Swedish In-Service Testing Program

On Emissions from Heavy-Duty Vehicles

Report for the Swedish Transport Agency

Certification & Regulation Compliance
AVL

#OMT2006
2012

Content

AVL MTC AB

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

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

List of Abbreviations

CFV	Critical Flow Venturi
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity Of Production
CVS	Constant Volume Sampling
ECU	Engine Control Unit
ED95	Ethanol Diesel
EEV	Environmentally Enhanced Vehicle
EGR	Exhaust Gas Recirculation
ESC	European Stationary Cycle
ETC	European Transient Cycle
FC	Fuel consumption
GTL	Gas To Liquid
HC	Total hydrocarbons (THC)
HDV/HC	Heavy Duty Vehicle/ Heavy Duty
HFID	Heated Flame Ionization Detector
IUC	In Use Compliance
JRC	Joint Research Centre
LDV/LD	Light Duty Vehicle/ Light Duty
MK1	Environmental class 1
NDIR	Non-Dispersive Infrared
NDUV	Non-Dispersive Ultraviolet
NO_2	Nitrogen dioxides
NOx	Nitrogen oxides
PASS	Photo-Acoustic principle
PEMS	Portable Emission Measurement System
PM	Particulate Matter
PN	Particulate Number
SCR	Selective Catalytic Reduction
SEPA	Swedish Environmental Protection Agency
SRA	Swedish Road Administration
STA	The Swedish Transport Agency
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle

Summary

AVL MTC AB has on the commission of The Swedish Transport Agency (STA) carried out The Swedish In-Service Testing Programme on Emissions from Heavy-Duty (HD) Vehicles. Thirteen vehicles have been tested on road in accordance with the PEMS (Portable Emission Measurement System) protocol which include urban, suburban, and highway driving. In addition six of these vehicles have also been tested on chassis dynamometer according to the Fige (chassis dynamometer version of European Transient Cycle (ETC)) and the WHVC (Worldwide Harmonized Vehicle Cycle, chassis dynamometer version of WHTC - Worldwide harmonized Transient Cycle). The selection of the vehicles was based on Euro III Euro IV and V standard.

The scope of the investigation was, beside in use compliance, to generate emission factors from commercial vehicles during a normal working day and representative driving. In addition aspects of retrofit system, alternative fuels and technologies, driving pattern, temperatures and loads were taken into consideration.

The vehicles are denoted A – M in this report.

Vehicle A was a garbage truck which was tested on road in the AVL MTC EURO V test route as well as a “start and stop” test route which represented typical driving for the particular vehicle. The vehicle was of euro standard V equipped with a SCR system and the fuel used during the tests was Mk1 diesel. Higher emissions where detected during the start/stop test procedure and the reason for this was most likely lower exhaust temperature during this test.

Vehicle B was a city bus which was tested on road in the AVL MTC EURO V test route as well as a bus route which represented typical driving for the particular vehicle. It was also tested on chassis dynamometer. The vehicle was of euro standard EEV equipped with a three-way catalytic converter and the fuel used during the tests was CNG. The overall impression of the vehicle emission performance was good and no mil light indicated exhaust after treatment failure.

Vehicle C was a distribution truck which was tested on road in a test route that represented a normal working day of the particular vehicle, with and without load, as well as on chassis dynamometer. The vehicle was of euro standard IV equipped with a SCR system and the fuel used during the tests was Mk1 diesel. The emissions where generally higher when tested on road compared to chassis dynamometer testing. Higher pay load and cold start where factors which caused increased emissions.

Vehicle D was a distribution truck which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. The vehicle was of euro standard V, equipped with a SCR system and the fuel used during the tests was Mk1 diesel. Due to lower exhaust temperatures in combination with a SCR system, the emissions where higher during urban driving compared to highway driving when the exhaust temperatures where higher.

Vehicle E was a distribution truck which was tested on road in a test route that represented a normal working day of the particular vehicle, with and without load, as well as on chassis dynamometer. The vehicle was of euro standard IV equipped with a EGR system and the fuel used during the tests was Mk1 diesel. The overall impression of the vehicle emission performance was good and no mil light indicated exhaust after treatment failure.

