components were also investigated:

- Aldehydes: sampled in DNPH-cartridges;
- Ethanol emissions: sampled with FTIR during the tests with the ED95 fuel;
- Particle number: Condensed Particle Counter (CPC);
- Particle size distribution: Electrical Low Pressure Impactor (ELPI);
- Particles: PAH (Polycyclic Aromatic Hydrocarbons) content.

Svensk sammanfattning

För att minska klimatpåverkan från transportsektorn finns det en ambition inom EU att öka andelen förnybara bränslen. Eftersom transportsektorn inte är homogen kommer det att krävas en rad åtgärder för att lyckas med detta.

De allt strängare emissionskrav som ställs på nya motorer och fordon kommer på sikt att leda till reducerad klimat- och miljöpåverkan från transportsektorn. Det tar dock tid att byta ut en befintlig fordonsflotta, framför allt när det gäller tunga fordon som har en stor miljöpåverkan. De bränslen som fordonen använder är dock en faktor som kan ge en förändring även på kort sikt.

Under senare tid har flera bränslen som kan användas i befintliga motorer introducerats på den europeiska marknaden. Transportsektorn består till stor del av tunga fordon, där motorer med kompressionständning dominerar på grund av dess höga verkningsgrad. I denna studie har två tunga fordon testats med sex olika bränslen, där samtliga bränslen är avsedda för motorer med kompressionständning. De bränslen som använts är B7 (konventionellt dieselbränsle), B7 med 30% HVO, 100% HVO, syntetisk diesel (GTL), B100 och ED95.

I studien har fordonen körts på chassidynamometer enligt den transienta körcykeln WHVC. Reglerade avgaskomponenter, CO2, aldehyder och etanol (för ED95-bränslet) har mätts. Partiklar har analyserat med avseende på massa, antal, storleksfördelning och PAH (Polycykliska Aromatiska Kolväten).

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Abbreviations

B7	7% FAME (conventional diesel fuel, containing 7% FAME)
B100	100% FAME
CO	Carbon monoxide
CO2	Carbon dioxide
CPC	Condensation Particle Counter
ECU	Electronic Control Unit
EEV	Enhanced Environmentally friendly Vehicles
ELPI	Electrical Low Pressure Impactor
Fc	Fuel consumption
FTIR	Fourier Transform Infrared Spectroscopy
GTL	Gas-To-Liquid
HC	Hydrocarbon
HFID	Heated Flame Ionization Detector
HVO	Hydrotreated Vegetable Oil
Mk1	"Miljöklass 1" (environmental class 1)
NDIR	Non-Dispersive Infrared detector
NOx	Nitrogen oxides
OC	Oxidation catalyst
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
PN	Particle number
SCR	Selective Catalytic Reduction
WHTC	Worldwide Harmonized Transient Cycle
WHVC	Worldwide Harmonized Vehicle Cycle

Introduction

In order to reduce the climate impact from the transport sector, there is an ambition in the European Union to increase the share of alternative fuels. Since the transport sector is very diverse, there are multiple ways to deal with this. The vehicles can be dedicated towards a certain fuel, or accepting different types of fuel blends where at least part of the fuel consists of conventional types (i.e. diesel or petrol).

In recent years, new fuels and blends have been introduced on the market. It is however important to look beyond the climate impact and thereby also involve other aspects of new fuels, such as parameters affecting environment or health.

In this study vehicle tests have been performed with five different diesel fuels and the ethanol fuel ED95 used for compression ignited vehicles. Two heavy duty trucks have been used, one diesel truck and one dedicated for ED95, both of EEV emission standard. The tests have been performed on chassis dynamometer, where the vehicles have been driven according to the Worldwide Harmonized Vehicle Cycle (chassis dynamometer version of WHTC).

The following fuels were used – B7 (conventional diesel fuel), B7+HVO30, HVO100, synthetic diesel (GTL), B100 and ED95. The B7+HVO30, HVO100 and the synthetic diesel (GTL) are so-called drop-in fuels, i.e. fuels that can be used in existing engines. The B100 can be used in existing vehicles, but adjustments of fuel system and ECU should be performed before permanent use. In the tests performed in this project, no adjustments were made. The ED95 fuel can only be used in dedicated vehicles.

The regulated components and CO2 have been measured. In addition, some unregulated components were also investigated: Aldehydes were sampled in DNPH-cartridges; ethanol emissions were measured with FTIR during the tests with the ED95 fuel; particle numbers were counted with a CPC; particle size distribution was analyzed with an ELPI instrument and the PAH content in the particles were analyzed.

Test vehicles

Two vehicles were used in the test program. One was a diesel truck, which were used for the testing with the diesel drop-in fuels. The other vehicle was a dedicated ED95 vehicle. The diesel truck is presented in Table 1 and the ED95 truck is presented in Table 2.

Table 1: Vehicle data – diesel truck.

Vehicle Make	Iveco
Vehicle Model	Truck
Model Year	2012
Chassis Number	ZCFA1EJ0402595831
Mileage (km)	29124
Gross vehicle weight (kg)	11990
Unladen weight (kg)	7535
Emission standard	Euro V (EEV)
Engine displacement (cm3)	5880
Max engine power (kW)	185
Aftertreatment	SCR
Test weight/inertia (kg)	9732

Table 2: Vehicle data – ED95 truck.

Vehicle Make	Scania
Vehicle Model	P270DA4X2MLA
Model Year	2012
Chassis Number	YS2P4X20002074109
Mileage (km)	24049
Gross vehicle weight (kg)	18000
Unladen weight (kg)	6590
Emission standard	Euro V (EEV)
Engine displacement (cm3)	8867
Max engine power (kW)	199
Aftertreatment	EGR
Test weight/inertia (kg)	12670

Test fuels

The diesel truck was tested with five different fuels:

- B7 (conventional diesel fuel);
- B7+HVO30;
- HVO100;
- B100;
- Synthetic diesel (GTL).

The B7, B7+HVO30, HVO100 and B100 were delivered from oil companies. The synthetic diesel was a GTL fuel which is commercially available, and was fuelled at a tank station.

The B7 fuel is a conventional diesel fuel ("Mk1" – environmental class 1) with 7% FAME. B7+HVO30 fuel is a conventional diesel fuel ("Mk1") with the addition of 7% FAME and 30% HVO.

B7, B7+HVO30, HVO100 and synthetic diesel (GTL) are so-called drop-in fuels, i.e. fuels which can be used in existing engines.
B100 can be used in existing vehicles, but adjustments of fuel system and ECU should be performed before permanent usage. No adjustments were performed prior to the tests in this project.

ED95 can only be used in dedicated vehicles. The fuel consists of 95% ethanol with the addition of ignition improver, lubricant and corrosion protection. Today, there is one fuel producer. ED95 is commercially available at one location in Stockholm, and the fuel is therefore primarily used in fleets. In this project the vehicle was tested by using the fuel from the vehicle fuel tank.

The fuels used in the test program are described in Table 3 and Table 4. The fuel specifications for the diesel fuels can be found in the Appendix.

Table 3: Fuel data: B7, B7+HVO30 and HVO100.

	Units	B7	B7 + HVO30	HVO100
Density	kg/m3	822,0	822,5	778,6
Total aromatic content	% V/V	4,7	4,7	0,2
Sulfur content	mg/kg	< 3	< 3	< 1
Cetane index	-	50,7	56,5	> 56,5
FAME and/or HVO content	% V/V	7,0	27,1+7,0	100

Table 4: Fuel data: B100, GTL and ED95.

	Units	B100 (RME)	GTL (Synthetic diesel)	ED95
Density	kg/m3	882,0	802,4	824
Total aromatic content	% V/V	-	< 0,5	0
Sulfur content	mg/kg	4	< 3,0	< 10
Cetane index	-	52,6 (number)	66,7	
FAME and/or HVO content	% V/V	98,4	< 0,05	0

Experimental

Chassis dynamometer test cell

The chassis dynamometer is a cradle dynamometer with 515 mm roller diameters. The maximum permitted axle load is 13 000 kg. Vehicle inertia is simulated by flywheels in steps of 226 kg from 2 500 kg to 20 354 kg. The maximum speed is 120 km/h without flywheels and 100 km/h with flywheels.

Two DC motors, each 200 kW maximum load, and separate control system serves as power absorption units. The DC motors and their computer-controlled software enable an excellent road load simulation capability. The software sets the desired road load curve through an iterative coast down procedure with test vehicle on the dynamometer.

An AVL PUMA computer system is used as a superior test cell computer for engine monitoring and also for the measurement and collection of all data emanating from the vehicle, emission measurement system and test cell.

A schematic description of the test cell is included in Appendix.

Engine power

The engine power was estimated by adding the integrated signals from measured acceleration force of the inertia used and the road load. No fan correction has been applied to the calculations. The integrated power is then used to calculate the total estimated work (kWh) during the test cycle which is used to calculate emissions in g/kWh. The estimation methodology is thorougly described in Appendix.

Measuring methods

Regulated and unregulated components were investigated in this study. The measuring methods for the gaseous components are presented in the first part of this chapter, followed by the methods for the particulate measurements.

Regulated gaseous emissions and CO2

The sampling- 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 total volume of the mixture of exhaust and dilution air is measured by a CFV (Critical Flow Venturi) system. For the subsequent collection of particulates, a sample of the diluted exhaust is passed to the particulate sampling system. The sample is here diluted once more in the secondary dilution tunnel, a system referred to as full flow double dilution.

According to the regulations for transient tests the diluted exhaust gases are both bagsampled and sent for further analysis *and* on-line sampled. Through the CVS system a proportional sampling is guaranteed.

The equipment used for analysing the gaseous regulated emissions consist of double Horiba 9400D systems. Hereby exists the possibility to measure both diluted and raw exhaust emissions on-line simultaneously. The sampling system fulfils the requirements of Regulation (EU) 582/2011 in terms of sampling probes and heated lines etc.

The measured components and measurement principles are specified in Table 5.

Table 5: Measured components and measurement principles.

Component	**Measurement principle**
Total hydrocarbons (THC)	HFID (heated flame ionization detector) (190°C)
Carbon monoxide (CO)	NDIR (non-dispersive infrared analyzer)
Carbon dioxide (CO_2)	NDIR
Nitrogen oxides (NO_X)	CL (chemiluminescence)
Fuel consumption (FC)	Carbon balance of HC, CO and CO_2

The fuel consumption was calculated through carbon balance, where the carbon weight fraction for the respective fuels were used.

Measurement of ethanol

Measurement of alcohols with FTIR (Fourier Transform Infrared Spectroscopy) is not a standard procedure, and is used mainly for research purposes. Different measurement principles for ethanol are thorougly described in [1].

The FTIR uses the fact that different substances absorb different frequencies of infrared light unequally. The FTIR analysis produces absorption peaks corresponding to the frequencies of vibrations between the bonds of the atoms in a molecule. Since different molecules are consisting of different combinations of atoms, the infrared spectrum is unique for a specific substance. This makes FTIR very useful for analyzing many different compounds. The size of the peaks is also corresponding to the amount of the substance.

The infrared beam from the source is divided by a beamsplitter, dividing the beam into two optical beams. One of the beams is reflected off of a non-mobile mirror back to the beamsplitter. The other beam is reflected off of a flat mirror which is mobile (only a few millimeters) back to the beamsplitter. The mobile mirror makes it possible to differentiate the beams. The two reflected beams are recombined at the beamsplitter, and the signal exiting the “interferometer” is a result of these two beams “interfering” with each other. The resulting signal is called an interferogram, which has the unique property that every data point (a function of the moving mirror position) which makes up the signal has information about every infrared frequency which comes from the source. This means that as the interferogram is measured, all frequencies are being measured simultaneously.

The analyzer requires a frequency spectrum in order to make an identification. This means that the individual frequencies need to be “decoded”, which is accomplished via a well-known mathematical technique called the Fourier transformation.

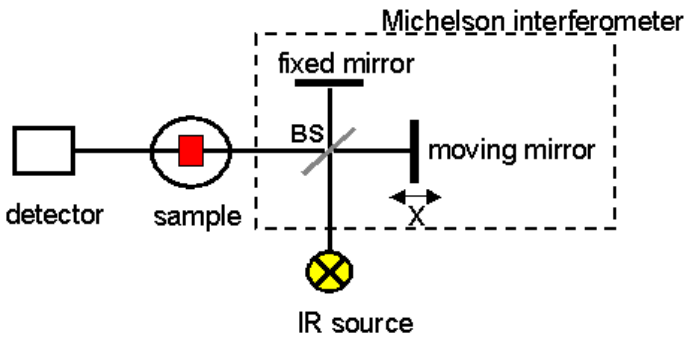


Figure 1: Schematic view of the principles of the FTIR (Source: *www.uni-ulm.de*).

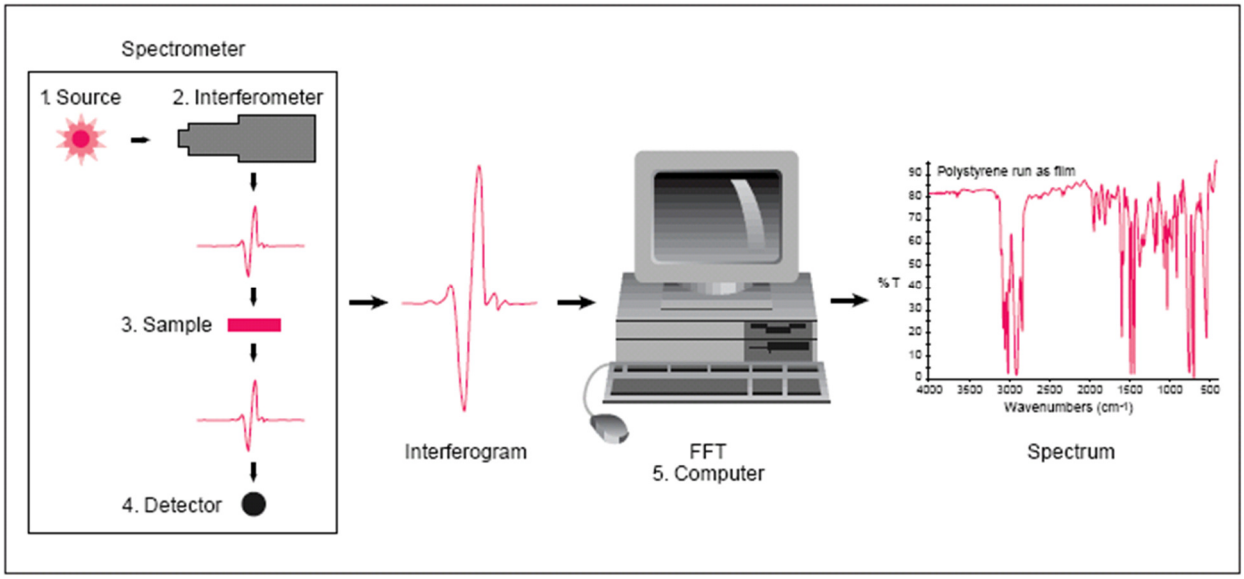


Figure 2: The working principle of the FTIR (Source: www.mmrc.caltech.edu).

The FTIR measurement is performed on raw exhaust emissions.

One advantage with the FTIR instrument is that it is possible to measure many substances at the same time, with a fast response.

Measurement of aldehydes

Analysis of aldehydes was carried out using 2.4-di nitro phenyl hydrazine (DNPH) coated filter cartridges. This method is in accordance with Method 1004 approved by US EPA and California ARB.

The DNPH-cartridges were, after sampling, extracted with distilled acetonitrile and analyzed on a C-18 silica column with a methanol/water gradient and HPLC/UV detection. Quantification was carried out with corresponding hydrazone as external standard.

Particulate emissions

The particulate emissions were analyzed gravimetrically, by number and by size distribution. The polycyclic aromatic hydrocarbons were sampled on large filters and polyurethane foam (PUF).

Particulate mass

The particulate mass was measured gravimetrically by the use of glass fibre filters. For the collection of particle matter (PM), a sample of the diluted exhaust is passed to the particulate sampling system. The sample is then diluted once more in the secondary dilution tunnel, a system referred to as full flow double dilution. The particles are collected on Teflon-coated Pallflex^{TM} filter and measured gravimetrically. The sampling of particle matter is in accordance with Directive 2005/55/EEC.

Particle number

The particle number is measured in a Condensation Particle Counter (CPC) with a size range of 23nm to 2.5µm. The particle number is limited for heavy duty diesel engines from emission standard Euro VI (limits for positive ignited engines are not yet decided).

In the counter, the particles are enlarged by condensation of butanol and are thereafter detected and counted using a light-scattering method. A schematic description of the detector is presented in Figure 3.

In order to count non-volatile particles, a special sampling method has been developed. A pump draws the exhaust gas into a sampling probe which eliminates all particles >2.5 µm due to its special shape. The sampled exhaust gas is then diluted with cleaned hot air at a temperature of 150°C. This stabilizes the particle number concentration and reduces the concentration so that agglomerations and particle deposits are largely prevented.

After the hot primary dilution, the diluted exhaust gas is further heated up to a temperature of 300°C to 400°C in an evaporation tube in order to convert all volatile particles into gaseous phase. A secondary dilution is then performed to prevent further condensation or adsorption of volatile substances and to ensure that the maximum inlet temperature of 35°C is not exceeded. The particle number concentration is measured in the Condensation Particle Counter (with a size range of 23nm to 2.5µm according to UNECE-R83 specifications). The particles are enlarged due to the condensation of butanol and are detected and counted using the lightscattering.method.

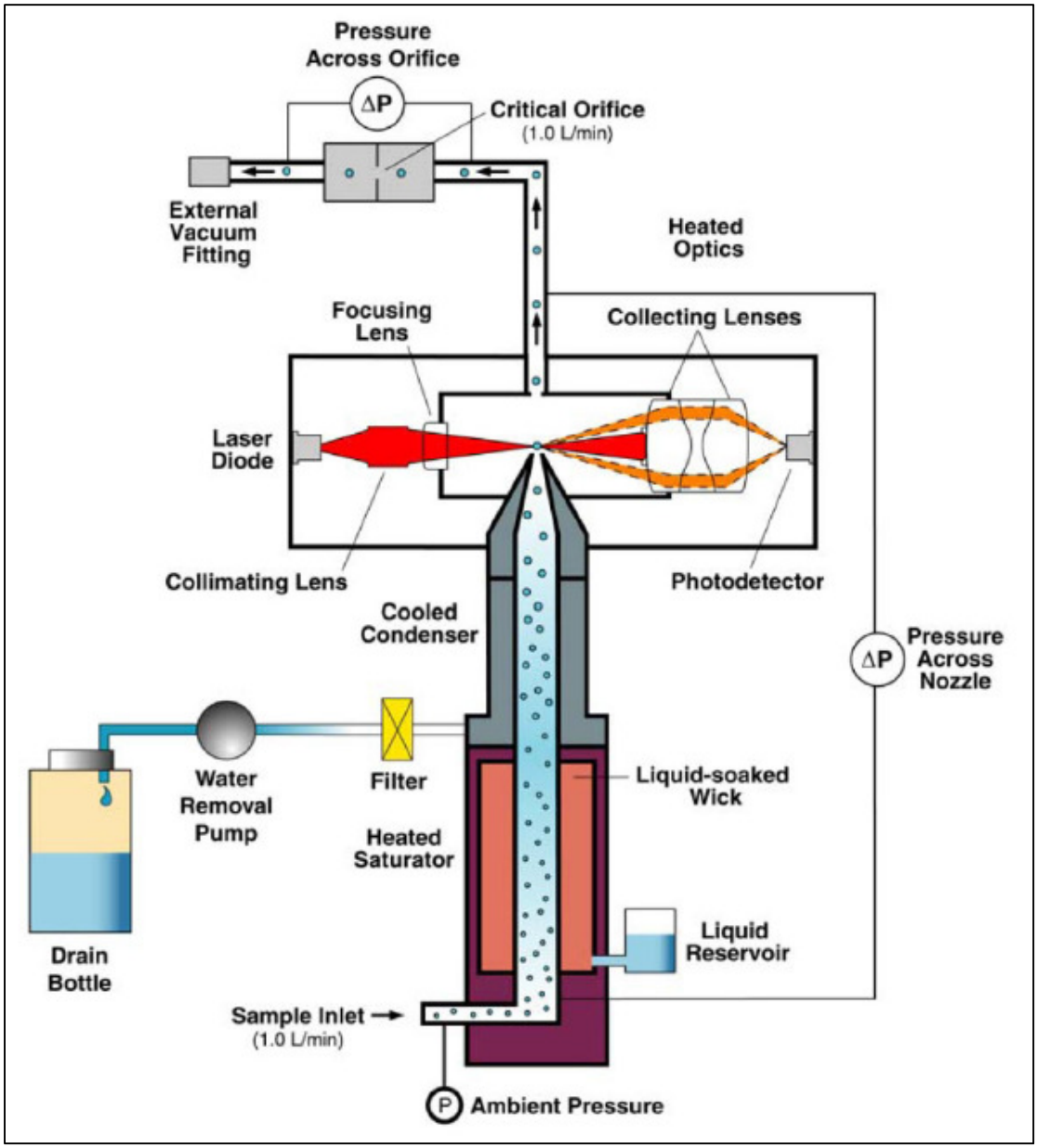


Figure 3: Schematic description of the detector in the Condensation Particle Counter.