Vehicle F was a city bus equipped with a retrofitted SCRT system, which according to the supplier upgrades the Euro III vehicle to a vehicle of Euro V emission standard. The vehicle was tested was tested on road in a bus route which represented typical driving for the particular vehicle. The fuel used during the tests was Mk1 diesel. According to the test results, the retrofitted system did reduce the emissions as expected.

Vehicle G was a distribution truck with trailer which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. The vehicle was of

euro standard V, equipped with a SCR system and the fuel used during the tests was Mk1 diesel. The overall impression of the vehicle emission performance was good and no mil light indicated exhaust after treatment failure.

Vehicle H was a hybrid garbage truck which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. The vehicle was of euro standard V, equipped with a SCR system and the fuel used during the tests was Mk1 diesel. In the part of the test route which was characterized with many starts and stops, the NOx emissions exceeded the Euro V limit values.

Vehicle I was a tractor trailer truck which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. In addition, the vehicle was tested on chassis dynamometer. The vehicle was of euro standard EEV, equipped with an EGR system and the fuel used during the tests was ED95 (Ethanol). Cold start emissions where generally higher than warm start emissions but the overall impression of the vehicle emission performance was good and no mil light indicated exhaust after treatment failure.

Vehicle J was a city bus which was tested on road in the AVL MTC EURO V test route as well as a bus route which represented typical driving for the particular vehicle. The vehicle was of euro standard EEV equipped with a DOC and the fuel used during the tests was CNG. The overall impression of the vehicle emission performance was good and no mil light indicated exhaust after treatment failure.

Vehicle K was a long haul truck with a Diesel Dual Fuel (DDF) system which was tested on road in the AVL MTC EURO V test route as well as the manufacturers EURO VI route with two different pay loads. The vehicle was also tested on chassis dynamometer. During Dual Fuel operation, the vehicle operates with a continuously varying mixture of diesel (Mk1) and methane gas (LBG). The emissions of THC and CH_4 where above the Euro V emission limits, which was the Euro standard the vehicle was supposed to meet.

Vehicle L and M where two 75 tonnes heavy duty timber trucks which were tested on road in a test route that represented a normal working day of the particular vehicles and with different loads throughout the day. The vehicles were of euro standard IV, equipped with a SCR systems and the fuel used during the tests was Mk1 diesel. With regard to brake specific emissions (g/kWh) the emissions where below the Euro IV certification limit values.

Introduction

Sweden has been considered as for runner related to emission legislations and emission testing especially for light duty vehicles among European countries. The first emission legislation, the ECE R15, was introduced in 1971. However, decision makers did not feel comfortable with the European emission legislation and therefore Sweden introduced US federal requirements in 1975. Later, when Sweden became member of the European Union, the European regulation laid down as directive 70/220/EEC with later amendments was introduced. Together with the requirements at type approval for light duty vehicles (LDV), Sweden introduced Conformity of Production (COP) and In-use compliance testing (IUC) at a very early stage. In-use compliance testing of LDV's in normal operation and owned by private persons has been carried out by AVL MTC/MTC for more than 20 years. During the years more than 900 passenger cars and light duty trucks have been subjected to IUC testing.

The development of emission requirements for diesel fuelled engines to be used in HDV´s has not been as progressive as the ones for LDV´s. Emission requirements for type approval were introduced in Sweden by directive 88/77/EEC, but the regulation is only dealing with the engine itself and not the vehicle. Therefore, IUC testing has been a difficult task.

Historically, the responsible party for administration and implementation of emission requirements in Sweden has been the Swedish Environmental Protection Agency (SEPA) but gradually the responsibility has been transferred to the Swedish Road Administration (SRA). Since 2009 STA has the full responsibility for emissions from the transportation sector.