Particulate size distribution

An Electrical Low Pressure Impactor (ELPI) was used for particle size distribution. In an impactor, the particles are classified according to their aerodynamic diameter. The ELPI impactor has 12 stages ranging from 7 nm to 10µm. The instrument was manufactured by Dekati Ltd. in Finland. The principle of the ELPI instrument is described below and a schematic description is presented inFigure 4.

Before entering the ELPI instrument, the exhaust gases are diluted in order to reduce their concentration. In this case, sampling was carried out from the full flow primary dilution tunnel.

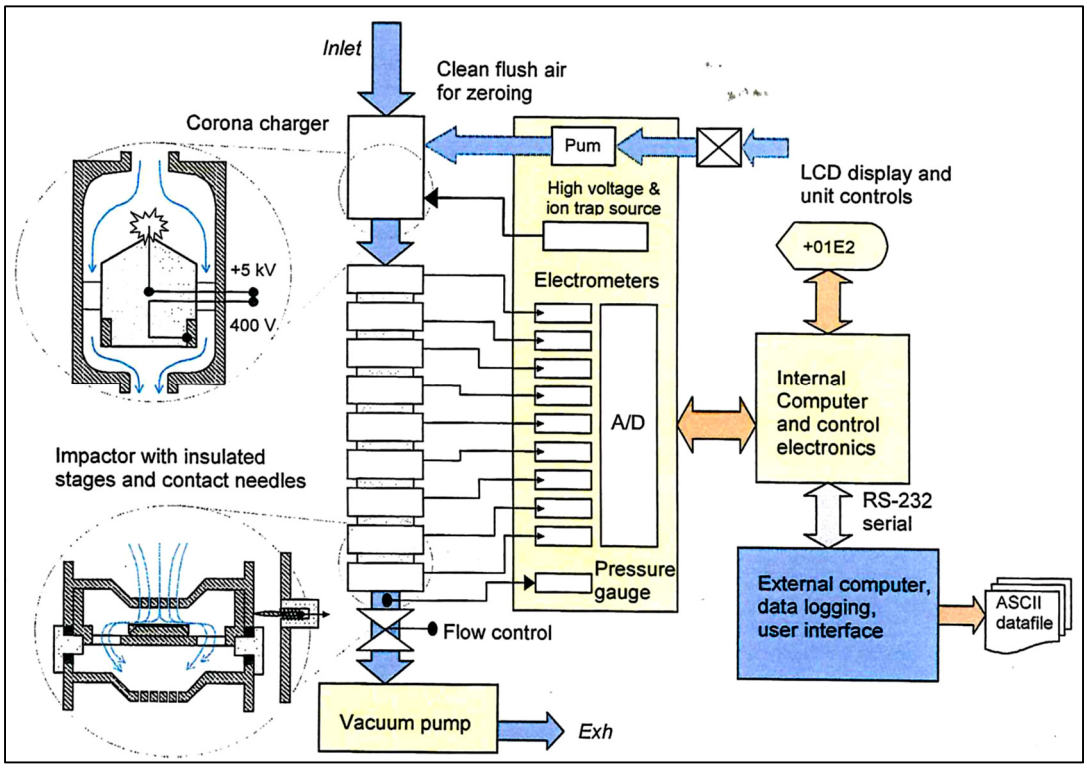


Figure 4: Schematic description of the operating principles in an ELPI instrument.

The ELPI™ operating principle can be divided into three major parts; particle charging in a unipolar corona charger, size classification in a cascade impactor and electrical detection with sensitive electrometers. The particles are first charged into a known charge level in the charger. After charging the particles enter a cascade low pressure impactor with electrically insulated collection stages. The particles are collected in the different impactor stages according to their aerodynamic diameter, and the electric charge carried by particles into each impactor stage is measured in real time by sensitive multichannel electrometers. This measured current signal is directly proportional to particle number concentration and size. The operating principle for the impactor is schematically described in Figure 5.

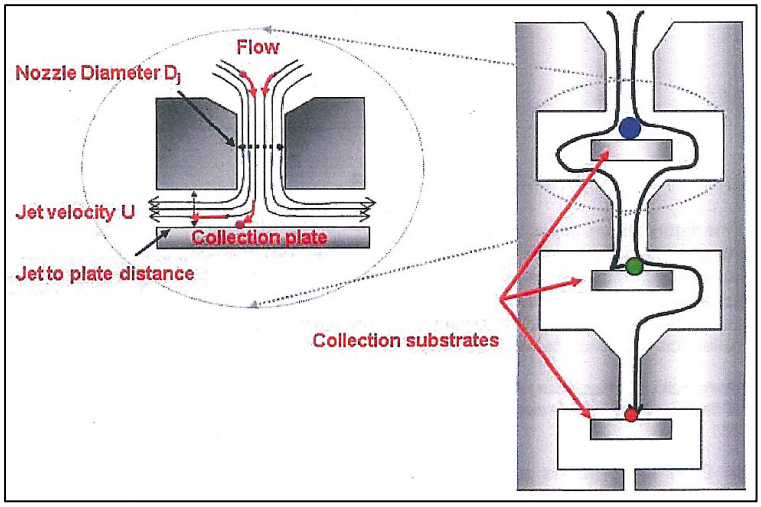


Figure 5: Operating principle for the impactor in ELPI.

The particle collection into each impactor stage is dependent on the aerodynamic size of the particles. Measured current signals are converted to (aerodynamic) size distribution using particle size dependent relations describing the properties of the charger and the impactor stages. The result is particle number concentration and size distribution in real-time.

PAH analysis

PAH are compounds with relatively high molecular weight. These compounds can be found condensed on particles and in gaseous phase. The particle associated compounds were collected on a large filter and the PAH in gaseous phase were collected in polyurethane foam (PUF) plugs. The dominating part of the PAH collected in the semivolatile phase are comparatively lighter PAH compounds (up to molecular weights of approximately 200 g/mole), whereas the PAH collected on the filters consists of both lighter and heavier PAH compounds. The filters and foam plugs were extracted before analysis. The extracts were chemically characterized and different types of PAH could be identified.

Hexane, toluene and methanol (all of HPLC-grade) were obtained from Rathburn Ltd, Scotland, UK. Dodecane (> 99 %) was obtained from Sigma-Aldrich, St. Louis, MO, USA and dimethyl sulfoxide (> 99.8 %) was from Merck Chemicals, Darmstadt, Germany.
A standard mixture of the PAHs determined in the present study and the deuterated PAHs phenanthrene-D_{10}, pyrene-D_{10}, benzo[a]anthracene-D_{12}, benzo[a]pyrene-D_{12}, benzo[ghi]perylene-D_{12} and dibenzo[a,i]pyrene-D_{14} was used for identification and quantification purposes.
A solution containing the deuterated PAHs phenanthrene-D_{10}, pyrene-D_{10}, benzo[a]anthracene-D_{12}, benzo[a]pyrene-D_{12} and benzo[ghi]perylene-D_{12} was used along with a solution of dibenzo[a,i]pyrene-D_{14} in toluene as internal standards. The manufacturer

and purity of the PAH standards used in the present study have been published in detail elsewhere [2].

The PUF and filter samples were extracted with pressurized fluid extraction using an ASE 200 accelerated solvent extraction system (Dionex Corporation, Sunnyvale, CA, USA).
The filter samples were extracted in 5 ml extraction cells with an ASE method recently developed and validated for analysis of PAHs in diesel particulate matter using standard reference materials from the US National Institute of Standards and Technology (NIST) [2] [3]. Extractions were performed with a mixture of toluene and methanol (9:1; v/v) at elevated temperature and pressure (200 °C and 3000 psi). The extraction consisted of five 30 min extraction cycles.
The PUF samples were extracted in 33 ml extraction cells with acetone at 110 °C and 500 psi using two extraction cycles of 5 min. A 20 % flush was used and the purge time was set to 60 seconds.

Before sampling the PUFs were cleaned in a washing machine at 90 °C and hand squeezed in ethanol. They are further cleaned-up in 33 ml extraction cells using the ASE with two consecutive 5 min extractions of toluene and acetone, respectively, at 110 °C and 500 psi. The flush was set to 60 % and the purge time was 60 seconds.

The extracts were concentrated to about 5 mL using a TurboVap® LV evaporator (Zymark Corp., Hopkinton, MA, USA) under a gentle stream of nitrogen gas. The extracts were then transferred to glass vials with screw caps and stored in a freezer at -20 °C.
For analysis of PAH content in the filter and PUF extracts aliquots were transferred from the glass vials containing the extracts to disposable test tubes. Internal standards were added and the filter extracts were evaporated to approximately 0.5 ml while 0.5 ml toluene was added to the PUF extracts before reducing the volume to about 0.5 ml. The samples were then cleaned-up using a solid phase extraction (SPE) protocol described in detail elsewhere [4].

The analysis of PAHs was performed using a hyphenated High Performance Liquid Chromatography- Gas Chromatography/Mass Spectrometry (HPLC-GC/MS) system, which was constructed in house as previously described in detail [5]. Detailed description on the method used is available elsewhere [2] and will only be briefly recapitulated. The HPLC system consisted of an autosampler (CMA/200 Microsampler; CMA Microdialysis AB, Sweden), a Varian 9012 Inert solvent delivery system (Varian Inc., Palo Alto, CA, USA), a UV detector (SPD-6A; Shimadzu, Japan) and a nitrophenylpropylsilica column (4.0 mm i.d. x 125 mm, 5 µm particle size; Phenomenex, Torrance, CA, USA). Isocratic separation was performed using hexane with 0.1% dodecane (v/v) as the mobile phase. The HPLC part was connected to a GC (6890N; Agilent Technologies, Palo Alto, CA, USA) through a fused silica capillary inserted into the Programmed Temperature Vaporizer injector (CIS-3; Gerstel, Germany), which was operated in the solvent vent mode. The GC separation was carried out

on a DB-17MS capillary column (60 m × 0.25 mm i.d. with 0.15 µm film thickness; J & W Scientific, Folsom, CA, USA) equipped with a retention gap (5 m x 250 µm i.d., J&W Scientific). Mass selective detection was performed using a quadrupole mass spectrometer (MSD 5973N; Agilent Technologies) operated in the electron ionization (EI) mode. Data acquisition was performed operating the quadrupole mass analyzer in selected ion monitoring (SIM) mode.

Test cycle

The vehicle was driven according to the WHVC (Worldwide Harmonized Vehicle Cycle) test cycle (Figure 6), which is a chassis dynamometer version of the WHTC (Worldwide Harmonized Transient Cycle) engine test cycle. The WHTC cycle is applicable for certification from Euro VI, where the engine will be tested both with cold start and hot start.

For each fuel, the tests consisted of one cold start and two hot starts. In order to achieve good repeatability for the two hot started tests, the vehicle was preconditioned prior to each test by driving at constant speed on the chassisdynamometer until the engine oil reached a stabilized temperature of approximately 90 °C. The vehicle was then idling in order to prepare and load necessary data parameters.

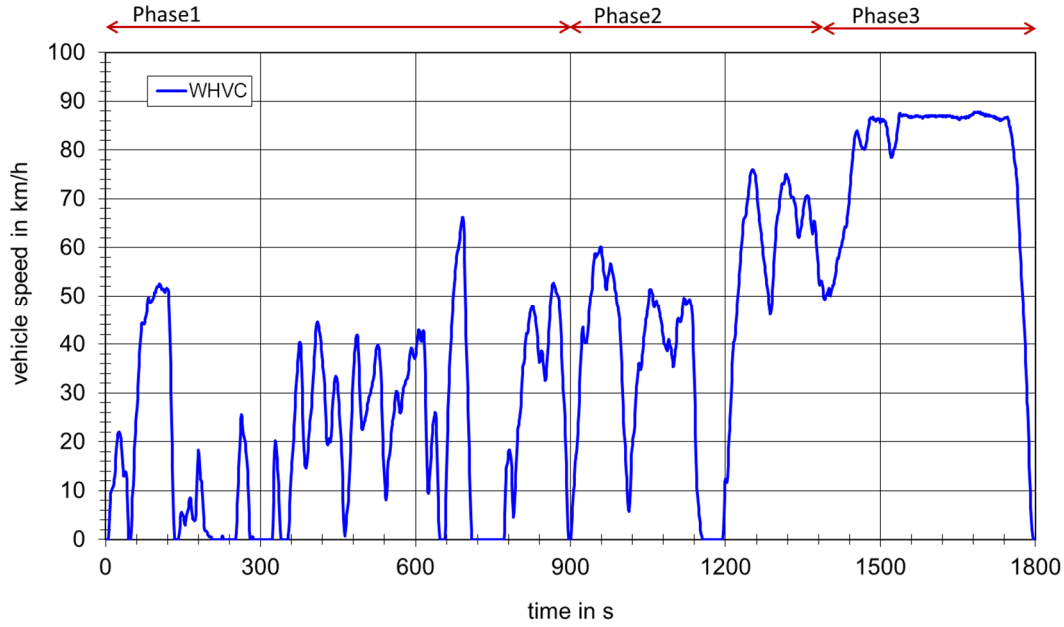


Figure 6: The WHVC test cycle – chassis dynamometer version of the WHTC cycle.

The WHVC driving cycle can be divided into three subcycles, each representing different driving patterns:

Phase 1: Urban driving (5,3 km)

Phase 2: Rural driving (5,6 km)

Phase 3: Motorway driving (9,1 km)

The test cycle has a total duration of 1800 seconds.

Test program

Two heavy duty trucks were used in the emission tests – one diesel truck, and one dedicated ED95 truck. The diesel truck was tested with five different fuels – B7 (conventional diesel fuel), B7+HVO30, HVO100, B100 and synthetic diesel (GTL).

For each of the fuels, the following tests were performed:

- 1 WHVC cold start
- 2 WHVC hot start

In connection to the fuel change, engine oil and oilfilter were changed.

In order to ascertain a good adaptation to the respective fuel, the diesel vehicle was prepared by driving three WHVC after each fuel change.

The tests were performed with 50% load. For the B7 fuel the test program was extended with the addition of measurement of regulated emissions at 100% load.

Test results

The test results are presented in this chapter. In the first section, the regulated components are presented, followed by the unregulated measurements. The cold start emissions are presented first, followed by the hot start emissions and the weighted results.

The vehicles used in the test program are of emission standard Euro V. The test cycles used in this project are applicable for legislative testing of the engine, on engine test bench, from Euro VI. The test results presented in this report should not be compared with the Euro V limits.

Please observe that different y-scales are used in the diagrams.

Regulated emissions – cold start

The cold start test was performed once for each fuel, except for the B7 fuel where the fuel was used for one test with 50% load and one with 100% load. The results are presented in Table 6 and Figure 7.

Table 6: Emission test results in g/km, cold start.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO	g/km	0,96	1,11	1,04	1,05	1,19	0,84	1,34
HC	g/km	0,02	0,01	0,01	0,00	0,00	0,00	1,52
NOx	g/km	3,61	3,47	3,29	3,29	3,18	3,58	3,62
PM	g/km	0,035	0,027	0,028	0,023	0,027	0,012	0,026

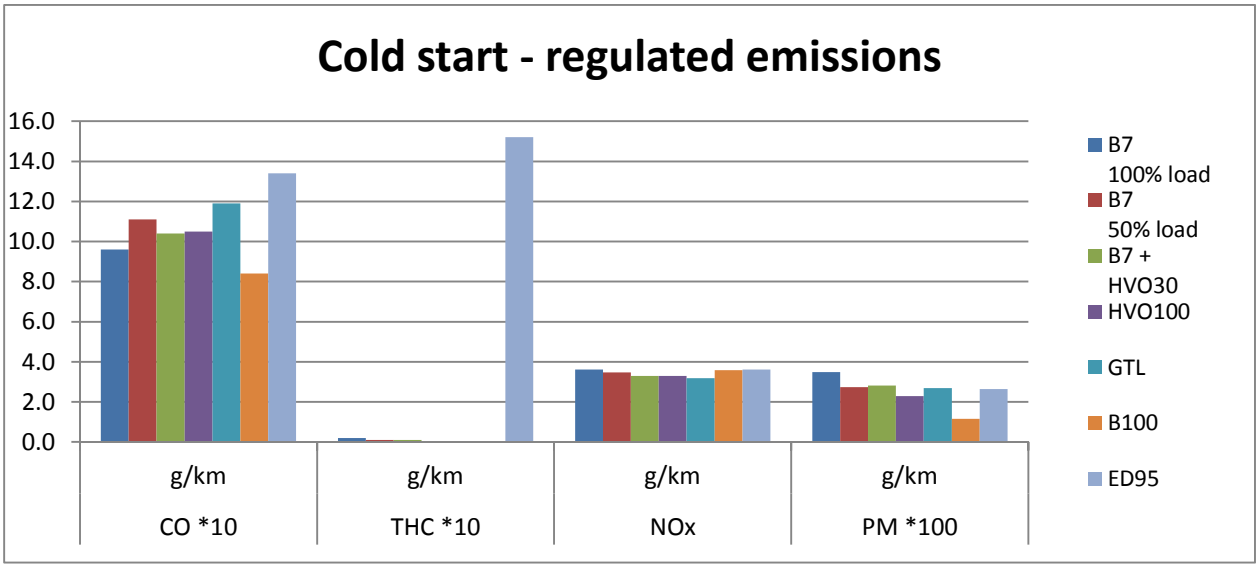


Figure 7: Regulated emissions from cold start test.

The THC emissions from the ED95 consist primarily of ethanol.

Regulated emissions – hot start

The hot start tests were performed twice for each fuel. For the B7 fuel, two tests with 50% load and with 100% load was performed. In the tables and diagrams presented in this chapter, the averaged results from the two tests are presented. The results are presented in Table 7 and Figure 8.

Table 7: Emission test results in g/km, averaged results from two hot start tests.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO	g/km	0,88	0,82	0,80	0,77	0,88	0,66	0,11
HC	g/km	0,01	0,01	0,00	0,00	0,00	0,01	0,25
NOx	g/km	3,00	2,63	2,29	2,51	2,84	3,16	3,35
PM	g/km	0,023	0,017	0,018	0,012	0,018	0,007	0,004

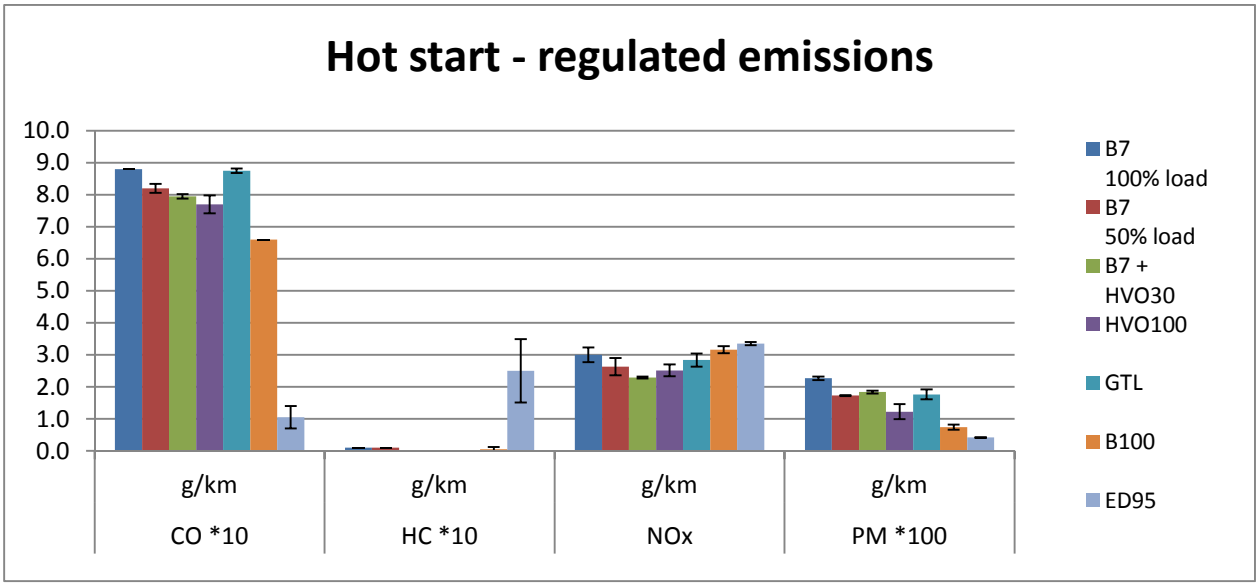


Figure 8: Regulated emissions from hot start tests, averaged from two tests.

The THC emissions from the ED95 consist primarily of ethanol.

The PM emissions from B100 are lower compared to the other fuels (with the exception of ED95). This can be explained by the increased amount of oxygen in the fuel, which can lead to more complete combustion and thereby reduce the PM emissions [6]. This explanation could probably also be applicable for the low PM emissions for the ED95 fuel.

The higher NOx emissions for B100 and ED95 can also be explained by the oxygen content in the fuel. A more complete combustion, in combination with the oxygen present, can lead to higher exhaust emissions of NOx. For B100, it can also be of relevance that no adaptation had been performed on the fuel system, such as injection timing and fuel pressure adjustments, prior to the tests [6].

Regulated emissions – weighted results

According to Regulation (EU) No 582/2011, applicable for Euro VI, the engine should be tested according to the transient cycle WHTC with one cold and one hot start. The results should be presented for the cold start, hot start and the weighted results for the two cycles.