The emission laboratory operated by AVL MTC comprises several test cells with various capabilities and performance. One test cell is dedicated to test HDV's on a chassis dynamometer, several other test cells are dedicated to test diesel engines to be used in HDV's. IUC testing of HD engines/vehicles started as a research and development program in year 2000. The first phase of the program tried to establish correlation between vehicle testing and engine testing under stationary test conditions later also a significant number of tests was carried out under transient conditions. Later, correlation between chassis dynamometer tests and real life on-board measurement was investigated. Since year 2000 approximately 100 heavy duty engines/vehicles have been tested, and several hundreds of tests have been carried out. The results have been published in cases of public financing of projects. Based on experiences gained from testing, the focus for IUC tests of HDV's has gradually shifted towards on-board measurement. However, testing of HDV's by the use of a chassis dynamometer is still open as an alternative.

The STA has commissioned AVL MTC by a long term contract from year 2009 to perform in-service testing on HDV's operating on Swedish roads. This type of testing has for a long time been performed on LDV's, not only in Sweden but also for example in Germany and the Netherlands. The intention is to include HDV's in this procedure from Euro VI.

The manufacturer has a responsibility that the type approved engine/vehicle does not exceed the emission limits stated in the type approval during a specified period of time or driving distance.

Since the type approval for HDV's is related to the engine, and based on tests performed in engine test bench, it is not uncomplicated to verify emission performance for vehicles in use. Earlier studies have included dismounting the engine from the vehicle, but since the engines and associated exhaust emission control systems get more and more complicated and more electronic controlled devices are used, this is an unreasonable procedure – not at least from cost and time perspectives. The development of in-use testing for heavy duty vehicles have therefore been towards methods that are more practically accomplished.

In Europe, activities to develop suitable test methods for on-road measurements and associated test protocol have been organized and coordinated by EU Joint Research Centre (JRC). JRC launched a pilot project year 2006 where manufacturer of engines/vehicles, manufacturer of instrument, approval authorities and technical services was invited to participate. The activity is called EU-PEMS project. Several meetings have been organized by JRC and interested parties have been invited to share experiences. A common way to calculate and present results from measurement have been introduced by JRC and a standardized test protocol has been established, the PEMS-protocol.

Sweden, represented by STA, is strongly promoting the activities of JRC and the EU-PEMS project. In 2006, STA initiated a national project based on the EU-PEMS project including on-road measurement of HDV's in normal operation, as well as comparative testing on chassis dynamometer. The result from national activities carried out 2012 is presented in this report.

Test program

Thirteen vehicles have been tested on road by a portable exhaust measurement system (PEMS). In addition, six of these vehicles (B, C, E, I, J and K) have also been tested on chassis dynamometer. The aim of the study was not to pinpoint specific manufacturer thus, the vehicles in this report will be denoted A – M and the engine power is presented as an approximate figure.

Selection of test vehicles

The vehicle selection has been performed in cooperation with the STA. The vehicle type chosen for testing was based on Euro III, IV and V, and EEV technology. The vehicles tested have been served in accordance to the manufacturer specification on a regular basis.

Table 1 EU Emission Standards for HD Diesel Engines

Dates for first registration. entry into service	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	PM [g/kWh]	Smoke m^{-1}
EEV - 2000.10					
European Stationary Cycle (ESC) and European Load Response (ELR)	1.5	0.25	2.0	0.02	0.15
European Transient Cycle (ETC)	3.0	0.40	2.0	0.02	
Euro III – 2001.10 – 2006.09					
European Stationary Cycle (ESC) and European Load Response (ELR)	2.1	0.66	5	0.1	0.8
European Transient Cycle (ETC)	5.45	0.78	5	0.16	
Euro IV – 2006.10 – 2009.09					
European Stationary Cycle (ESC) and European Load Response (ELR)	1.5	0.46	3.5	0.02	0.5
European Transient Cycle (ETC)	4	0.55	3.5	0.03	
Euro V - 2009.10 – 2013.12					
European Stationary Cycle (ESC) and European Load Response (ELR)	1.5	0.46	2	0.02	0.5
European Transient Cycle (ETC)	4	0.55	2	0.03	
Euro VI[1] - 2014.01 –					
Worldwide Harmonized Stationary Cycle (WHSC)	1.5	0.13	0.4	0.01	
Worldwide Harmonized Transient Cycle (WHTC)	4	0.16	0.4	0.01	

[1] Euro VI also include maximum particle number requirements which are $8.0*10^{11}$ #/kWh (WHSC) and $6.0*10^{11}$ #/kWh (WHTC)

Testing on chassis dynamometer

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.

Measuring methods – gaseous emissions

The sampling- and analysing equipment are based on full flow dilution systems, i.e. the total exhaust is diluted using the Constant Volume Sampling (CVS) concept. The total volume of the mixture of exhaust and dilution air is measured by a Critical Flow Venturi (CFV) 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 steady state tests, the raw exhaust gases are sampled for further gaseous analysis before the dilution in the tunnel occurs. 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 directive 2005/55/EEC and also the U.S. Federal Register in terms of sampling probes and heated lines etc.

Table 2 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

Measuring methods – particle emissions

The particulate emissions were measured gravimetrically by the use of glass fibre filters. The diluted exhausts were sampled on the filters according to standard procedures. Two filters were used, mounted in series.

Test cycles

The ETC/FIGE driving cycle

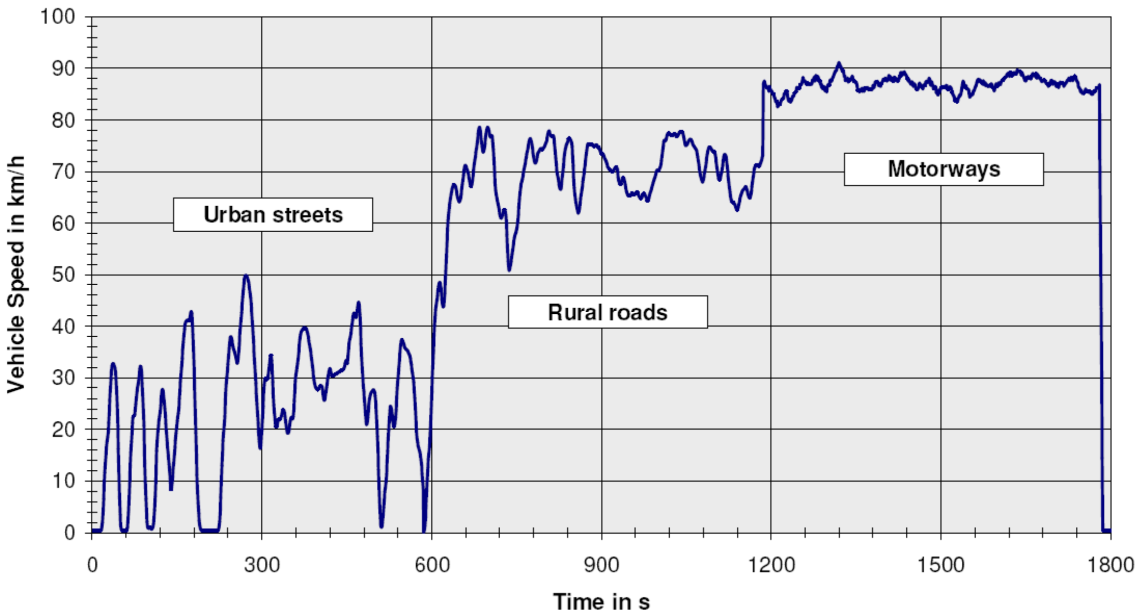


Figure 1 The FIGE driving cycle

The FIGE test cycle has been developed by the FIGE Institute, Aachen, Germany, based on real road cycle measurements of heavy duty vehicles. FIGE Institute developed the cycle in two variants: as a chassis and an engine dynamometer test. The engine dynamometer version of the test is the so called ETC cycle (European Transient Cycle) which today is used for certification purposes of diesel engines to be used in heavy duty vehicles. The chassis dynamometer version is normally referred to as the FIGE test cycle.