The weighted result is calculated according to the following equation:

$$e = \frac{(0{,}14 \text{ x } m_{\text{cold}}) + (0{,}86 \text{ x } m_{\text{hot}})}{(0{,}14 \text{ x } W_{\text{act, cold}}) + (0{,}86 \text{ x } W_{\text{act, hot}})}$$

where:

e	specific emission, in g/kWh
m_{cold}	is the mass emission of the component in the cold start test, g/test
m_{hot}	is the mass emission of the component on the hot start test, g/test
$W_{\text{act,cold}}$	is the actual cycle work on the cold start test, kWh
$W_{\text{act,hot}}$	is the actual cycle work on the hot start test, kWh

In this study the hot start tests were repeated twice. The weighted results have therefore been counted for each of the two cycles, i.e. cold start together with hot start no 1, and cold start together with hot start no 2. The averaged results from these calculations are presented in Table 8 and Figure 9.

In the presented results, the total estimated work calculated through the method presented in Appendix has been applied.

Table 8: Weighted results for the regulated components, average from two hot start tests. Total estimated work (calculated) has been used.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO	g/kWh	1,09	1,11	1,07	1,04	1,19	0,89	0,32
HC	g/kWh	0,01	0,01	0,01	0,00	0,01	0,01	0,69
NOx	g/kWh	3,78	3,53	3,13	3,35	3,75	4,15	3,86
PM	g/kWh	0,030	0,024	0,025	0,018	0,025	0,010	0,008

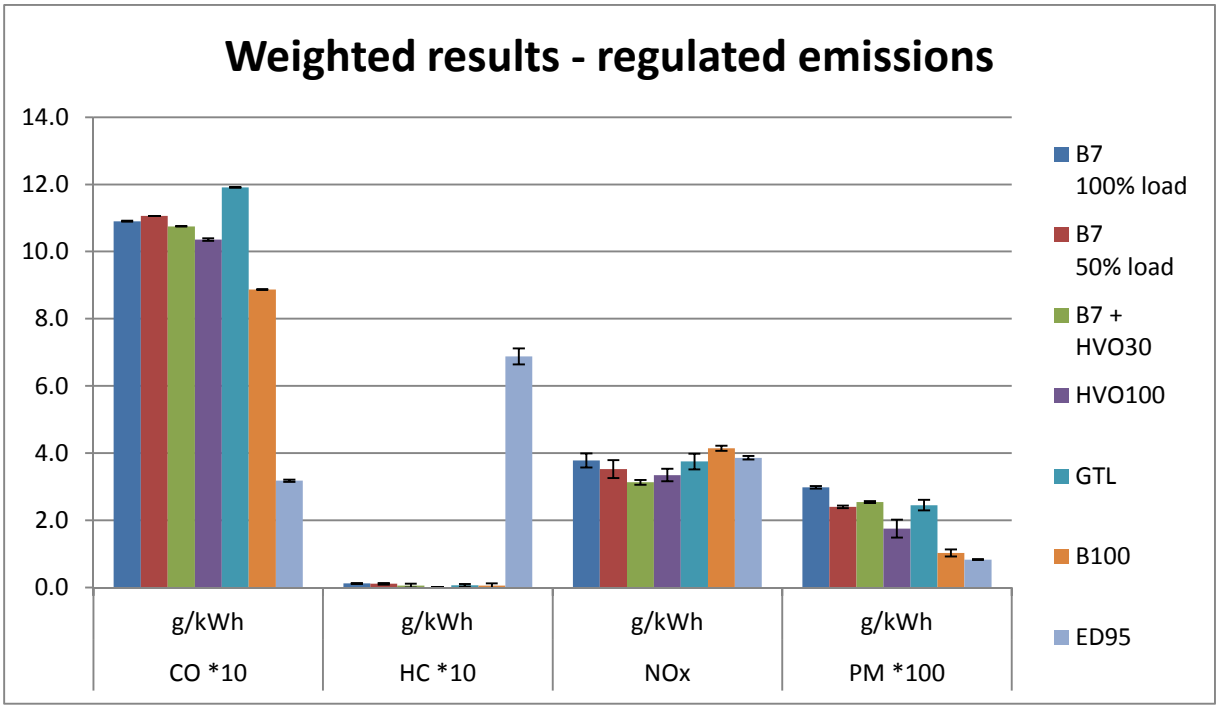


Figure 9: Weighted results for the regulated components, average from two hot start tests. Total estimated work (calculated) has been used.

CO2 emissions and fuel consumption

Cold start

The cold start test was performed once for each fuel, except for the B7 fuel where the fuel was used for one test with 50% load and one with 100% load. The test was performed once for each fuel, and the CO2 results and fuel consumption are presented in Table 9 and Figure 10.

Table 9: CO2 and fuel consumption – cold start tests.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO2	g/km	659,1	641,3	659,3	625,1	632,1	645,6	759,4
Fc	l/100km	25,6	24,9	25,7	26,1	25,3	26,2	51,4

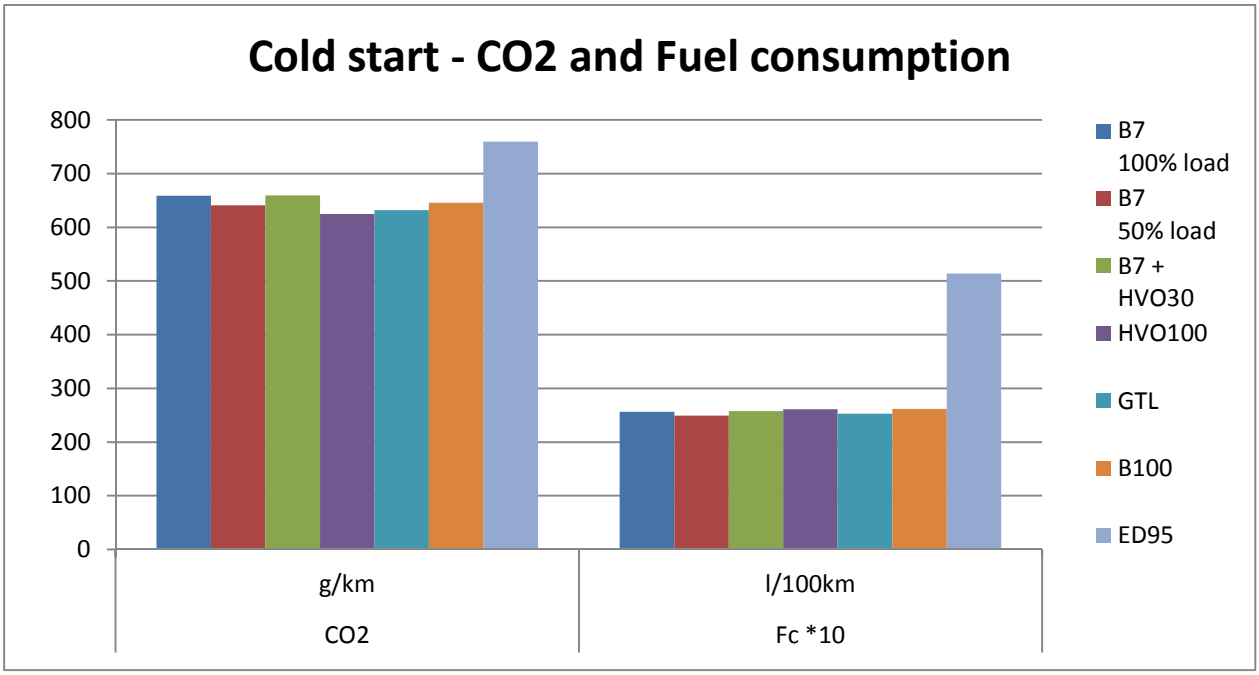


Figure 10: CO2 and fuel consumption – cold start tests.

Hot start

The hot start tests were performed twice for each fuel. For the B7 fuel, two tests with 50% load and with 100% load was performed. In the tables and diagrams presented in this chapter, the averaged results of CO2 and fuel consumption from the two tests are presented in Table 10 and Figure 11.

Table 10: CO2 and fuel consumption – hot start tests. Averaged results from two tests.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO2	g/km	622,2	602,5	596,5	570,6	583,5	611,8	669,4
Fc	l/100km	24,2	23,4	23,3	23,8	23,3	24,8	45,8

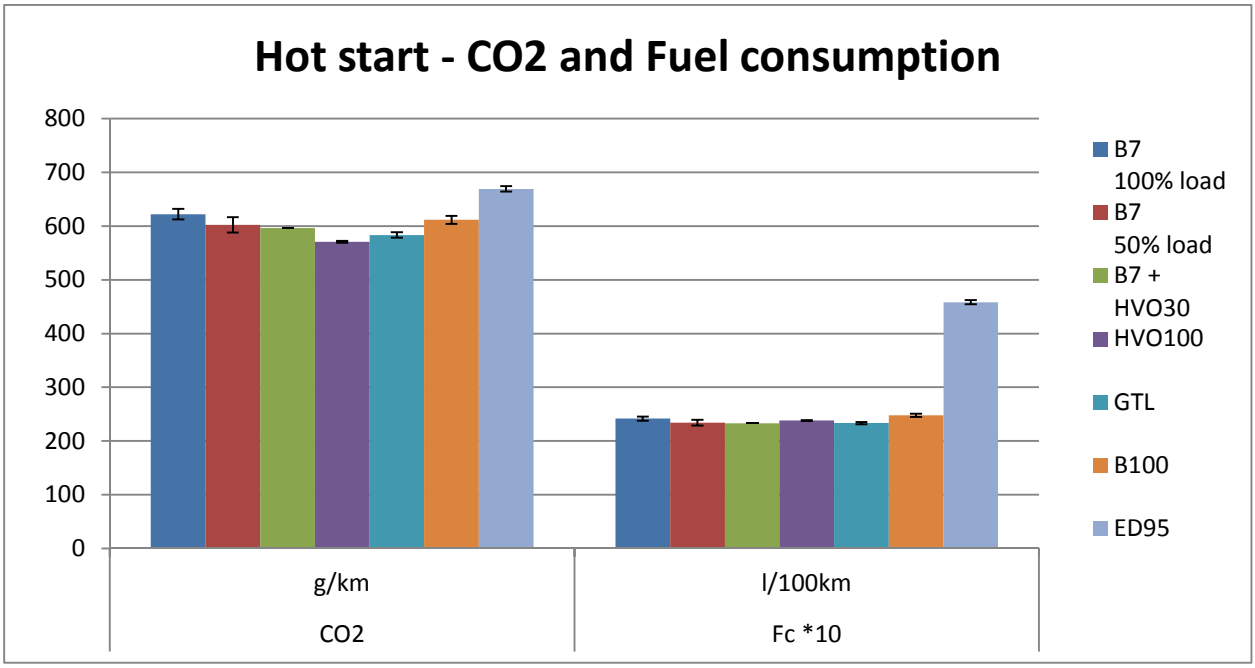


Figure 11: CO2 and fuel consumption – hot start tests. Averaged results from two tests.

Weighted results

According to Regulation (EU) No 582/2011, applicable for Euro VI, the weighted results from the cold start and the hot start WHTC should be used. The emissions of CO2 and fuel consumption should be presented in g/kWh. For the calculation, g/test is used.

In this study the hot start tests were repeated twice. The weighted results have therefore been counted for each of the two cycles, i.e. cold start together with hot start no 1, and cold start together with hot start no 2. The averaged results from these calculations are presented in Table 11 and Figure 12.

In the presented results, the total estimated work calculated through the method presented in Appendix has been applied.

Table 11: Weighted results for CO2 and fuel consumption, average from two hot start tests. Total estimated work (calculated) has been used.

		B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
CO2	g/kWh	766,6	779,5	777,0	737,7	763,2	791,5	776,1
Fc	g/kWh	244,4	248,4	248,1	239,8	245,4	282,0	427,8

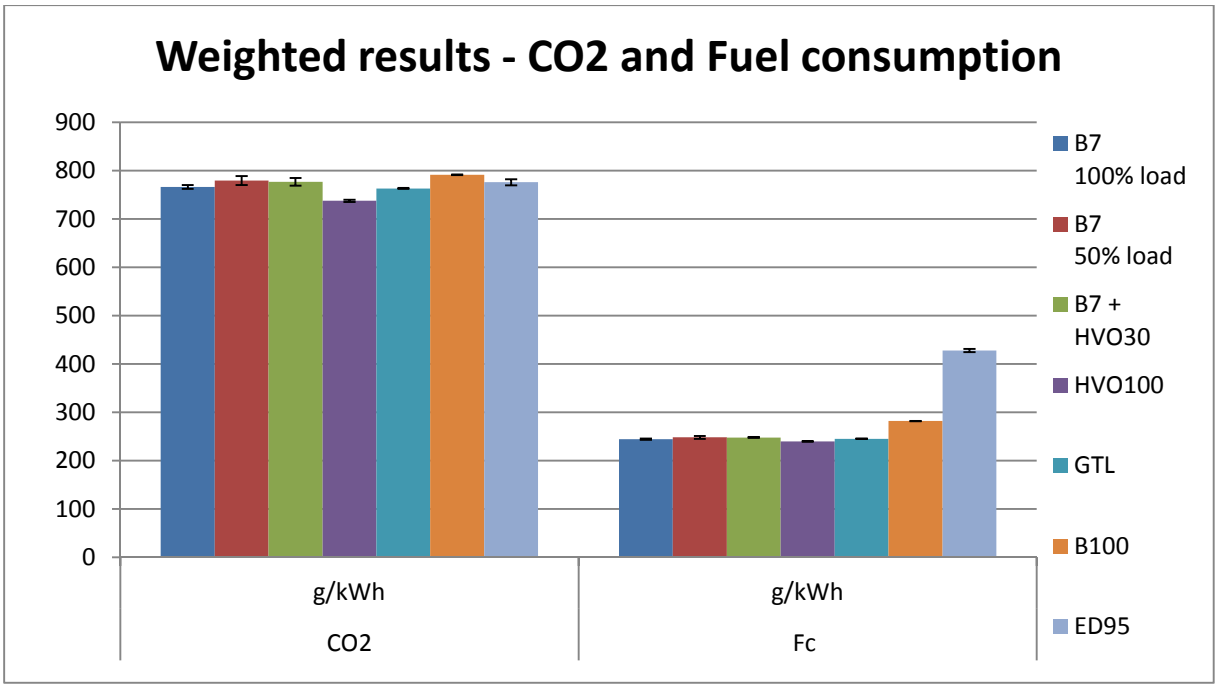


Figure 12: Weighted results for CO2 and fuel consumption, average from two hot start tests. Total estimated work (calculated) has been used.

Unregulated emissions

NO/NO2

The main components of NOx are NO and NO2. In the tests, the FTIR was used to measure NO and NO2. The test method is thorougly described in the Experimental chapter.

In Table 12 the NO and NO2 results are presented. NOx is calculated from the sum of NO and NO2. The calculated NO/NO2 ratio is presented in Table 12 and in Figure 13.

Table 12: NO and NO2 measured by FTIR. The calculated NO/NO2 ratio is presented in italic.

		WHVC	B7 100% load	B7 50% load	B7 + HVO30	HVO100	GTL	B100	ED95
NOx FTIR	g/km	Cold	3,449	3,284	3,165	3,119	3,042	3,424	3,480
NO FTIR	g/km	Cold	3,359	3,251	3,054	3,018	2,945	3,351	2,450
NO2 FTIR	g/km	Cold	0,093	0,036	0,112	0,104	0,099	0,075	1,030
Ratio NO/NO2		*Cold*	*36*	*90*	*27*	*29*	*30*	*45*	*2,4*
NOx FTIR, average	g/km	Hot	2,781	2,472	2,081	2,364	2,732	2,983	3,370
NO FTIR, average	g/km	Hot	2,768	2,465	2,070	2,346	2,713	2,967	1,920
NO2 FTIR, average	g/km	Hot	0,016	0,012	0,013	0,020	0,021	0,019	1,450
Ratio NO/NO2		*Hot*	*179*	*214*	*159*	*120*	*129*	*160*	*1,32*

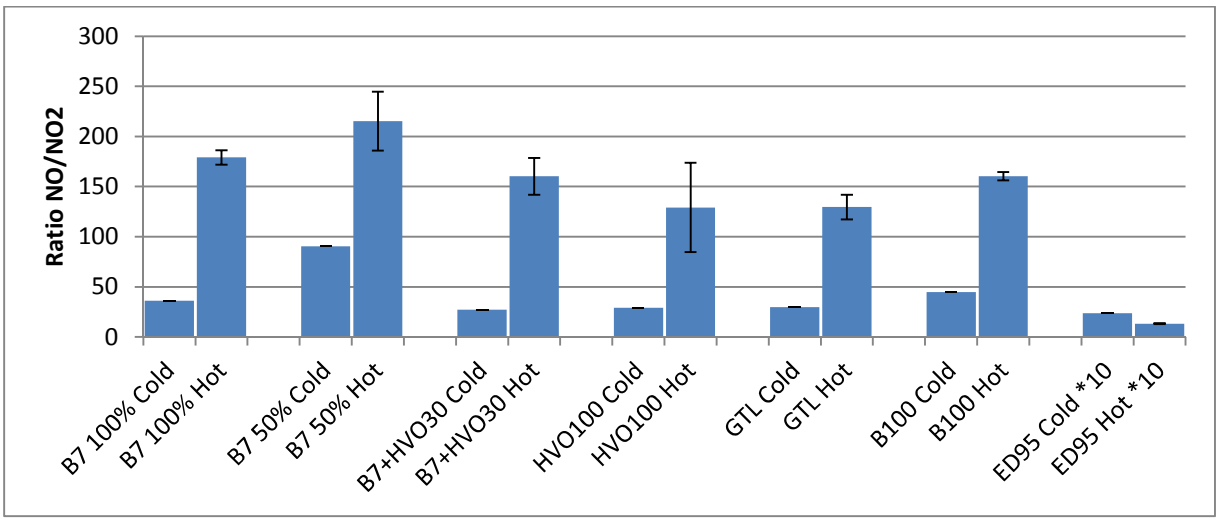


Figure 13: The calculated NO/NO2 ratio for hot and cold start tests.

Ethanol emissions

Ethanol emissions were measured with FTIR on the dedicated ED95 vehicle. The results presented in Figure 14 are from one cold start WHVC and averaged from two hot starts.

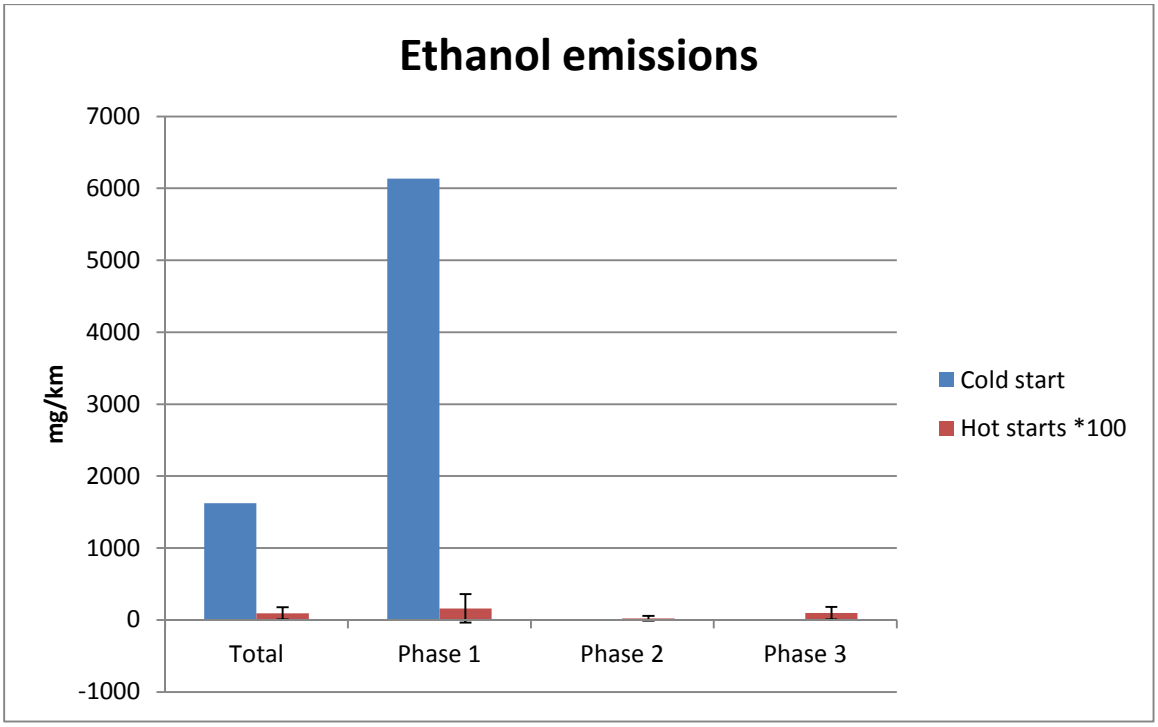


Figure 14: Ethanol emissions measured by FTIR on the ED95 vehicle. Please note the calculation factor for the hot start tests.

The cold started test yielded high ethanol emissions, where the first phase of the driving cycle dominates totally.

The ethanol emissions in the two hot started tests deviated, but the emissions were much lower compared to the cold started test.

Aldehydes

The following aldehydes were analyzed:

- Formaldehyde
- Acetaldehyde
- Acrolein
- Propionaldehyde
- Crotonaldehyde
- Metacrolein
- Butyraldehyde
- Bensaldehyde

The International Agency for Research on Cancer (IARC) [7] has classified Formaldehyde as carcinogenic to humans (Group 1), whereas Acetaldehyde has been classified as possibly carcinogenic to humans (Group 2B).