Different driving conditions are represented by three parts of the ETC/FIGE cycle, including urban, rural and motorway driving.

The duration of the entire cycle is 1800s. The duration of each part is 600s.

- Part one represents city driving with a maximum speed of 50 km/h, frequent starts, stops, and idling.
- Part two is rural driving starting with a steep acceleration segment. The average speed is about 72 km/h
- Part three is motorway driving with average speed of about 88 km/h.

The WHVC/WHTC test cycle

The WHTC (World Harmonized Transient Cycle) test cycle will become the future test cycle for certification of engines. The WHVC (World Harmonized Vehicle Cycle) test cycle, which can be used for testing entire vehicles on a chassis dynamometer, is the test cycle from which the WHTC was developed. The WHVC is not identical to the WHTC since it was only an intermediate step from data collection to engine test bench cycle, but it is the closest there is today.

The test procedures for chassis dynamometer testing are not identical to the procedures used for engine dynamometer testing, but the results using the WHVC test cycle can be used in order to compare the emission levels from a vehicle with the emissions levels of an engine tested with the WHTC test cycle. The emission results are presented in g/km but also converted from g/km to g/kWh using estimations of executed work during the transient test cycle.

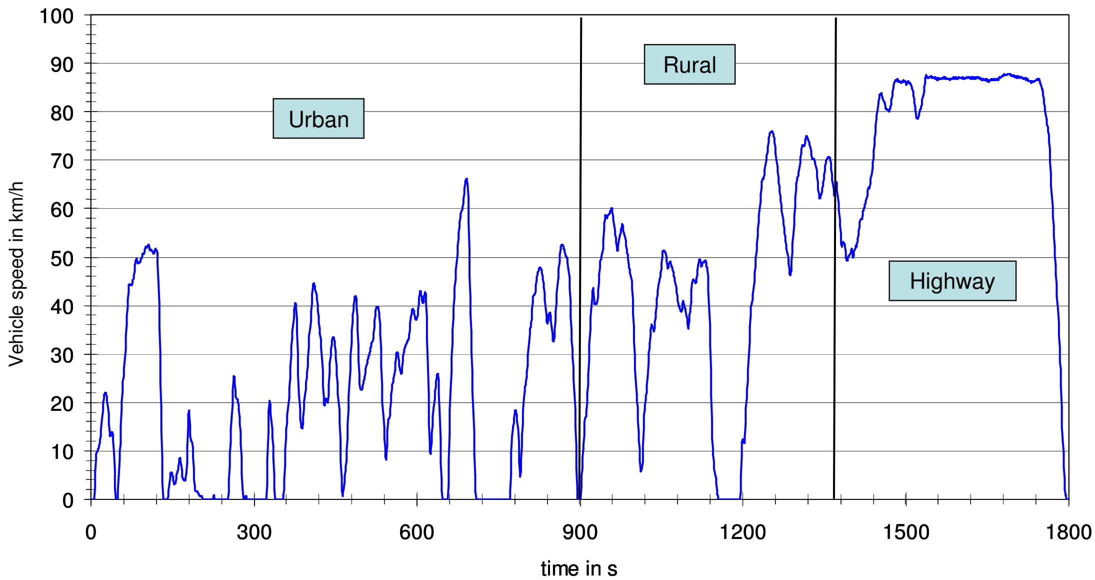


Figure 2 The WHVC test cycle

The transient cycle used in the test was the “WHVC” test cycle (unofficial).

The WHVC is a transient test of 1800 s duration, with several motoring segments.

Different driving conditions are represented by three parts of the WHVC cycle, including urban, rural and highway driving.

The duration of the entire cycle is 1800s.

- The first 900 seconds represents urban driving with an average speed of 21 km/h, maximum speed of 66 km/h. This part includes frequent starts, stops and idling.
- The following 468 seconds represents rural driving with an average speed of 43 km/h and maximum speed of 76 km/h.
- The last 432 seconds are defined as highway driving with average speed of about 76 km/h.

On-road measurement

Two different PEMS equipments have been used for the measurements. The Semtech-DS was developed by Sensors and the M.O.V.E (Mobile on-board Vehicle Equipment) was developed by AVL.

Both devices were developed for testing all classes of light as well as heavy duty vehicles under real-world operating conditions. The instruments consists of on-board emissions analyzers which enables tailpipe emissions to be measured and recorded simultaneously while the vehicle is in operation.

The following measurement subsystems are included in the emission analyzers of both instruments:

- Heated Flame Ionization Detector (HFID) for total hydrocarbon (THC) measurement.
- Non-Dispersive Ultraviolet (NDUV) analyzer for nitric oxide (NO) and nitrogen dioxide (NO_2) measurement.
- Non-Dispersive Infrared (NDIR) analyzer for carbon monoxide (CO) and carbon dioxide (CO_2) measurement.
- Electrochemical sensor for oxygen (O_2) measurement.

Both equipments are operated in combination with an electronic vehicle exhaust flow meter, Semtech E_xFM. The equipments uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size. All tests were carried out with a 4” flow meter, which was suitable for the engine sizes of the tested vehicles.

In addition to the gas analysing instruments an AVL 483 Micro Soot Sensor was used to measure the soot emissions. The AVL 483 Micro Soot Sensor works on a photo-acoustic principle (PASS) and the cell design chosen (called the "resonant measuring cell") allows a detection limit of ≤10 µg/m³, (typically ~ 5 µg/m³).

The instrument is operated in combination with an electronic vehicle exhaust flow meter, Semtech E_xFM. The Semtech-DS instrument uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size. A 4” flow meter was used, which is suitable for the engine size of the tested vehicles.

The PM PEMS combines the AVL the photo-acoustic soot measurement principle with a gravimetric PM measurement. The complete system consists of two 19” enclosures for the Micro Soot Sensor Measuring Unit (MSS), the Gravimetric Filter Module (GFM) and an external heated dilution cell and transfer line.

The program for emission calculation (EMROAD) from the PEMS instruments was supplied by JRC (Joint Research Center).

The on-road testing and calculation has for all vehicles been performed in accordance with the PEMS protocol. According to the PEMS protocol the measurements should be carried out during a normal working day representative for the vehicle type and if possible include hill climbs, segments with cruising at constant speed and segments that is highly transient in their character as well as different altitudes.

Frequently used PEMS test routes

The AVL "PEMS test route" starts at the AVL headquarters at Armaturvägen in Haninge, continues through Handens centrum, Årsta Havsbad, Ösmo and ends back at Armaturvägen. The route has been inspected and accepted by JRC.