The aldehydes were sampled in DNPH-cartridges. The cartridges were analyzed at an external laboratory.

The diesel fuels are presented first, with separate diagram for cold (Figure 15 and Figure 16) and hot start (Figure 17 and Figure 18) tests. The ED95 tests are presented separately due to the higher levels of emitted aldehydes.

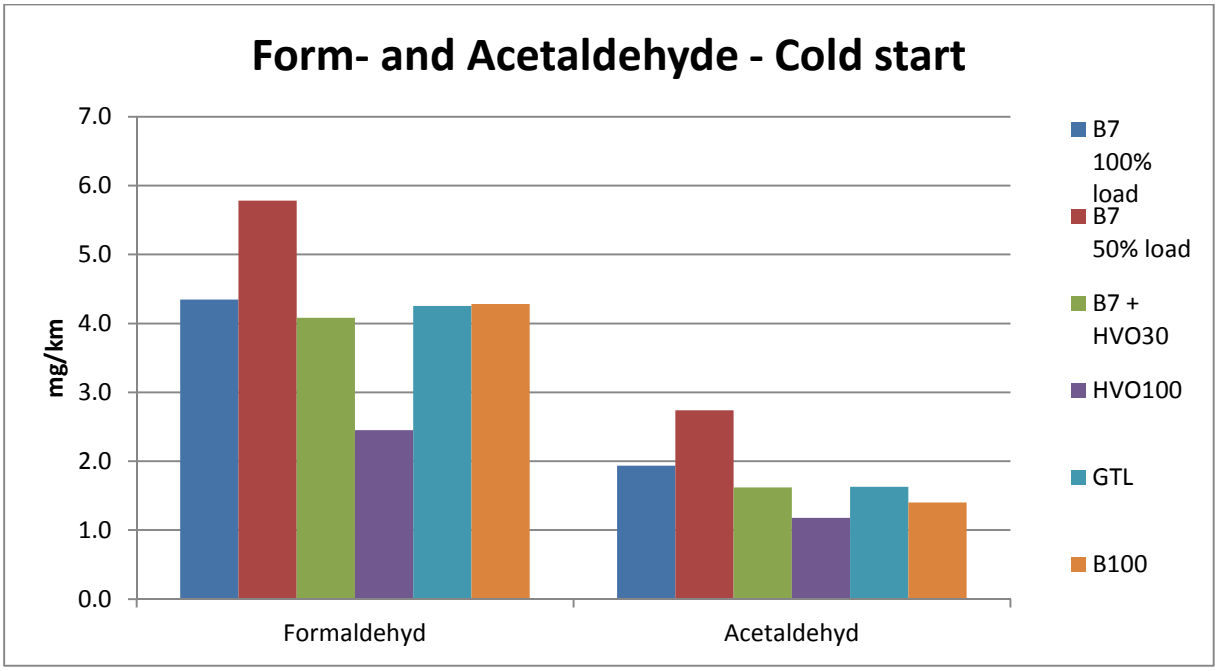


Figure 15: Formaldehyde and Acetaldehyde emissions, diesel fuels, cold start.

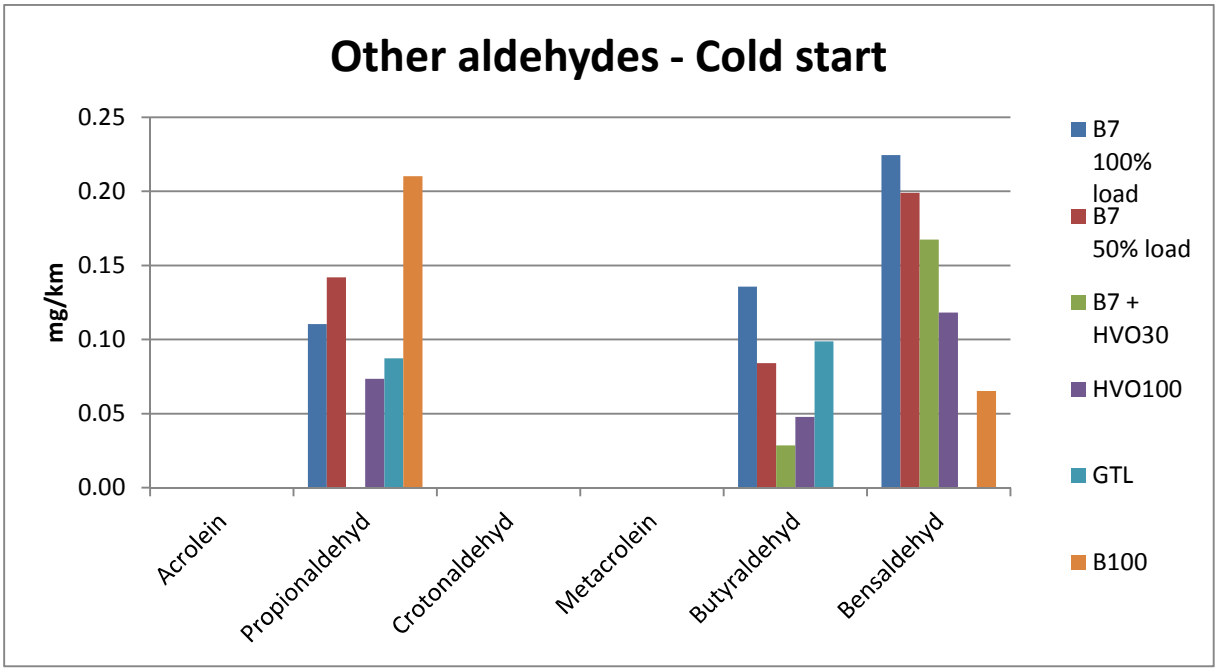


Figure 16: Emissions of other aldehydes, diesel fuels, cold start.

The aldehyde emissions from the cold start test are presented in Figure 15 and Figure 16. The aldehyde emissions are dominated by Formaldehyde and Acetaldehyde. The HVO100 generates the lowest aldehyde emissions of the compared fuels. Among the diesel fuels, the highest emissions of Formaldehyde and Acetaldehyde were from the 50% load test with B7 fuel. The results from the cold start test are generated from one emission test for each fuel. To be able to tell if the differences between the fuels are significant, the tests have to be repeated.

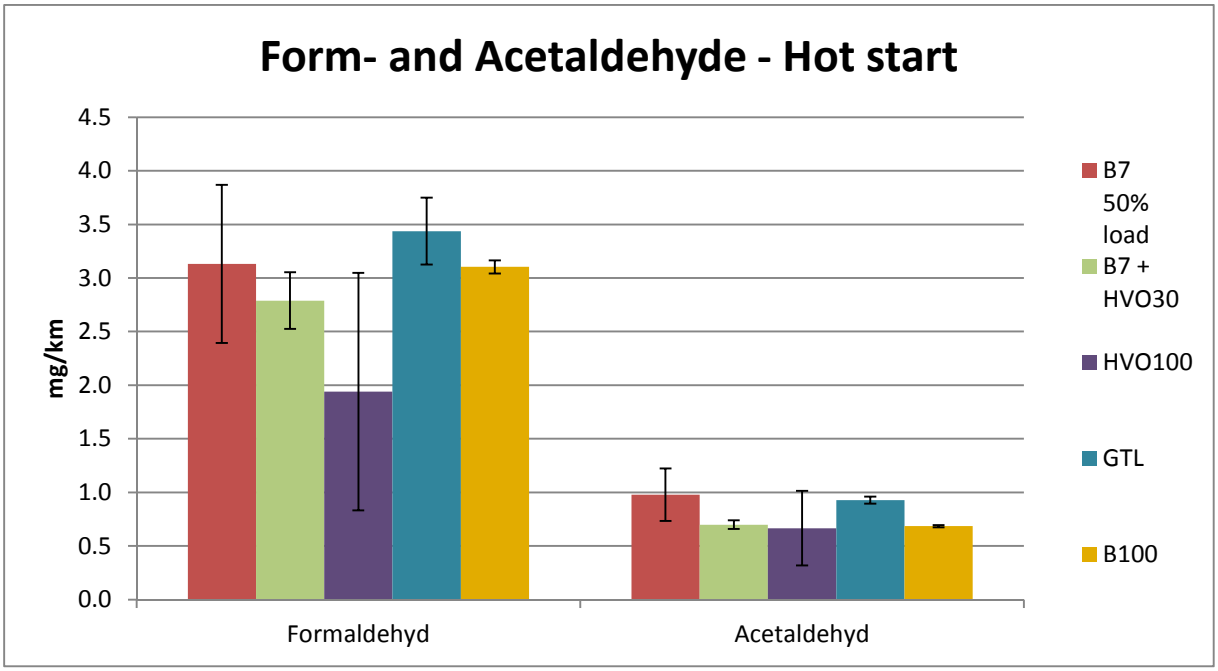


Figure 17: Formaldehyde and Acetaldehyde emissions, diesel fuels, averaged results from hot start tests.

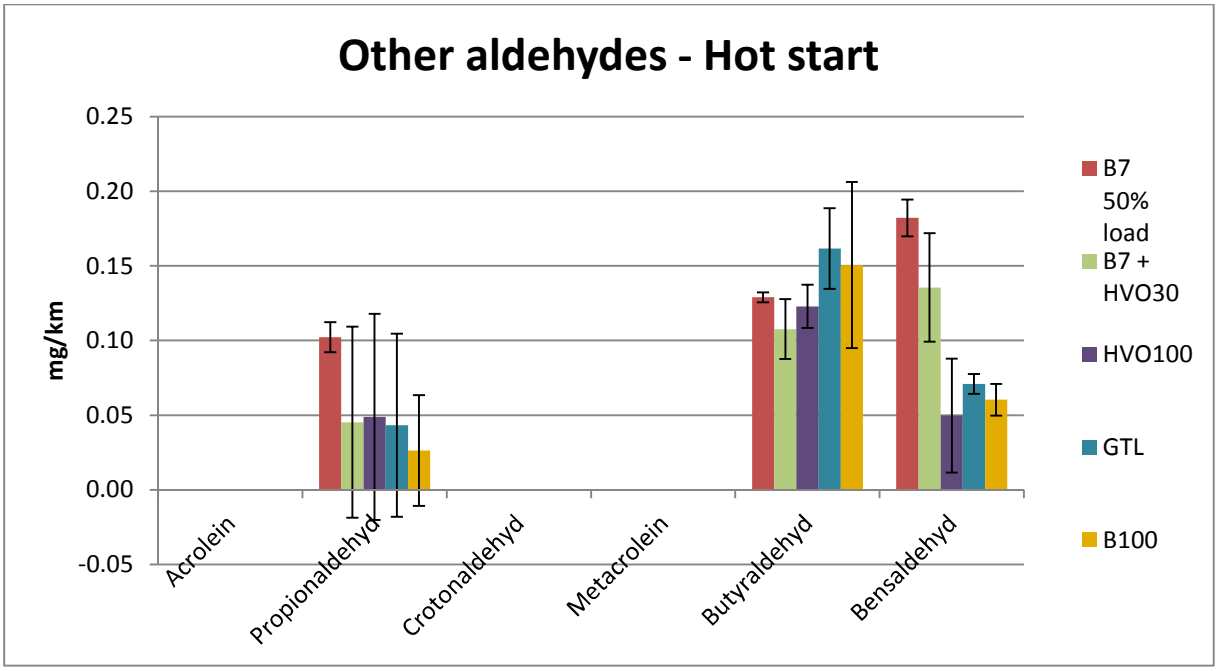


Figure 18: Emissions of other aldehydes, diesel fuels, averaged results from hot start tests.

The averaged results from the aldehyde emissions from the hot started tests are presented in Figure 17 and Figure 18. The pattern is similar to the cold start tests, with Formaldehyde

and Acetaldehyde as dominating components, but the levels are decreased. In accordance to the cold start test, the HVO100 seems to generate lower emissions of Formaldehyde. The standard deviation is however large, so this difference can not be considered as significant.

The emissions of Bensaldehyde are significantly higher for the B7 50% and B7+HVO30 compared to the other fuels. These fuels have higher levels of aromatics in the fuel, and the higher levels of Bensaldehyde in the emissions are probably a reaction product from these aromatics.

Aldehydes are formed in an oxidation reaction of alcohols, such as ethanol. The levels of emitted aldehydes when the tests were performed on ED95 are therefore much higher compared to the diesel fuels. The results for the ED95 tests are presented in Figure 19 and Figure 20. Formaldehyde and Acetaldehyde are dominating and are therefore presented separately.

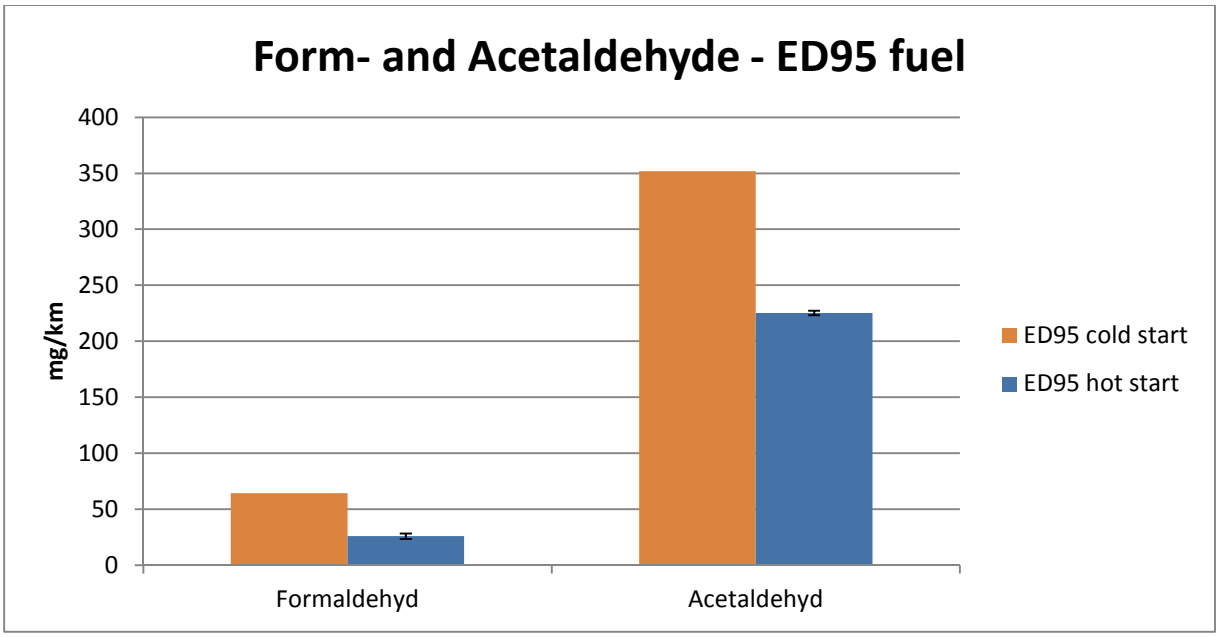


Figure 19: Formaldehyde and acetaldehyde emissions from tests using ED95 fuel – cold and hot started tests.

The aldehydes were sampled in DNPH-cartridges, two in series in order to prevent breakthrough. However, during the analysis of the cartridges from the ED95 tests, high levels of Acetaldehyde were observed also in the second cartridge. There is therefore a possibility that the actual Acetaldehyde emissions are higher than presented in this study.

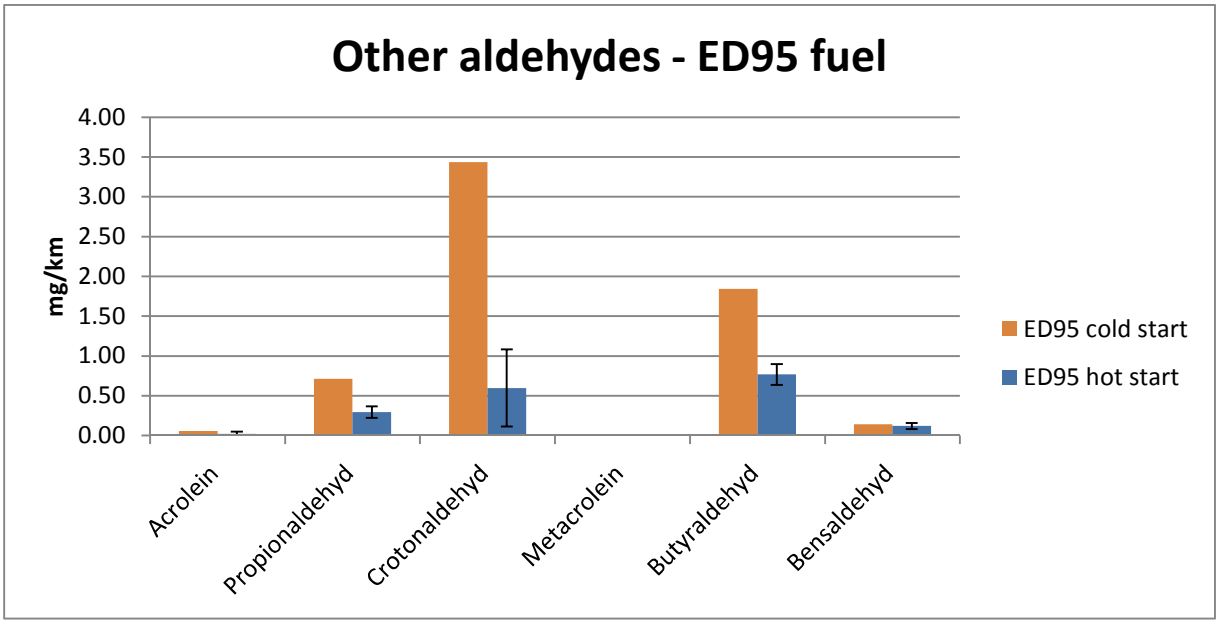


Figure 20: Other aldehydes from tests using ED95 fuel – cold and hot started tests.

In conformity with the emissions of Formaldehyde and Acetaldehyde from the ED95 testing, the other aldehydes analysed in this study are also at higher levels compared to the diesel fuel testing.

Metacrolein was not present in any of the tests.

Particle number

The particle number emissions were measured with CPC (Condensed Particle Counter). The CPC measures particles in the size span of 23 nm to 2,5 µm. For further details, please see instrument description in the Experimental chapter.

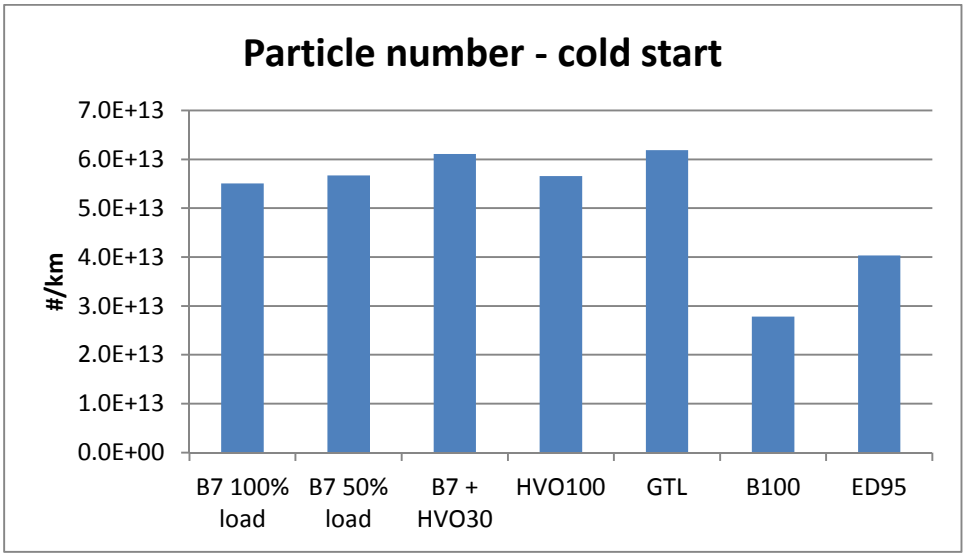


Figure 21: Particle number – cold start test.

The particle number from the cold start tests are presented in Figure 21. For the particle size span measured by the CPC, the B100 fuel generated the lowest number of particles. The particle number emissions from the ED95 fuel was lower compared to the diesel fuels, with the exception of the B100 fuel. The lower PN emissions for B100 and ED95 can probably be explained by the higher amount of oxygen in the fuel, which can lead to more complete combustion.

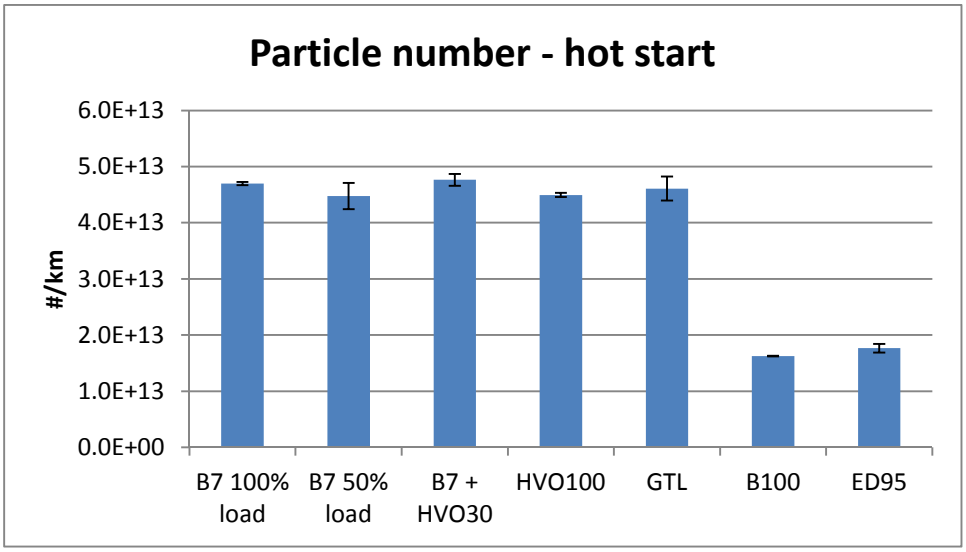


Figure 22: Particle number – averaged results from hot start tests.

The averaged results from particle number from the hot start tests are presented in Figure 22. The B100 and ED95 generated significantly lower levels of particles compared to the other fuels in this investigation.

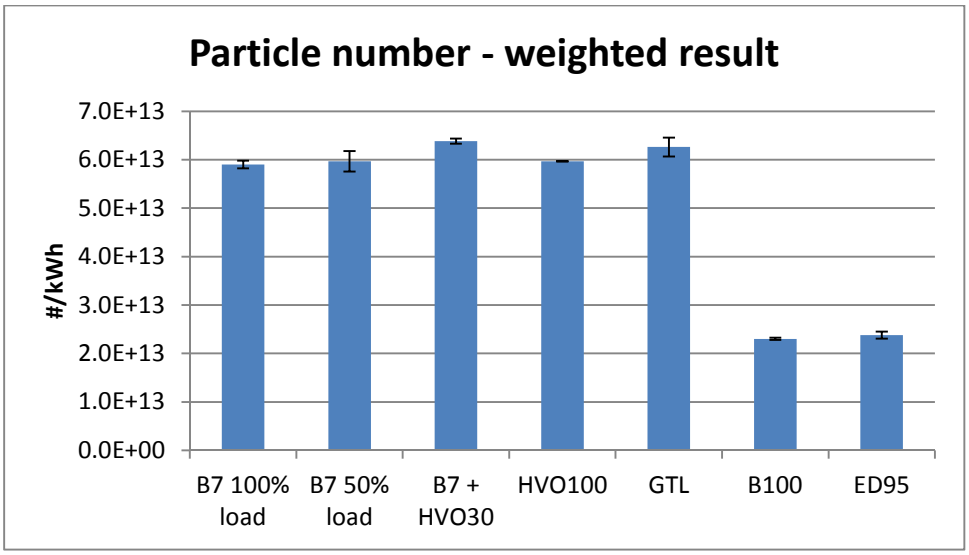


Figure 23: Particle number – average weighted results. Presented in #/kWh, where the total estimated work (calculated) has been used.

The average results from the weighted emissions of particle number are presented in Figure 23. The results are presented in #/kWh, where the total estimated work calculated through the method presented in Appendix has been applied.

Similar pattern can be observed as for the cold and hot starts, with significantly lower levels of particle numbers for the B100 and ED95 fuels.

The particle emissions are reduced for B100 and ED95 both regarding mass (PM) and number (PN). One explanation for the reduction of particles for B100 can be the increased amount of oxygen in the fuel, which can lead to more complete combustion and thereby reduce the particle emissions [6]. This explanation could probably also be applicable for the lower particle emissions for the ED95 fuel.

Particle size distribution

The particle size distribution was measured with an ELPI (Electrical Low Pressure Impactor) instrument. The particles are separated in the impactor in 12 stages according to their aerosol size. The lowest stage collects particles from 7 nm. The specification for the instrument is described in the Experimental chapter.

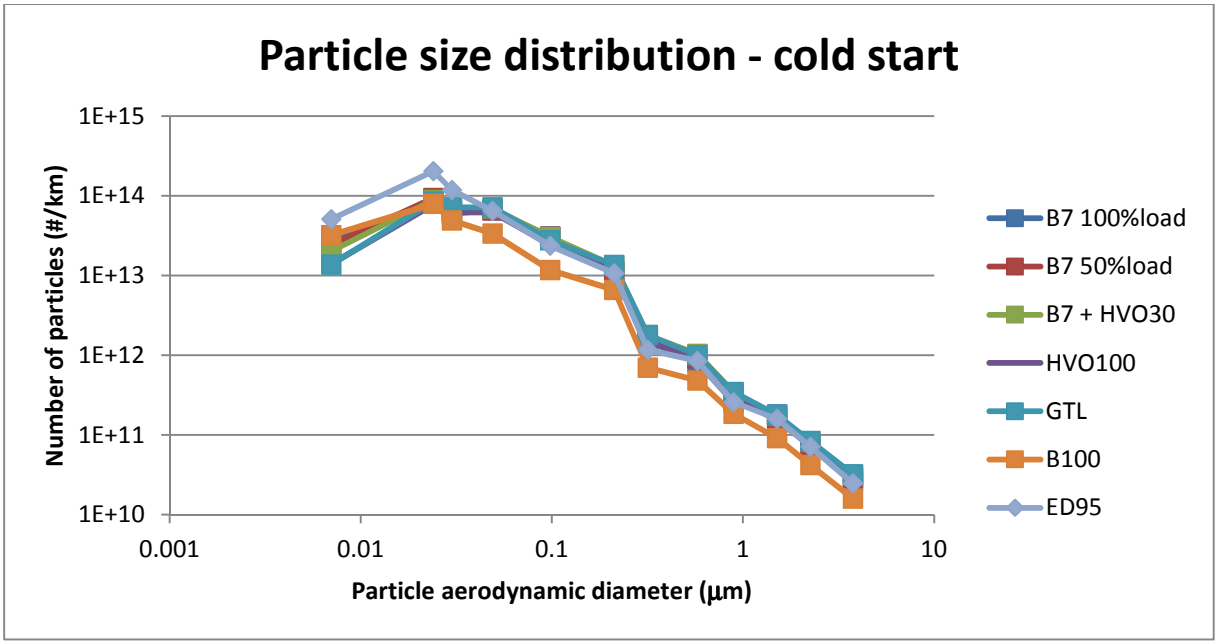


Figure 24: Particle size distribution – cold start. Number of particles per km.

The size distribution of particles emitted during the cold start test is presented in Figure 24. For the smallest particle sizes, the ED95 test had the highest amount. This is in agreement with the findings presented by VTT [8]. In the larger size stages the emitted particles are at the same level for all of the fuels, with the exception of B100 with lower emission levels.

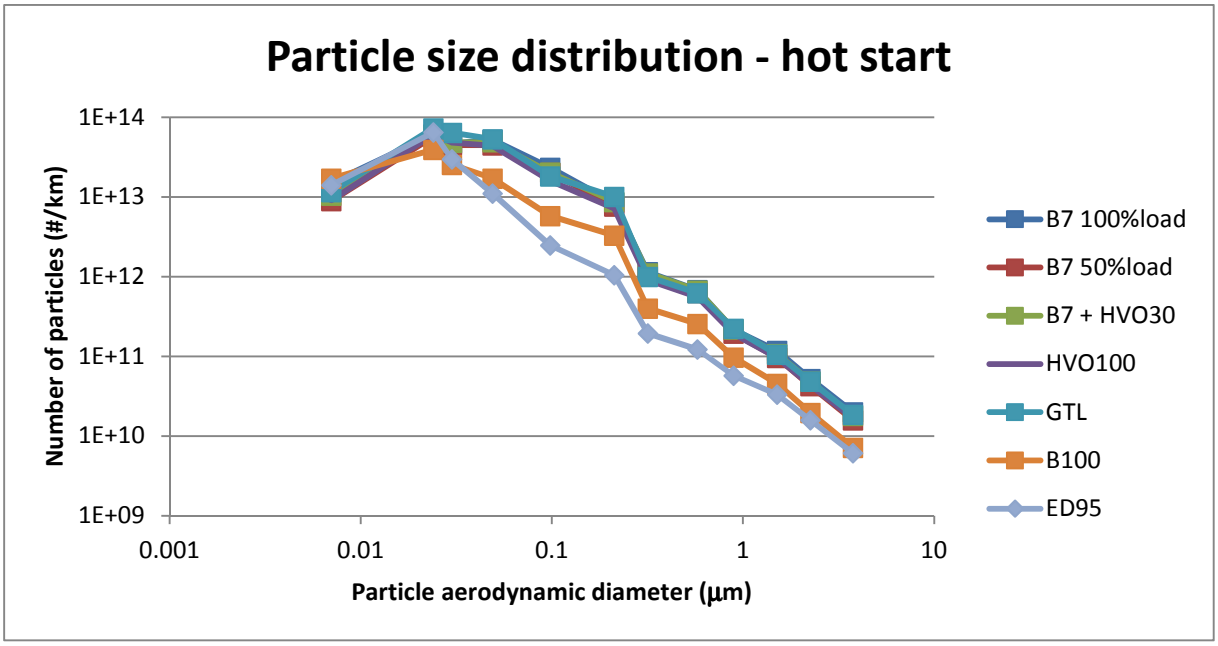


Figure 25: Particle size distribution – hot start tests. Number of particles per km.

The particle size distribution from the hot start tests are presented in Figure 25. The number of particles emitted during the hot start tests are reduced, compared to cold start. For the larger particles sizes, the B100 and ED95 tests are distinguished with lower levels of emitted particles. The reduction of particles for B100 can be explained by the higher amount of oxygen in the fuel, leading to improved combustion and reduction of particle emissions [6]. This explanation could probably also be applicable for the lower particle emissions for the ED95 fuel.

Polycyclic Aromatic Hydrocarbons (PAH)

PAH are compounds with relatively high molecular weight. These compounds can be found condensed on particles and in gaseous phase. The particle associated compounds were collected on a large filter and the PAH in gaseous phase were collected in polyurethane foam (PUF) plugs. The dominating part of the PAH collected in the semivolatile phase are comparatively lighter PAH compounds (up to molecular weights of approximately 200 g/mole), whereas the PAH collected on the filters consists of both lighter and heavier PAH compounds. The filters and foam plugs were extracted and analysed separately to distinguish between the different phases. The extracts were chemically characterized and different PAH compounds could be identified.

For an easier overview, the analyzed compounds have been summarized for the respective phase (filter and semivolatile). The total emissions of the analyzed PAH from the cold start

test are presented in Figure 26 and Figure 28, whereas the total emissions from the hot start tests are presented in Figure 27 and Figure 29. In these overviews there has not been any distinction between the different PAH compounds. The characteristics differ, as well as the effect on environment and human health. Complete lists of the analyzed compounds can be found in Appendix.

The PAH in the emissions can be derived from unburned residues of fuel, as a byproduct from the combustion or from the engine oil. According to the fuel specifications, the diesel fuels denoted B7 and B7+HVO30 have higher total aromatic content. This is is also reflected in the filter phase of the particle extracts presented in Figure 26 (cold start) and Figure 27 (hot start), with somewhat elevated levels. The difference in the hot start tests is however not significant, due to the high standard deviations.

The B100 fuel shows the lowest emissions for summarized PAH in filter phase in the cold start test. In the hot start tests, the summarized PAH in filter phase for B100 is significantly lower compared to the B7 fuel.

With the exception of B100, the summarized PAH emissions in filter phase shows no major differences between the fuels.

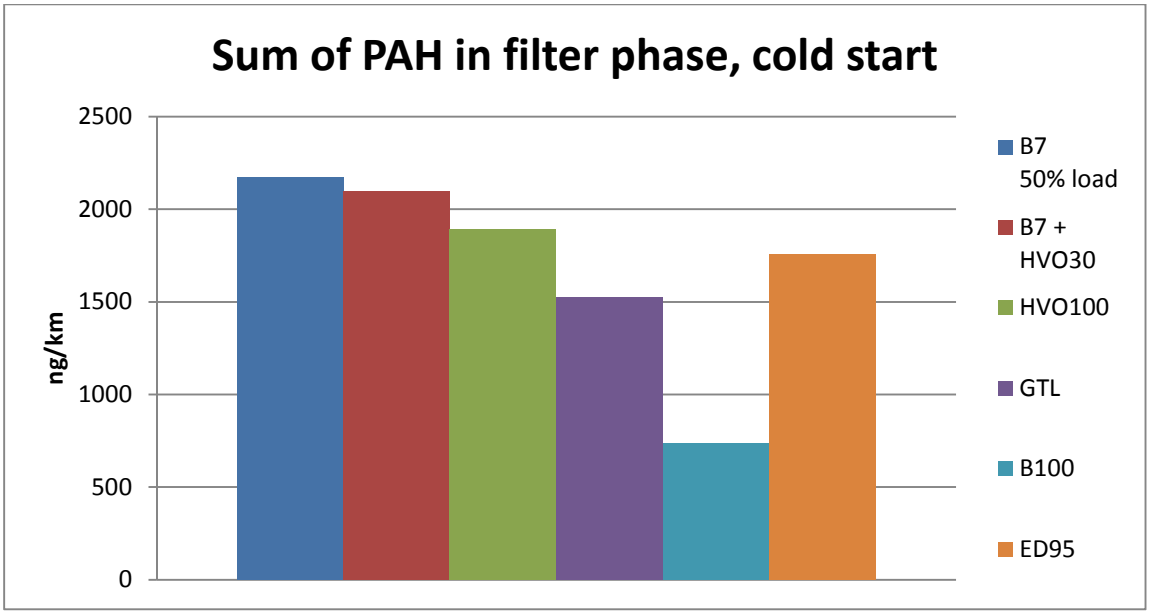


Figure 26: Total emissions of analyzed PAH in filter phase, cold start.

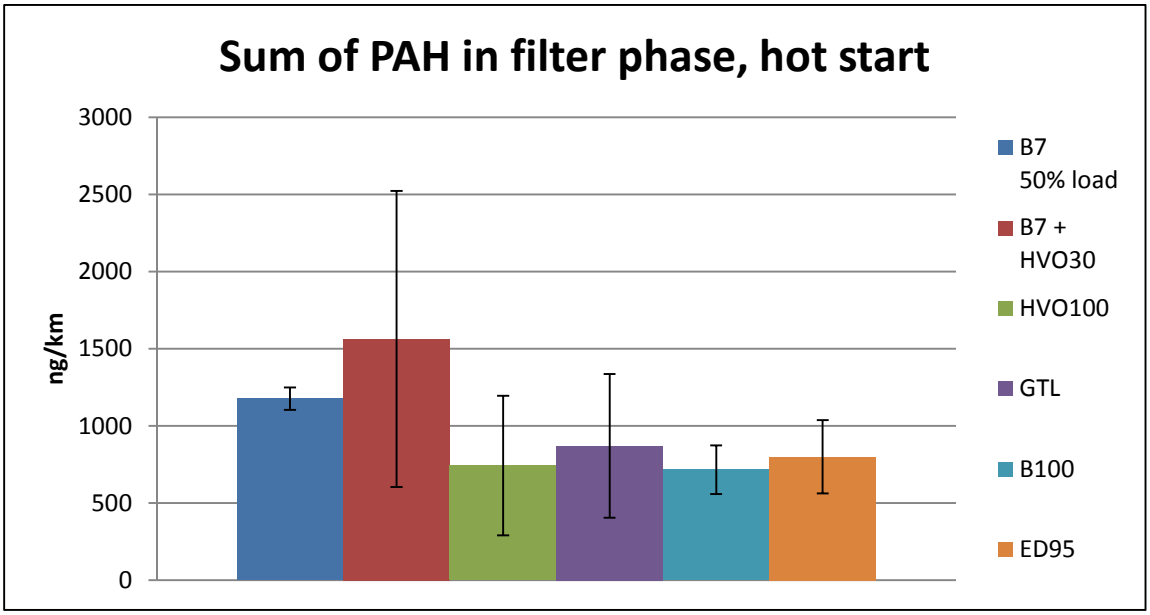


Figure 27: Total emissions of analyzed PAH in filter phase, averaged results from the hot start tests.

The summarized emissions of PAH in semivolatile phase is presented in Figure 28 (cold start) and Figure 29 (hot start). In the cold start test, the HVO100 and ED95 fuels show elevated levels compared to the other fuels.

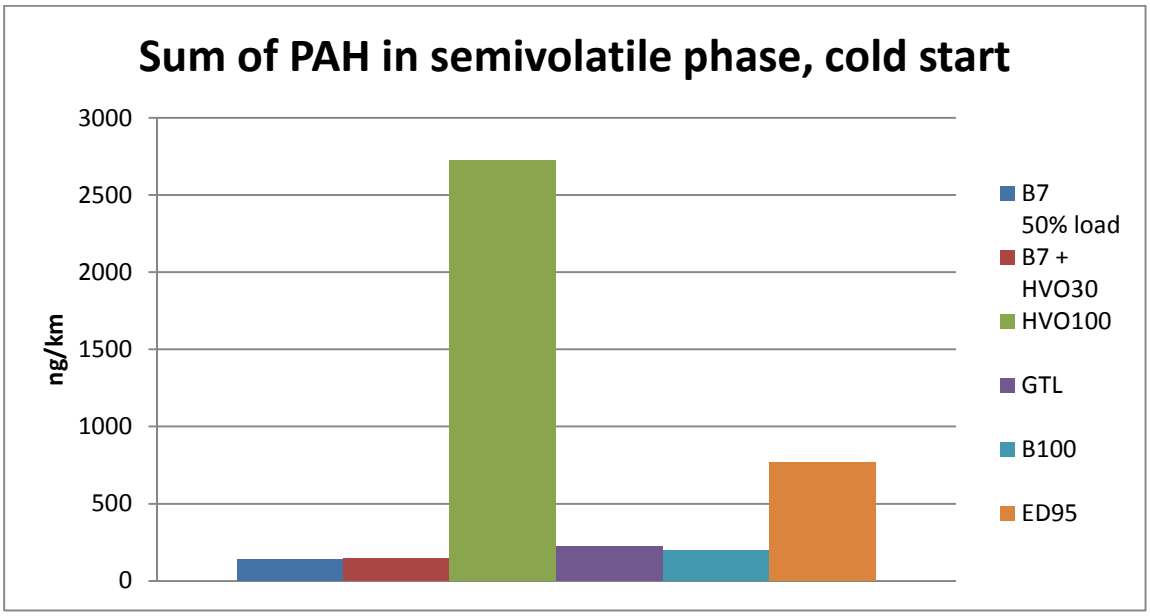


Figure 28: Total emissions of analyzed PAH in semivolatile phase, cold start.

For the HVO fuel test with cold start, the PAH emissions in semivolatile phase consists almost exclusively of Benzo(c)phenanthrene. A literature survey could not give any specific information on this PAH compound from emission measurement studies, and no conclusive evidence of mutagenic effect could be found.

In the hot start tests, the GTL and B7 fuels have the lowest levels of summarized PAH in semivolatile phase. The GTL fuel is significantly lower in these tests compared to HVO100 and ED95. No significant differences could be distinguished for the other fuels due to the high standard deviations.

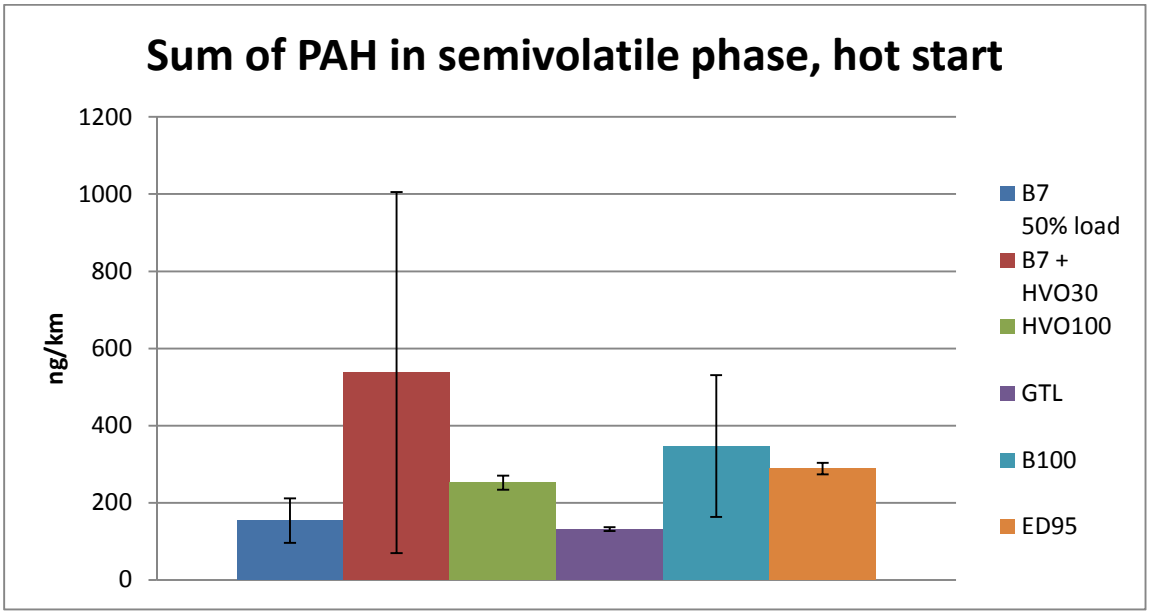


Figure 29: Total emissions of analyzed PAH in semivolatile phase, averaged results from the hot start tests.

PAH and Toxic Equivalence

The PAH group consists of many different compounds with varying characteristics. Some PAHs have been more thoroughly investigated regarding health effects.

The US EPA uses a theoretical method where the potential effects of some compounds have been translated into Toxic Equivalence Factors (TEF). The factor is established through toxicological studies. This method assumes that compounds have additive effect, and that the effect is linear. Some of the investigated PAHs are presented in Table 13 together with their TEF values. Please note that the list is not complete and the TEFs can be updated or changed.

Table 13: Toxic Equivalence Factors for some PAH [9].

PAH	TEF
Anthracene	0,01
Benzo(a)pyrene	1
Benzo(b)fluoranthene	0,1
Benzo(k)fluoranthene	0,05
Dibenzo(a,e)pyrene	0,2
Dibenzo(a,h)pyrene	1
Dibenzo(a,i)pyrene	1
Dibenzo(a,l)pyrene	100
Fluoranthene	0,05
Phenanthrene	0,0005
Pyrene	0,001

The TEF can be used to calculate TEQ (Toxic Equivalence) which is described as the potency to induce cancer. The factor for respective compound is multiplied by the emission in ng/km for the specific compound. The products are thereafter summarized to achieve the TEQ value for the emission test.

The TEQ values for the PAH compounds listed in Table 13 were calculated, and the results from the filter phase are presented in Figure 30 and Figure 31. The TEQ results from the semivolatile phase are presented in Figure 32 and Figure 33.

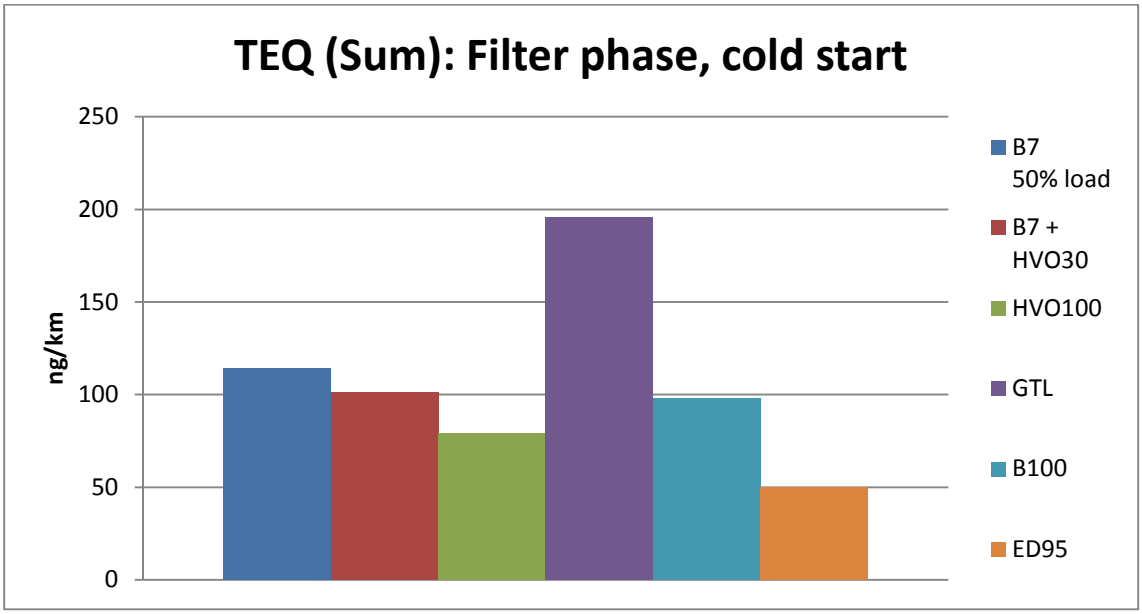


Figure 30: Sum of TEQ for the filter phase, cold start test.

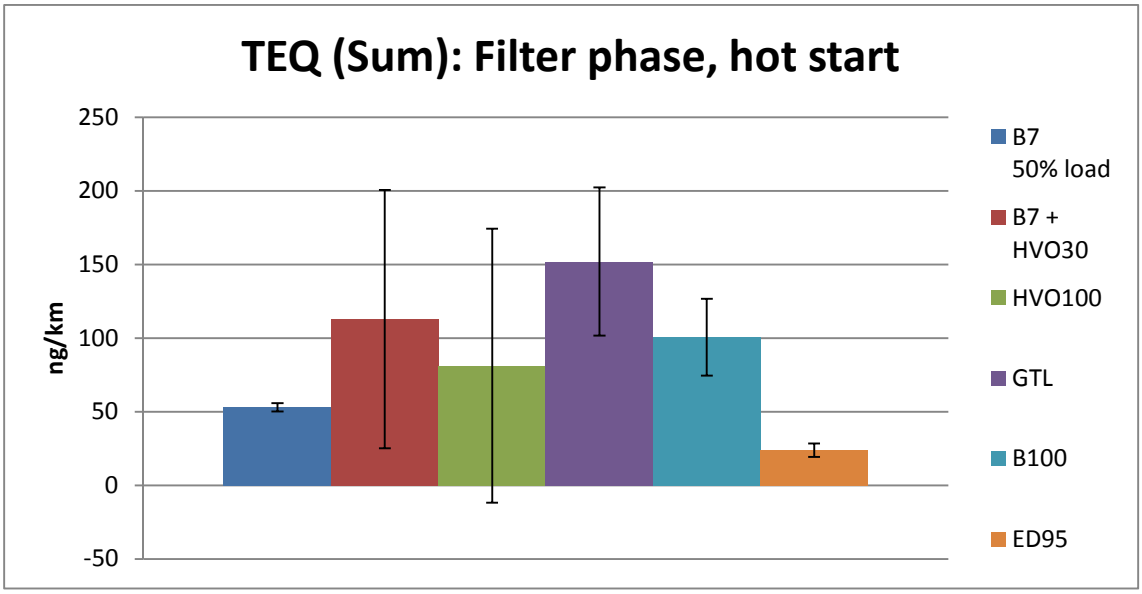


Figure 31: Sum of TEQ for filter phase, average of hot start tests.

For the filter phase, the summarized TEQ values in the cold start test are higher for the GTL fuel and lower for the ED95 fuel – compared to the other fuels. For the hot start tests, the ED95 is significantly lower than B7. For the other fuels, the standard deviations are too high to distinguish significant differences.

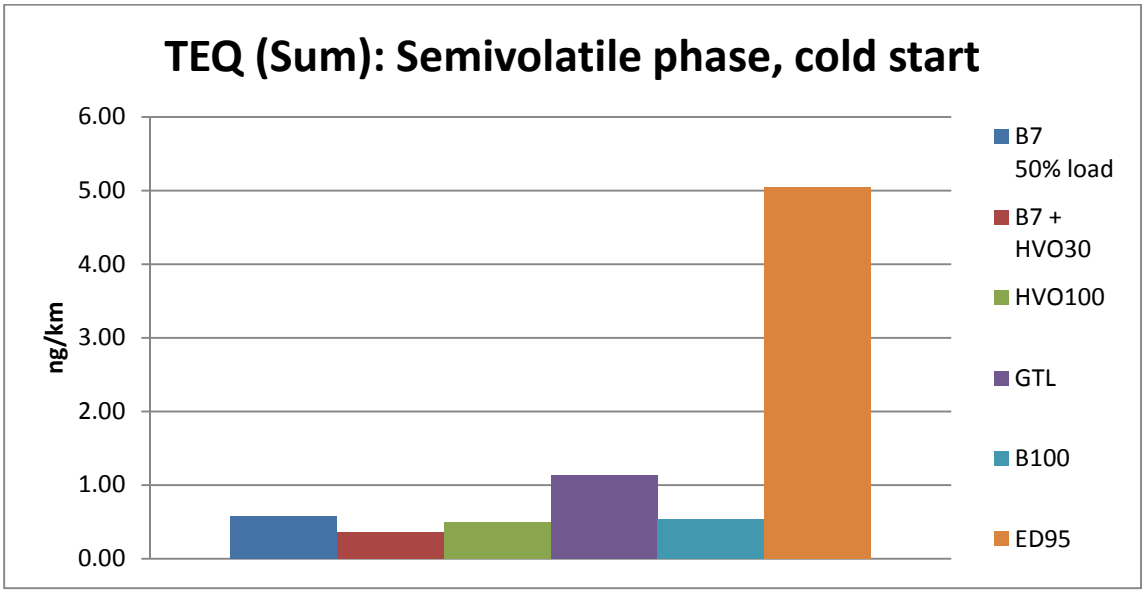


Figure 32: Sum of TEQ for semivolatile phase, cold start test.

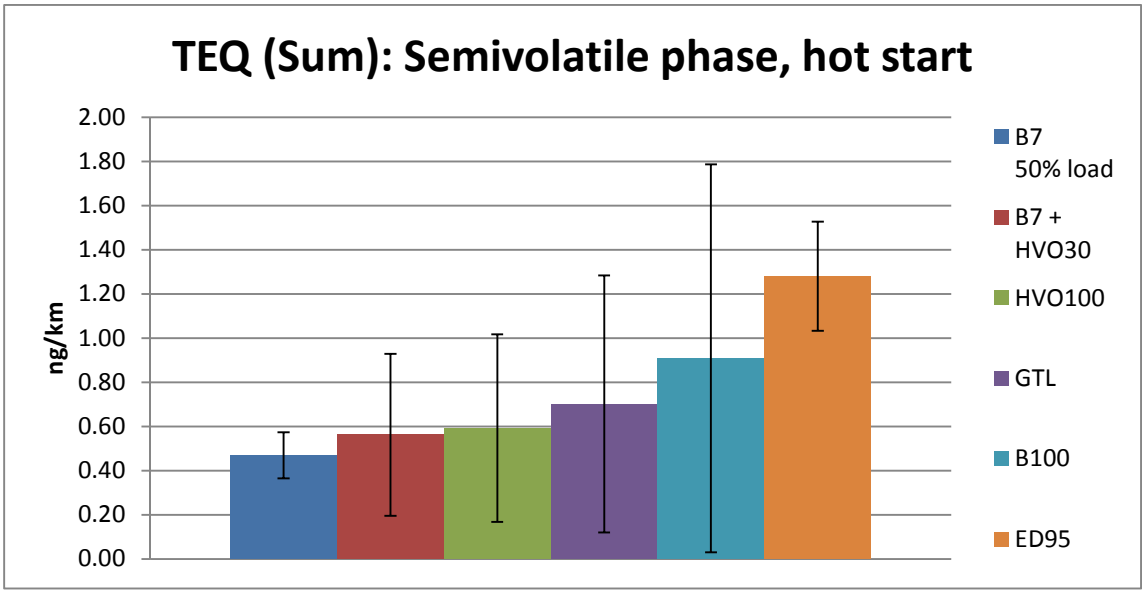


Figure 33: Sum of TEQ for semivolatile phase, average of hot start tests.

For the semivolatile phase, consisting of lighter PAHs, the summarized TEQ values are very low for all fuels. The ED95 shows comparatively high TEQ values both at cold start and hot start, and is significantly higher than B7.

Health effect studies are complex, and the results are dependent on the endpoints in the studies. It is not adviceable to draw conclusions regarding health effects only from TEQ results, but Toxic Equivalence Factors could be useful as a screening method. High TEQ values for exhaust emissions from a fuel should be followed up with more thorough health effect studies.

Discussion

The climate impact from the transport sector needs to be reduced. The sector is however diverse and there is a need to approach the problems in several ways. Stricter emission standards will reduce the regulated emissions in the future, but for the heavy duty sector, the fleet will consist of vehicles from different emissions standards. The fuels available on the market have however the potential to effect the emissions from the existing vehicle fleet.

The heavy duty sector is dominated by the compression ignited engine, due to its higher efficiency. By influencing the fuels used for these vehicles, the climate impact can be substantial. It is however important to investigate the climate impact in combination with other aspects affecting environment and health.

In this study, totally six fuels for compression ignited engines have been investigated. The following fuels were used – B7 (conventional diesel fuel), B7+HVO30, HVO100, synthetic diesel (GTL), B100 and ED95. The B7+HVO30, HVO100 and the synthetic diesel (GTL) are so-called drop-in fuels, i.e. fuels that can be used in existing engines. The B100 can be used in existing vehicles with some adjustments, whereas the ED95 fuel can be used in dedicated vehicles.

The regulated components and CO2 have been measured. In addition, some unregulated components were also investigated: Aldehydes were sampled in DNPH-cartridges; ethanol emissions were measured with FTIR during the tests with the ED95 fuel; particle numbers were counted with a CPC; particle size distribution was analyzed with an ELPI instrument and the PAH content in the particles were analyzed.

For the majority of the analyzed components, there are no major differences in emission levels compared to the conventional diesel fuel. Some exceptions are the higher levels of aldehydes (mainly Formaldehyde and Acetaldehyde) emitted by the ethanol fuelled vehicle, both during cold and hot started tests. The ethanol vehicle showed higher levels of ultrafine particles in the cold start test, but had lower levels than conventional diesel for the larger particles during hot start test. The B100 fuel had overall lower particle levels in all size stages.

The general conclusion is that none of the investigated fuels have any major negative impact on the components analyzed in this study. The included fuels contain components which have the possibility to come from renewable sources, and an increased usage can have a positive impact on the climate.

Regarding the emissions, it is however clear that the effects of fuel change are limited for the investigated fuels. To reduce the levels of regulated components, the introduction of engines which can meet more stringent emission legislation are needed. It will however still be important to analyze components which can have negative impact on health and environment, and which are not regulated in the emission legislations.

Bibliography

[1] C. Sandström-Dahl, "Measurement Technologies for Emissions from Ethanol Fuelled Vehicles - METEV," IEA AMF, 2010.

[2] I. Sadiktsis, J. Koegler, T. Benham, C. Bergvall and R. Westerholm, "Particulate associated polycyclic aromatic hydrocarbon exhaust emissions from a portable generator fueled with three different fuels - A comparison between petroleum diesel and two biodiesels," *Fuel,* no. 115, pp. 573-580, 2013.

[3] S. Masala, T. Ahmed, C. Bergvall and R. Westerholm, "Improved efficiency of extraction of polycyclic aromatic hydrocarbons (PAHs) from the National Institute of Standards and Technology (NIST) Standard Reference Material Diesel Particulate Matter (SRM 2975) using accelerated solvent extraction.," *Anal Bioanal Chem,* no. 401, pp. 3305-3315, 2011.

[4] C. W. R. Bergvall, "Determination of dibenzopyrenes in standard reference materials (SRM) 1649a, 1650, and 2975 using ultrasonically assisted extraction and LC-GC-MS.," *Anal Bioanal Chem,* vol. 2, no. 384, pp. 438-447, 2006.

[5] A. Christensen, C. Östman and R. Westerholm, "Ultrasound-assisted extraction and on-line LC-GC-MS for determination of polycyclic aromatic hydrocarbons (PAH) in urban dust and diesel particulate matter.," *Anal Bioanal Chem,* vol. 6, no. 381, pp. 1206-1216, 2005.

[6] M. Lapuerta, O. Armas and J. Rodriguez-Fernández, "Effect of biodiesel fuels on diesel engine emissions," *Progress in Energy and Combustion Science,* no. 34, pp. 198-223, 2008.

[7] "IARC - International Agency for Research on Cancer (WHO)," [Online]. Available: http://www.iarc.fr.

[8] N.-O. Nylund and K. Koponen, "Fuel and Technology Alternatives for Buses - Overall energy efficiency and emission performance," VTT technology 46, 2012.

[9] M. Lindgren, "Regeringsuppdrag att belysa skillnader i hälso- och miljöpåverkan av att använda diesel av miljöklass 1 och miljöklass 3," Trafikverket, 2012.

Appendix

The diesel fuel specifications are included in Appendix. For the synthetic diesel, typical analysis data is presented.

Diesel fuel specification: B7

Properties	Results	Units	Ref. Test Methods
Appearance at 20°C	1	rating	ASTM D 4176-04
Appearance at 20°C	BRIGHT AND CLEAR		Visual inspection
Aromatic content	4,7	% V/V	SS 15 51 16:1993
Ash content	< 0,010	% m/m	SS-EN ISO 6245:2003
Carbon residue (on 10% dist res)	< 0,20	% m/m	SS-EN ISO 10370:1996
Cetane index	50,7	-	SS-EN ISO 4264:2007
Cetane number	55,0		SS-EN ISO 5165:1998
Cloud point	-30	°C	SS-EN 23015:1994
Cold Filter Plugging Point	-32	°C	SS-EN 116:1999
Colour (ASTM scale)	< 0,5		SS-ISO 2049:1997
Conductivity	800	pS/m	SS-ISO 6297:1998
Cu strip corrosion (3h at 50°C)	1A		SS-EN ISO 2160:1998
Density at 15°C	822,0	kg/m3	SS-EN ISO 12185 T1:99
Dist: IBP	182,0	°C	SS-EN ISO 3405:2011
Dist: Temp. at 95% V/V rec.	318,5	°C	SS-EN ISO 3405:2011
FAME content	8,7	% V/V	SS-EN 14078:2009
FAME content	7,0	% V/V	SS-EN 14078:2009
Flash point	71,0	°C	SS-EN ISO 2719:2003
Lubricity (WSD 1.4) at 60°C	< 400	µm	SS-EN ISO 12156-1:06
Oxidation stability	< 25	g/m3	SS-EN ISO 12205:1996
PAH content	0,02	% V/V	SS 15 55 16:1993
Sulphur content	< 3	mg/kg	SS-EN ISO 20884:2011
Total contamination	< 24	mg/kg	SS-EN 12662:2008
Water content	58	mg/kg	SS-EN ISO 12937:2001
Viscosity at 40°C	2,151	mm2/s	SS-EN ISO 3104/AC:99

Results according to ISO 4259

Diesel fuel specification: B7+HVO30

Properties	Results	Units	Ref. Test Methods
Appearance at 20°C	1	rating	ASTM D 4176-04
Appearance at 20°C	BRIGHT AND CLEAR		Visual inspection
Aromatic content	4,7	% V/V	SS 15 51 16:1993
Ash content	< 0,010	% m/m	SS-EN ISO 6245:2003
Carbon residue (on 10% dist res)	< 0,20	% m/m	SS-EN ISO 10370:1996
Cetane index	56,5	-	SS-EN ISO 4264:2007
Cetane number	63,8		SS-EN ISO 5165:1998
Cloud point	-8	°C	SS-EN 23015:1994
Cold Filter Plugging Point	-13	°C	SS-EN 116:1999
Colour (ASTM scale)	< 1,0		SS-ISO 2049:1997
Conductivity	850	pS/m	SS-ISO 6297:1998
Cu strip corrosion (3h at 50°C)	1A		SS-EN ISO 2160:1998
Density at 15°C	822,5	kg/m3	SS-EN ISO 12185 T1:99
Dist: IBP	193,9	°C	SS-EN ISO 3405:2011
Dist: Temp. at 95% V/V rec.	326,6	°C	SS-EN ISO 3405:2011
FAME content	7,0	% V/V	SS-EN 14078:2009
Flash point	73,0	°C	SS-EN ISO 2719:2003
Lubricity (WSD 1.4) at 60°C	< 400	µm	SS-EN ISO 12156-1:06
Manganese content	NOT ADDED		--
Oxidation stability	< 25	g/m3	SS-EN ISO 12205:1996
PAH content	< 0,02	% V/V	SS 15 55 16:1993
Sulphur content	< 3	mg/kg	SS-EN ISO 20884:2011
Total contamination	< 24	mg/kg	SS-EN 12662:2008
Water content	52	mg/kg	SS-EN ISO 12937:2001
Viscosity at 40°C	2,520	mm2/s	SS-EN ISO 3104/AC:99
Renewable content	27,1 *	% V/V	Intern
* innan tillsatt 7% FAME			

Results according to ISO 4259

Diesel fuel specification: HVO100

Physical property	Method	Unit	Sample 1.
Density at 15°C	ENISO12185	kg/m3	778,6
Cloud point with the ISL mini automatic device	ASTMD7689	°C	-37
Cold filter plugging point	EN116	°C	-40
Viscosity at 20 °C	ENISO3104	mm2/s	4,360
Viscosity at 40 °C	ENISO3104	mm2/s	2,831
Sulphur, UV	ENISO20846	mg/kg	<1
Water coloumetric	ENISO12937	mg/kg	17
Flash point, Pensky Martens	ENISO2719	°C	83,0
Copper Corrosion 3 h 50 °C	ENISO2160	no	1a
Contamination	EN12662	mg/kg	3
Ash, 775°C	ENISO6245	wt-%	<0,001
Aniline point	ISO2977	°C	96,3
Cetane index	ENISO4264		>56,5
Micro Carbon Residue 10% bottom	ENISO10370	wt-%	<0,01
Acidity Total (TAN)	ASTMD3242	mg KOH/g	0,001
Monoaromatics	EN12916	wt-%	0,2
Diaromatics	EN12916	wt-%	<0,1
Tri+-aromatics	EN12916	wt-%	<0,10
Polyaromatics	EN12916	wt-%	<0,1
Aromatics	EN12916	wt-%	0,2
Gross heat of comb. calor.	ASTMD4809	MJ/kg	47,169
Oxidation stability	ENISO12205	g/m3	24
Carbon, C	ASTMD5291	wt-%	84,5
Hydrogen	ASTMD5291	wt-%	15,1
High Frequency Reciprocating Rig	ENISO12156-1	µm/60°C	341
Cetane Number by IQT-analyser	ASTMD6890		77,0
Distillation IBP	ENISO3405	°C	186,8
Distillation 5 vol-%	ENISO3405	°C	237,8
Distillation 10 vol-%	ENISO3405	°C	254,6
Distillation 20 vol-%	ENISO3405	°C	267,0
Distillation 30 vol-%	ENISO3405	°C	272,2
Distillation 40 vol-%	ENISO3405	°C	275,2
Distillation 50 vol-%	ENISO3405	°C	277,4
Distillation 60 vol-%	ENISO3405	°C	279,8
Distillation 70 vol-%	ENISO3405	°C	282,2
Distillation 80 vol-%	ENISO3405	°C	285,3
Distillation 90 vol-%	ENISO3405	°C	289,7
Distillation 95 vol-%	ENISO3405	°C	293,9
Distillation FBP	ENISO3405	°C	302,1
Distillation Recovery	ENISO3405	vol-%	97,7
Distillation Residue	ENISO3405	vol-%	2,3

Diesel fuel: GTL

Analysis	Unit	Method	Result	Uncertainty
Density at 15°C	kg/m3	*SS-EN-ISO 12185-96	802,4	0,35
Aromatics	%mass	EN 12916-2000	<0,5	
Polyaromatics di and higher			<0,1	
Ash	%mass	*SS-EN-ISO 6245-2003	<0,001	0,0057
Carbon Residue on 10% residue	%mass	EN-ISO 10370-96	<0,03	0,041
Cetane index		*EN-ISO 4264	66,7	2,67
Cetane Number		*SS-EN-ISO 5165-98	52,2	
DFPP	°C	*EN 116-98	<-35	
Cloud Point	°C	SS-EN 23015-94m	<-35	
Copper corrosion 3h at 50°C		*EN-ISO 2160-98	1A	
Distillation		*EN-ISO 3405-11		
Recovered at 180°C	%vol			
Recovered at 250°C	%vol		43,6	
Recovered at 350°C	%vol		95,4	
95% Recovered at	°C		345,6	
Flash point (proc. A)	°C	*EN-ISO 2719-2002	97,0	3,00
Lubricating property at 60°C		EN-ISO 12156-00		
Wear scar diam. WS1.4 corr.	µm		262	
Fatty Acid Methylester (FAME)	%vol	SS-EN 14078:2004	<0,05	
Oxidation Stability	g/m3	SS-EN-ISO 12205-96	5	3,8
Total contamination	mg/kg	EN 12662/98	1	1,70
Sulphur content	mg/kg	*EN-ISO 20846-2011	<3,0	0,70
Viscosity at 40°C	mm3/s	*ASTM D7042-12	2,975	
Water Karl Fischer	mg/kg	EN-ISO 12937-01	24	10,2

Diesel fuel specification: B100 (RME)

Properties	Results	Units	Ref. Test Methods
Acid value	0,11	mg KOH/g	EN 14104:2004
Cetane number	52,6		EN ISO 5165:1998
Cloud point	-6	°C	EN 23015:1994
Cold Filter Plugging Point	-14	°C	EN 116:1997/AC:1999
Cu strip corrosion (3h at 50°C)	1A		EN ISO 2160:1998
Density at 15°C	882,0	kg/m3	EN ISO 12185:96/C1:01
Diglyceride content	0,03	% m/m	EN 14105:2003
Ester content	98,4	% m/m	EN 14103:2004
Free glycerol	0,01	% m/m	EN 14105:2003
Group 1 metals (Na + K)	< 2,0	mg/kg	EN 14538:2006
Group 2 metals (Ca + Mg)	< 2,0	mg/kg	EN 14538:2006
Iodine value	111	g I/100g	EN 14111:2003
Linolenic acid methyl ester	10	% m/m	EN 14103:2004
Methanol content	0,11	% m/m	EN 14110:2004
Monoglyceride content	0,34	% m/m	EN 14105:2003
Oxidation stability at 110°C	8,0	hours	EN 15751:2009
Phosphorus content	< 1,0	mg/kg	EN 14107:2007
Polyunsaturated methyl esters	< 1,00	% m/m	--
Sulfated ash content	< 0,020	% m/m	ISO 3987:2004
Sulphur content	4	mg/kg	EN ISO 20884:2011
Total contamination	9	mg/kg	EN 12662:2008
Total glycerol	0,09	% m/m	EN 14105:2003
Triglyceride content	0,02	% m/m	EN 14105:2003
Use of CFPP additive - name	no		--
Use of oxidation stabiliser - name	no		--
Water content	153	mg/kg	EN ISO 12937:2000
Viscosity at 40°C	4,355	mm2/s	EN ISO 3104:96/AC:99

Results according to ISO 4259

Dynamometer power vs. engine power

The engine power was estimated by adding the integrated signals from measured acceleration force of the inertia used and the road load. No fan correction has been applied to the calculations. The positive portions of the power is integrated and used to calculate the total estimated work (kWh) during the test cycle. This figure is then used to calculate emissions in g/kWh.

Instead of measuring the torque and speed of the crank shaft of the engine or the torque shaft close to the engine the estimation of work is here based on the power transferred via the traction of the tyres to the surface of the dynamometer roll and absorbed by the dynamometer. This power constitutes of two parts:

- P_{road} which is the power needed to overcome the road load curve, i.e. $P_{road} = f(v)$ where v is the vehicle speed. The road load curve is the combination of frictional forces depending of road surface, tyres and vehicle load and vehicle air drag that the dynamometer is set to simulate. The road load is the sum of resistances when rolling the vehicle at constant speed on a straight and levelled road at 20°C and without metrological wind. When setting the dynamometer, the internal power absorption unit of the dynamometer is tuned to simulate the requested $P_{road} = f(v)$ when the vehicle is run on the dynamometer with warm tyres. In reality this means that the internal power absorption usually is negative, i.e. power is transferred to the system at vehicle speeds below about 40 to 50 km/h (due to the high frictional forces of the tyres running on the dynamometer roll compared to running on a road). Only at vehicle speeds higher than this speed interval the internal power absorption actually absorbs power.

- $P_{inertia}$ which is the power needed to accelerate and decelerate the rotational inertia in the system. Apart from the simulated road load, the simulated vehicle mass or the vehicle inertia is crucial for the transient chassis testing. This power is simply the $P_{inertia} = dv/dt * m * v$, i.e. the measured acceleration of the system measured as the change in dynamometer roll speed times the simulated vehicle mass times the roll speed.

- So, the sum of $P_{road} + P_{inertia}$ is a measure of the instantaneous power transferred to the system. This power originates from the engine and is transferred via the gearbox through the drive shaft and rear axis and wheels to the surface of the dynamometer roll. In cases of retardation in the test cycle, either the engine is motoring or the exhaust brake or the wheel brakes are used. In those cases the sum of $P_{road} + P_{inertia}$ may become negative, i. e. power is transferred from the dynamometer system to the vehicle. All such portions should of cause not be included when integrating the work performed by the engine. Only events when the sum $(P_{road} + P_{inertia})$ is positive must be included in the integrated work.

- The boundary between the dynamometer system and the engine goes at the outgoing axis from the vehicle gear box, because this axis and the downstream drive train is included when road load setting is done for the vehicle. Going upstream from the outgoing axis of the gearbox will add also the frictional losses of the gearbox itself to the calculated number so far. Further on, when comparing to the power definition of the engine applied at engine bench test, specifically regarding the auxiliaries, where there should be no cooling fan fitted

at test (or a fan running on maximum slip if the fan is of the proportional type). But running the vehicle on a chassis dynamometer comprises also the vehicle cooling fan which in turn also absorbs power originating from the engine.

The resulting used formula for calculating the work is the following:

$$\text{engine work} = \int [(P_{inerta} + P_{road} + P_{drivtrain} + P_{gearbox} + P_{fan}) + abs(P_{inerta} + P_{road} + P_{drivtrain} + P_{gearbox} + P_{fan})] / 2$$

where

$P_{inerta} + P_{road}$ is measured and explained as above
$P_{drivtrain}$ is the eventual difference in drivetrain frictional forces depending on the transferred torque (only the “idle” frictional forces are included in the road load figure)
$P_{gearbox}$ corresponds to the frictional losses in the gearbox (depending on used gear ratio)
P_{fan} corresponds to the power absorbed by the cooling fan during the chassis test

The trick in the formula to add the sums of power two times and divide the sum by 2 is made to eliminate the negative portions of sums from the integrated work. This is archived by the abs-function of the second sum.

This way to calculate the power also assumes that the P_{road} is unambiguously consistent throughout chassis test series. This may not be the case. Probably there is a considerate influence on P_{road} by temperature depending system friction such as those caused by the tyres and hence the instantaneous tyre temperature.

In our case we have chosen to approximate the $P_{drivtrain}$, $P_{gearbox}$ and P_{fan} to zero. So instead of being the work delivered by the engine, it is instead more or less the work delivered at the outgoing axis of the gear box. So the engine work defined according to the engine test methods regarding auxiliaries is most likely to be slightly underestimated by this calculation method.

B7 50% load: PAH filter phase

Unit: ng/km	B7 50% load	B7 50% load	B7 50% load
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	423,3	297,5	267,5
Anthracene	63,0	29,6	31,8
3-Methylphenanthrene	42,1	41,0	35,6
2-Methylphenanthrene	55,4	48,2	44,1
2-Methylanthracene	12,3	6,4	6,1
9-Methylphenanthrene	47,4	42,5	40,2
1-Methylphenanthrene	45,7	34,3	30,6
4H-cyclopenta(def)phenanthrene	20,2	8,9	7,3
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	42,4	22,2	21,5
3,6-Dimethylphenanthrene	0,0	3,8	3,4
3,9-Dimethylphenanthrene	27,9	35,2	35,0
Fluoranthene	178,6	85,6	76,9
Pyrene	211,8	90,5	83,9
9,10-Dimethylanthracene	79,5	69,2	67,8
1-Methylfluoranthene	18,8	6,4	6,0
Benz(a)fluorene	12,6	4,4	3,7
Benz(b)fluorene	8,1	2,4	5,8
2-Methylpyrene	11,9	5,3	4,0
4-Methylpyrene	14,7	6,0	5,2
1-Methylpyrene	18,8	5,6	0,0
Benzo(ghi)fluoranthene	83,9	30,2	28,5
Benzo(c)phenanthrene	5,2	4,4	2,4
Benzo(b)naphto(1,2-d)thiop	0,0	0,0	0,0
Cyclopenta(cd)pyrene	96,4	43,7	38,5
Benz(a)anthracene	89,4	31,7	29,8
Chrysene	121,5	48,0	44,0
3-Methylchrysene	2,1	0,0	0,0
2-Methylchrysene	7,7	5,9	5,3
6-Methylchrysene	5,5	0,0	0,0
1-Methylchrysene	15,8	5,4	0,0
Benzo(b)fluoranthene	79,7	32,9	31,3
Benzo(k)fluoranthene	39,4	16,2	16,4
Benzo(e)pyrene	79,1	29,4	28,1
Benzo(a)pyrene	94,7	45,8	42,9
Perylene	13,8	6,1	5,8
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	0,0
Indeno(1,2,3-cd)pyrene	34,7	24,3	20,5
Dibenz(a,h)anthracene	0,0	3,6	3,5
Picene	5,4	2,9	2,7
Benzo(ghi)perylene	54,6	38,2	33,1
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,0	0,5	3,2
Coronene	11,3	12,1	11,5
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
Sum PAH ng/km	2175,1	1226,7	1124,1

B7 50% load: PAH semivolatile phase

Unit: ng/km	B7 50% load	B7 50% load	B7 50% load
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	49,4	31,7	49,1
Anthracene	9,0	4,3	6,7
3-Methylphenanthrene	5,6	5,0	6,8
2-Methylphenanthrene	5,2	5,3	6,2
2-Methylanthracene	0,0	1,1	1,8
9-Methylphenanthrene	5,5	5,1	5,8
1-Methylphenanthrene	5,2	5,1	6,4
4H-cyclopenta(def)phenanthrene	2,2	1,1	1,7
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	3,0	1,9	2,2
3,6-Dimethylphenanthrene	0,0	0,0	0,0
3,9-Dimethylphenanthrene	0,0	0,0	0,0
Fluoranthene	9,5	6,0	8,7
Pyrene	9,9	8,7	9,6
9,10-Dimethylanthracene	0,0	0,0	0,0
1-Methylfluoranthene	0,0	0,0	0,0
Benz(a)fluorene	0,0	0,0	0,0
Benz(b)fluorene	0,0	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	0,0	0,0	0,0
1-Methylpyrene	0,0	0,0	0,0
Benzo(ghi)fluoranthene	0,0	0,0	0,5
Benzo(c)phenanthrene	30,6	36,6	88,1
Benzo(b)naphto(1,2-d)thiop	0,0	0,0	0,0
Cyclopenta(cd)pyrene	0,0	0,0	0,0
Benz(a)anthracene	0,0	0,0	0,0
Chrysene	0,0	0,0	0,0
3-Methylchrysene	0,0	0,0	0,0
2-Methylchrysene	0,0	0,0	0,0
6-Methylchrysene	0,0	0,0	0,0
1-Methylchrysene	0,0	0,0	0,1
Benzo(b)fluoranthene	0,0	0,0	0,0
Benzo(k)fluoranthene	0,0	0,0	0,0
Benzo(e)pyrene	0,0	0,0	0,0
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	0,0	0,0
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	0,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,1	0,4	0,1
Benzo(ghi)perylene	0,0	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,4	0,4	0,3
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	135,6	112,7	194,2

B7 + HVO30: PAH filter phase

Unit: ng/km	B7 + HVO30	B7 + HVO30	B7 + HVO30
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	437,5	324,0	195,5
Anthracene	69,7	79,4	22,6
3-Methylphenanthrene	40,1	212,3	19,3
2-Methylphenanthrene	50,1	249,5	24,3
2-Methylanthracene	13,5	68,1	5,9
9-Methylphenanthrene	39,4	278,1	20,8
1-Methylphenanthrene	43,1	245,8	19,4
4H-cyclopenta(def)phenanthrene	22,7	52,5	7,6
9-Methylanthracene	7,0	0,0	0,0
2-Phenylnaphthalene	44,3	16,6	16,9
3,6-Dimethylphenanthrene	4,3	3,6	2,1
3,9-Dimethylphenanthrene	34,0	34,7	18,9
Fluoranthene	173,1	73,5	62,8
Pyrene	212,7	92,1	68,7
9,10-Dimethylanthracene	65,2	70,4	34,9
1-Methylfluoranthene	16,1	10,7	4,6
Benz(a)fluorene	11,3	7,1	3,1
Benz(b)fluorene	8,0	5,0	3,9
2-Methylpyrene	9,3	7,3	2,9
4-Methylpyrene	12,9	9,8	3,4
1-Methylpyrene	17,8	10,6	3,7
Benzo(ghi)fluoranthene	75,0	25,8	20,8
Benzo(c)phenanthrene	16,6	4,8	4,2
Benzo(b)naphto(1,2-d)thiop	2,3	0,7	0,0
Cyclopenta(cd)pyrene	129,2	40,5	38,7
Benz(a)anthracene	77,8	36,1	26,3
Chrysene	99,3	44,9	33,8
3-Methylchrysene	1,8	1,4	0,7
2-Methylchrysene	7,1	3,0	2,4
6-Methylchrysene	4,9	2,4	1,6
1-Methylchrysene	14,1	1,8	3,9
Benzo(b)fluoranthene	60,3	35,8	25,7
Benzo(k)fluoranthene	29,6	18,8	13,2
Benzo(e)pyrene	58,9	27,5	22,3
Benzo(a)pyrene	84,6	50,8	43,8
Perylene	12,4	6,3	5,7
Indeno(1,2,3-cd)fluoranthe	0,0	1,7	2,4
Indeno(1,2,3-cd)pyrene	29,5	26,8	29,4
Dibenz(a,h)anthracene	4,6	4,5	0,0
Picene	4,1	3,2	0,2
Benzo(ghi)perylene	51,1	38,0	43,4
Dibenzo(a,l)pyrene	0,0	1,1	0,0
Dibenzo(a,e)pyrene	0,4	2,8	4,6
Coronene	0,3	10,4	19,7
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
Sum PAH ng/km	2095,9	2240,5	884,0

B7 + HVO30: PAH semivolatile phase

Unit: ng/km	B7 + HVO30	B7 + HVO30	B7 + HVO30
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	38,9	63,0	20,0
Anthracene	4,1	6,5	5,9
3-Methylphenanthrene	4,9	11,8	2,8
2-Methylphenanthrene	5,2	11,2	2,7
2-Methylanthracene	1,0	1,9	0,3
9-Methylphenanthrene	4,5	0,0	2,5
1-Methylphenanthrene	4,2	0,0	2,4
4H-cyclopenta(def)phenanthrene	1,6	2,9	0,7
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	2,4	4,2	1,4
3,6-Dimethylphenanthrene	0,0	0,0	0,0
3,9-Dimethylphenanthrene	0,0	0,0	0,0
Fluoranthene	6,3	11,4	5,0
Pyrene	7,9	11,1	4,4
9,10-Dimethylanthracene	0,0	0,0	0,0
1-Methylfluoranthene	0,0	0,0	0,0
Benz(a)fluorene	0,0	0,0	0,0
Benz(b)fluorene	0,0	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	0,0	0,0	0,0
1-Methylpyrene	0,0	0,0	0,0
Benzo(ghi)fluoranthene	0,0	0,0	0,6
Benzo(c)phenanthrene	65,4	82,1	813,9
Benzo(b)naphto(1,2-d)thiop	0,0	0,0	0,0
Cyclopenta(cd)pyrene	0,0	0,0	0,0
Benz(a)anthracene	0,0	0,0	0,0
Chrysene	0,0	0,0	2,6
3-Methylchrysene	0,0	0,0	0,0
2-Methylchrysene	0,0	0,0	0,0
6-Methylchrysene	0,1	0,0	0,0
1-Methylchrysene	0,0	0,0	0,0
Benzo(b)fluoranthene	0,0	0,0	0,1
Benzo(k)fluoranthene	0,0	0,0	2,8
Benzo(e)pyrene	0,0	0,0	0,0
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	0,0	0,0
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	0,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,1	0,0	0,0
Benzo(ghi)perylene	0,0	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,1	0,3	0,2
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	146,7	206,4	868,3

HVO100: PAH filter phase

Unit: ng/km	HVO100	HVO100	HVO100
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	456,5	122,2	233,2
Anthracene	48,2	12,7	24,8
3-Methylphenanthrene	36,5	11,3	29,4
2-Methylphenanthrene	46,1	12,6	35,9
2-Methylanthracene	10,7	2,9	5,8
9-Methylphenanthrene	36,6	12,7	31,5
1-Methylphenanthrene	36,3	9,9	27,3
4H-cyclopenta(def)phenanthrene	22,9	4,9	9,8
9-Methylanthracene	0,0	0,0	5,2
2-Phenylnaphthalene	37,0	8,0	21,9
3,6-Dimethylphenanthrene	3,7	1,3	2,8
3,9-Dimethylphenanthrene	30,9	10,6	24,8
Fluoranthene	160,4	33,4	78,2
Pyrene	199,1	34,8	87,8
9,10-Dimethylanthracene	0,0	17,5	51,3
1-Methylfluoranthene	13,7	2,1	6,4
Benz(a)fluorene	10,1	1,1	4,0
Benz(b)fluorene	7,7	0,6	2,7
2-Methylpyrene	8,2	1,4	3,6
4-Methylpyrene	10,0	1,5	4,7
1-Methylpyrene	13,5	1,5	5,3
Benzo(ghi)fluoranthene	63,7	10,6	24,3
Benzo(c)phenanthrene	25,1	2,0	5,5
Benzo(b)naphto(1,2-d)thiop	0,0	0,0	0,8
Cyclopenta(cd)pyrene	109,5	16,9	44,5
Benz(a)anthracene	63,4	8,5	26,3
Chrysene	97,6	16,4	38,0
3-Methylchrysene	2,2	0,2	0,8
2-Methylchrysene	6,2	0,8	2,5
6-Methylchrysene	4,2	0,5	1,6
1-Methylchrysene	10,4	2,0	1,6
Benzo(b)fluoranthene	54,9	8,7	30,8
Benzo(k)fluoranthene	29,6	4,3	14,7
Benzo(e)pyrene	53,9	8,3	26,7
Benzo(a)pyrene	63,2	12,6	45,3
Perylene	10,0	1,9	5,6
Indeno(1,2,3-cd)fluoranthe	2,2	0,6	1,6
Indeno(1,2,3-cd)pyrene	30,6	7,0	26,3
Dibenz(a,h)anthracene	4,4	0,0	3,3
Picene	4,1	1,3	2,2
Benzo(ghi)perylene	49,1	12,5	45,5
Dibenzo(a,l)pyrene	0,0	0,0	0,9
Dibenzo(a,e)pyrene	2,8	0,1	2,4
Coronene	15,3	4,9	14,2
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
Sum PAH ng/km	1890,4	423,3	1061,8

HVO100: PAH semivolatile phase

Unit: ng/km	HVO100	HVO100	HVO100
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	37,3	18,0	37,7
Anthracene	4,4	1,6	5,0
3-Methylphenanthrene	4,7	2,7	5,4
2-Methylphenanthrene	4,4	2,6	5,0
2-Methylanthracene	0,8	0,1	0,9
9-Methylphenanthrene	4,6	2,4	4,7
1-Methylphenanthrene	2,3	1,8	3,7
4H-cyclopenta(def)phenanthrene	1,7	0,8	1,8
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	2,3	1,4	3,6
3,6-Dimethylphenanthrene	0,0	0,0	0,0
3,9-Dimethylphenanthrene	0,0	0,0	0,0
Fluoranthene	7,8	5,4	13,2
Pyrene	7,9	5,1	11,3
9,10-Dimethylanthracene	0,0	0,0	0,0
1-Methylfluoranthene	0,0	0,0	0,0
Benz(a)fluorene	0,0	0,0	0,0
Benz(b)fluorene	0,0	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	0,0	0,0	0,0
1-Methylpyrene	0,0	0,0	0,0
Benzo(ghi)fluoranthene	1,0	0,4	0,5
Benzo(c)phenanthrene	2605,3	195,0	170,6
Benzo(b)naphto(1,2-d)thiop	0,0	0,0	0,0
Cyclopenta(cd)pyrene	8,4	0,0	0,0
Benz(a)anthracene	0,0	0,0	0,0
Chrysene	5,1	1,5	0,0
3-Methylchrysene	24,2	0,0	0,0
2-Methylchrysene	0,0	0,0	0,0
6-Methylchrysene	0,0	0,0	0,0
1-Methylchrysene	0,0	0,0	0,0
Benzo(b)fluoranthene	0,3	0,0	0,0
Benzo(k)fluoranthene	0,2	0,0	0,0
Benzo(e)pyrene	0,0	0,1	0,5
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	0,0	0,0
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	0,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,1	0,1	0,2
Benzo(ghi)perylene	0,0	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,2	0,0	1,0
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	2723,0	239,1	265,2

GTL: PAH filter phase

Unit: ng/km	GTL	GTL	GTL
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	330,6	297,3	115,3
Anthracene	42,5	34,8	16,0
3-Methylphenanthrene	33,6	29,5	11,1
2-Methylphenanthrene	41,6	35,4	13,7
2-Methylanthracene	6,4	4,4	2,6
9-Methylphenanthrene	34,5	31,7	12,5
1-Methylphenanthrene	31,6	25,9	10,2
4H-cyclopenta(def)phenanthrene	18,1	9,4	3,9
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	37,9	24,0	10,3
3,6-Dimethylphenanthrene	2,6	2,9	1,2
3,9-Dimethylphenanthrene	24,1	24,6	9,2
Fluoranthene	133,7	85,3	36,5
Pyrene	157,7	95,8	43,7
9,10-Dimethylanthracene	49,6	44,5	16,3
1-Methylfluoranthene	12,9	6,3	2,9
Benz(a)fluorene	8,8	4,1	2,0
Benz(b)fluorene	5,9	2,9	1,4
2-Methylpyrene	6,2	4,2	1,9
4-Methylpyrene	8,3	4,9	2,3
1-Methylpyrene	11,2	5,6	2,8
Benzo(ghi)fluoranthene	47,5	35,1	13,9
Benzo(c)phenanthrene	13,9	10,4	3,3
Benzo(b)naphto(1,2-d)thiop	1,3	1,0	0,5
Cyclopenta(cd)pyrene	77,7	53,3	27,7
Benz(a)anthracene	51,4	35,1	18,1
Chrysene	64,7	50,0	24,8
3-Methylchrysene	5,7	0,0	0,5
2-Methylchrysene	6,0	0,0	1,6
6-Methylchrysene	0,0	0,0	1,1
1-Methylchrysene	3,1	0,0	3,1
Benzo(b)fluoranthene	44,6	35,8	19,2
Benzo(k)fluoranthene	22,1	17,3	10,0
Benzo(e)pyrene	39,8	33,1	18,0
Benzo(a)pyrene	63,2	51,2	28,1
Perylene	9,3	7,3	3,9
Indeno(1,2,3-cd)fluoranthe	1,8	1,8	1,0
Indeno(1,2,3-cd)pyrene	22,1	24,6	13,3
Dibenz(a,h)anthracene	3,7	3,7	1,8
Picene	2,5	2,7	1,4
Benzo(ghi)perylene	35,8	43,0	23,5
Dibenzo(a,l)pyrene	1,2	1,3	0,8
Dibenzo(a,e)pyrene	2,2	3,9	2,0
Coronene	7,4	15,0	7,2
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
Sum PAH ng/km	1524,8	1198,9	540,6

GTL: PAH semivolatile phase

Unit: ng/km	GTL	GTL	GTL
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	78,7	45,6	20,6
Anthracene	7,4	3,1	1,8
3-Methylphenanthrene	10,5	5,8	2,4
2-Methylphenanthrene	12,2	6,3	2,8
2-Methylanthracene	1,6	0,8	0,6
9-Methylphenanthrene	11,7	5,2	2,2
1-Methylphenanthrene	11,3	4,1	2,0
4H-cyclopenta(def)phenanthrene	3,5	1,6	1,1
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	5,0	2,5	1,5
3,6-Dimethylphenanthrene	0,0	0,0	0,0
3,9-Dimethylphenanthrene	0,0	0,0	0,0
Fluoranthene	17,9	8,0	5,3
Pyrene	16,1	6,8	4,4
9,10-Dimethylanthracene	0,0	0,0	0,0
1-Methylfluoranthene	0,0	0,0	0,0
Benz(a)fluorene	0,0	0,0	0,0
Benz(b)fluorene	0,3	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	0,0	0,0	0,3
1-Methylpyrene	0,0	0,0	2,4
Benzo(ghi)fluoranthene	0,0	0,0	0,0
Benzo(c)phenanthrene	43,8	26,8	64,9
Benzo(b)naphto(1,2-d)thiop	0,0	0,1	0,2
Cyclopenta(cd)pyrene	0,0	0,0	0,0
Benz(a)anthracene	0,0	0,0	0,0
Chrysene	0,0	2,6	3,5
3-Methylchrysene	0,0	0,0	3,1
2-Methylchrysene	0,0	0,0	0,0
6-Methylchrysene	0,0	0,0	0,0
1-Methylchrysene	0,0	9,0	0,2
Benzo(b)fluoranthene	0,0	6,5	0,0
Benzo(k)fluoranthene	0,0	0,0	0,0
Benzo(e)pyrene	0,0	0,4	0,8
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	0,0	5,8
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	2,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,2	0,0	0,1
Benzo(ghi)perylene	0,0	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,9	0,1	0,2
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	221,2	135,3	127,9

B100: PAH filter phase

Unit: ng/km	B100	B100	B100
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	123,9	129,8	91,0
Anthracene	76,8	14,0	87,2
3-Methylphenanthrene	13,7	19,7	15,8
2-Methylphenanthrene	16,9	25,1	21,2
2-Methylanthracene	2,4	2,2	16,2
9-Methylphenanthrene	15,2	23,1	19,1
1-Methylphenanthrene	12,9	17,5	15,5
4H-cyclopenta(def)phenanthrene	7,4	3,9	3,9
9-Methylanthracene	1,4	0,0	0,0
2-Phenylnaphthalene	14,5	10,9	13,6
3,6-Dimethylphenanthrene	1,7	2,0	1,7
3,9-Dimethylphenanthrene	13,7	16,4	17,8
Fluoranthene	55,1	38,3	41,5
Pyrene	62,7	39,7	42,5
9,10-Dimethylanthracene	25,3	31,3	32,7
1-Methylfluoranthene	4,5	2,5	2,7
Benz(a)fluorene	3,3	1,6	2,0
Benz(b)fluorene	2,4	0,8	1,1
2-Methylpyrene	2,4	1,7	1,9
4-Methylpyrene	3,2	2,0	2,0
1-Methylpyrene	5,1	2,3	2,3
Benzo(ghi)fluoranthene	19,9	9,8	12,2
Benzo(c)phenanthrene	3,7	10,5	119,8
Benzo(b)naphto(1,2-d)thiop	0,5	0,3	0,3
Cyclopenta(cd)pyrene	40,3	14,4	22,8
Benz(a)anthracene	18,5	13,0	14,9
Chrysene	27,4	19,9	23,3
3-Methylchrysene	0,5	0,3	0,4
2-Methylchrysene	1,5	0,9	1,1
6-Methylchrysene	1,2	1,0	1,2
1-Methylchrysene	5,6	1,1	2,1
Benzo(b)fluoranthene	20,0	13,8	17,1
Benzo(k)fluoranthene	9,9	7,5	9,0
Benzo(e)pyrene	20,2	11,8	15,2
Benzo(a)pyrene	31,1	23,5	30,6
Perylene	4,3	3,0	3,9
Indeno(1,2,3-cd)fluoranthe	1,3	1,7	2,3
Indeno(1,2,3-cd)pyrene	17,2	22,0	29,3
Dibenz(a,h)anthracene	2,2	2,9	3,5
Picene	1,4	2,2	2,5
Benzo(ghi)perylene	28,9	28,2	40,4
Dibenzo(a,l)pyrene	0,6	0,5	0,8
Dibenzo(a,e)pyrene	1,2	4,1	5,7
Coronene	15,4	24,6	34,3
Dibenzo(a,i)pyrene	0,0	1,4	1,9
Dibenzo(a,h)pyrene	0,0	1,1	1,6
Sum PAH ng/km	737,6	604,3	828,0

B100: PAH semivolatile phase

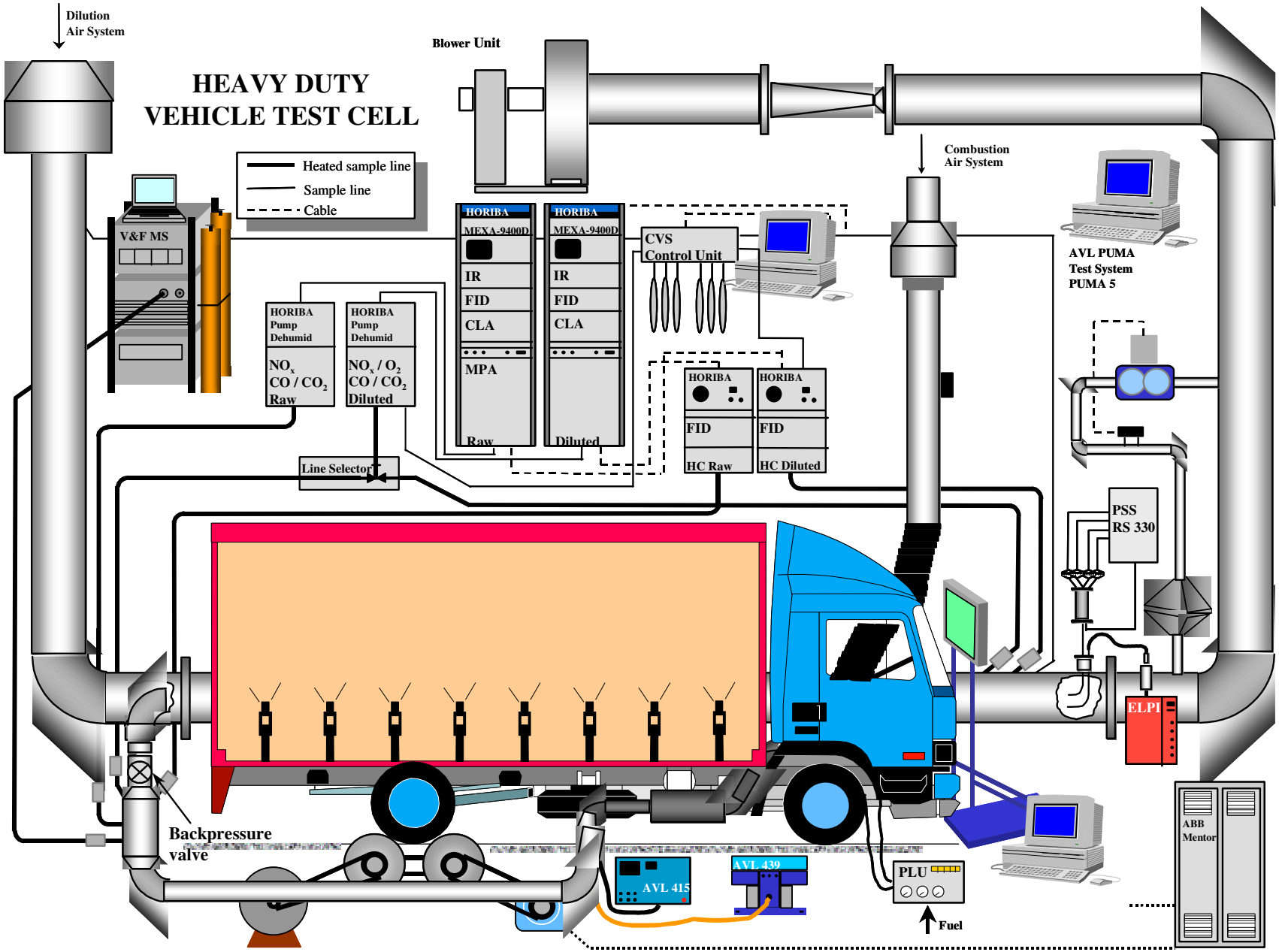
Unit: ng/km	B100	B100	B100
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	49,1	90,8	78,0
Anthracene	6,7	8,4	7,3
3-Methylphenanthrene	6,8	7,8	5,3
2-Methylphenanthrene	6,2	7,8	4,7
2-Methylanthracene	1,8	1,4	1,0
9-Methylphenanthrene	5,8	8,8	5,7
1-Methylphenanthrene	6,4	5,8	3,9
4H-cyclopenta(def)phenanthrene	1,7	3,0	2,4
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	2,2	2,3	1,5
3,6-Dimethylphenanthrene	0,0	0,0	0,0
3,9-Dimethylphenanthrene	0,0	6,9	0,0
Fluoranthene	8,7	7,9	4,3
Pyrene	9,6	11,1	13,2
9,10-Dimethylanthracene	0,0	22,1	0,0
1-Methylfluoranthene	0,0	0,0	0,0
Benz(a)fluorene	0,0	0,0	0,0
Benz(b)fluorene	0,0	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	0,0	0,0	0,0
1-Methylpyrene	0,0	0,0	0,0
Benzo(ghi)fluoranthene	0,5	0,4	0,4
Benzo(c)phenanthrene	88,1	0,4	345,3
Benzo(b)naphto(1,2-d)thiop	0,0	1,1	0,1
Cyclopenta(cd)pyrene	0,0	0,6	0,1
Benz(a)anthracene	0,0	0,0	0,0
Chrysene	0,0	2,5	3,0
3-Methylchrysene	0,0	2,1	0,1
2-Methylchrysene	0,0	1,1	0,0
6-Methylchrysene	0,0	0,0	0,0
1-Methylchrysene	0,1	0,2	0,1
Benzo(b)fluoranthene	0,0	7,0	0,0
Benzo(k)fluoranthene	0,0	7,1	0,0
Benzo(e)pyrene	0,0	0,5	0,0
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	6,7	0,0
Indeno(1,2,3-cd)fluoranthe	0,0	2,9	0,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,1	0,1	0,1
Benzo(ghi)perylene	0,0	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,3	0,1	0,1
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	194,2	216,9	476,6

ED95: PAH filter phase

Unit: ng/km	ED95	ED95	ED95
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	39,1	52,0	74,2
Anthracene	5,2	7,8	7,4
3-Methylphenanthrene	9,3	9,4	10,8
2-Methylphenanthrene	10,8	11,3	14,7
2-Methylanthracene	1,6	1,3	1,2
9-Methylphenanthrene	7,2	10,1	10,8
1-Methylphenanthrene	7,5	9,5	8,6
4H-cyclopenta(def)phenanthrene	4,6	2,5	4,0
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	10,7	3,7	7,8
3,6-Dimethylphenanthrene	2,3	1,4	1,6
3,9-Dimethylphenanthrene	10,8	6,3	10,3
Fluoranthene	68,6	39,4	70,3
Pyrene	91,5	50,8	87,9
9,10-Dimethylanthracene	28,3	18,5	34,3
1-Methylfluoranthene	5,9	3,4	6,6
Benz(a)fluorene	5,4	2,3	3,5
Benz(b)fluorene	3,9	1,1	1,5
2-Methylpyrene	3,7	2,6	4,3
4-Methylpyrene	4,8	2,9	4,7
1-Methylpyrene	4,4	2,3	3,1
Benzo(ghi)fluoranthene	36,5	8,2	10,9
Benzo(c)phenanthrene	21,6	2,7	23,2
Benzo(b)naphto(1,2-d)thiop	0,9	0,5	0,5
Cyclopenta(cd)pyrene	30,5	11,9	14,9
Benz(a)anthracene	28,7	8,4	7,8
Chrysene	52,2	17,6	18,1
3-Methylchrysene	1,1	0,5	0,5
2-Methylchrysene	2,6	1,2	1,1
6-Methylchrysene	1,6	1,0	1,3
1-Methylchrysene	1,6	0,9	1,0
Benzo(b)fluoranthene	40,7	13,8	15,4
Benzo(k)fluoranthene	20,8	6,2	6,6
Benzo(e)pyrene	62,4	16,2	18,4
Benzo(a)pyrene	40,3	16,4	21,0
Perylene	7,4	2,9	3,4
Indeno(1,2,3-cd)fluoranthe	2,3	0,9	1,5
Indeno(1,2,3-cd)pyrene	64,2	17,5	28,6
Dibenz(a,h)anthracene	4,3	1,6	2,2
Picene	2,7	1,4	1,7
Benzo(ghi)perylene	311,6	74,7	121,8
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	4,6	2,3	3,2
Coronene	694,7	185,9	297,5
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
Sum PAH ng/km	1758,4	631,3	968,1

ED95: PAH semivolatile phase

Unit: ng/km	ED95	ED95	ED95
Driving cycle: WHVC	Cold start	Hot start 1	Hot start 2
0 = < 0,1			
Phenanthrene	246,8	127,4	123,3
Anthracene	9,8	8,2	6,9
3-Methylphenanthrene	24,2	12,1	10,8
2-Methylphenanthrene	27,4	12,7	11,8
2-Methylanthracene	2,6	1,2	1,2
9-Methylphenanthrene	23,9	10,4	9,9
1-Methylphenanthrene	21,9	10,9	9,7
4H-cyclopenta(def)phenanthrene	26,9	7,9	8,5
9-Methylanthracene	0,0	0,0	0,0
2-Phenylnaphthalene	12,9	8,0	7,2
3,6-Dimethylphenanthrene	3,2	0,0	0,0
3,9-Dimethylphenanthrene	15,6	7,5	6,9
Fluoranthene	91,5	20,3	21,7
Pyrene	163,5	20,2	22,5
9,10-Dimethylanthracene	49,7	21,8	20,2
1-Methylfluoranthene	2,8	0,0	0,0
Benz(a)fluorene	1,3	0,0	0,0
Benz(b)fluorene	0,0	0,0	0,0
2-Methylpyrene	0,0	0,0	0,0
4-Methylpyrene	4,1	0,0	0,0
1-Methylpyrene	2,6	0,0	0,0
Benzo(ghi)fluoranthene	6,0	0,0	0,7
Benzo(c)phenanthrene	17,2	26,3	9,7
Benzo(b)naphto(1,2-d)thiop	0,4	0,2	0,3
Cyclopenta(cd)pyrene	3,3	0,0	0,0
Benz(a)anthracene	0,0	0,0	0,2
Chrysene	1,9	1,7	1,7
3-Methylchrysene	0,0	1,4	0,0
2-Methylchrysene	0,0	0,0	0,0
6-Methylchrysene	0,0	0,0	0,0
1-Methylchrysene	0,2	0,2	0,0
Benzo(b)fluoranthene	0,1	0,0	1,4
Benzo(k)fluoranthene	3,3	0,0	2,6
Benzo(e)pyrene	0,3	0,3	0,3
Benzo(a)pyrene	0,0	0,0	0,0
Perylene	0,0	0,0	0,0
Indeno(1,2,3-cd)fluoranthe	0,0	0,0	0,0
Indeno(1,2,3-cd)pyrene	0,0	0,0	0,0
Dibenz(a,h)anthracene	0,0	0,0	0,0
Picene	0,0	0,1	0,1
Benzo(ghi)perylene	1,9	0,0	0,0
Dibenzo(a,l)pyrene	0,0	0,0	0,0
Dibenzo(a,e)pyrene	0,0	0,1	0,1
Coronene	0,0	0,0	0,0
Dibenzo(a,i)pyrene	0,0	0,0	0,0
Dibenzo(a,h)pyrene	0,0	0,0	0,0
SumPAH ng/km	765,6	298,8	277,7


Dilution
Air System
HEAVY DUTY
VEHICLE TEST CELL
Blower Unit
Heated sample line
Sample line
Cable
Combustion
Air System
V&F MS
HORIBA
MEXA-9400D
IR
FID
CLA
MPA
Raw
HORIBA
MEXA-9400D
IR
FID
CLA
Diluted
CVS
Control Unit
AVL PUMA
Test System
PUMA 5
HORIBA
Pump
Dehumid
NOx
CO / CO2
Raw
HORIBA
Pump
Dehumid
NOx / O2
CO / CO2
Diluted
HORIBA
FID
HC Raw
HORIBA
FID
HC Diluted
Line Selector
PSS
RS 330
ELPI
Backpressure
valve
AVL 415
AVL 439
PLU
Fuel
ABB
Mentor