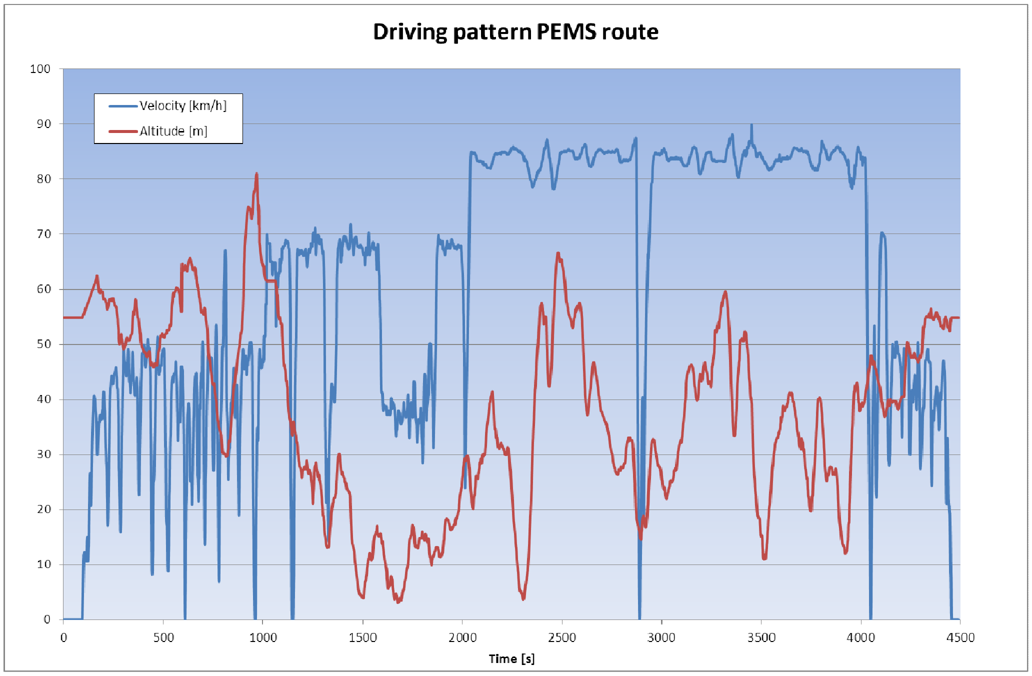


Figure 3. PEMS route driving pattern.

Table 3

Trip duration (s)	4493 - 4644
Trip distance (km)	75.5 – 75,7
Average speed (km/h)	59 – 61
Average altitude (m)	30,5
Altitude range (m)	2,5-86,8

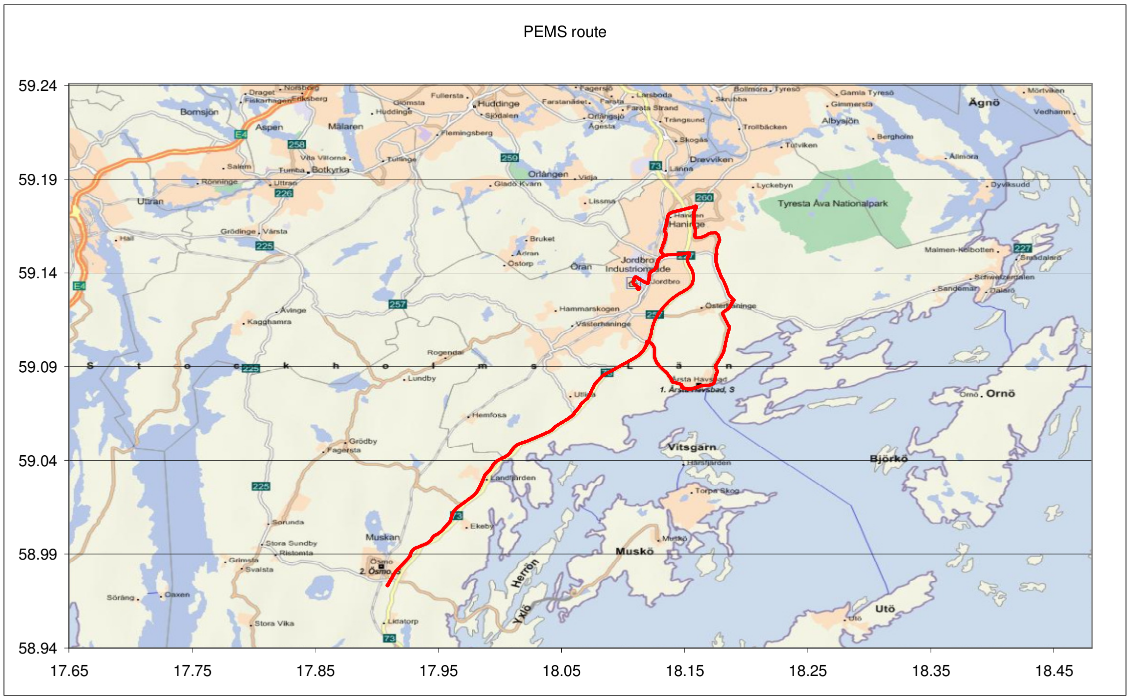


Figure 4 The PEMS test route.

The AVL “bus route” is a true bus route in southern Stockholm. It starts in Lillgården, Tungelsta and ends at Coop Forum, Haninge. The route contains 22 bus stops.

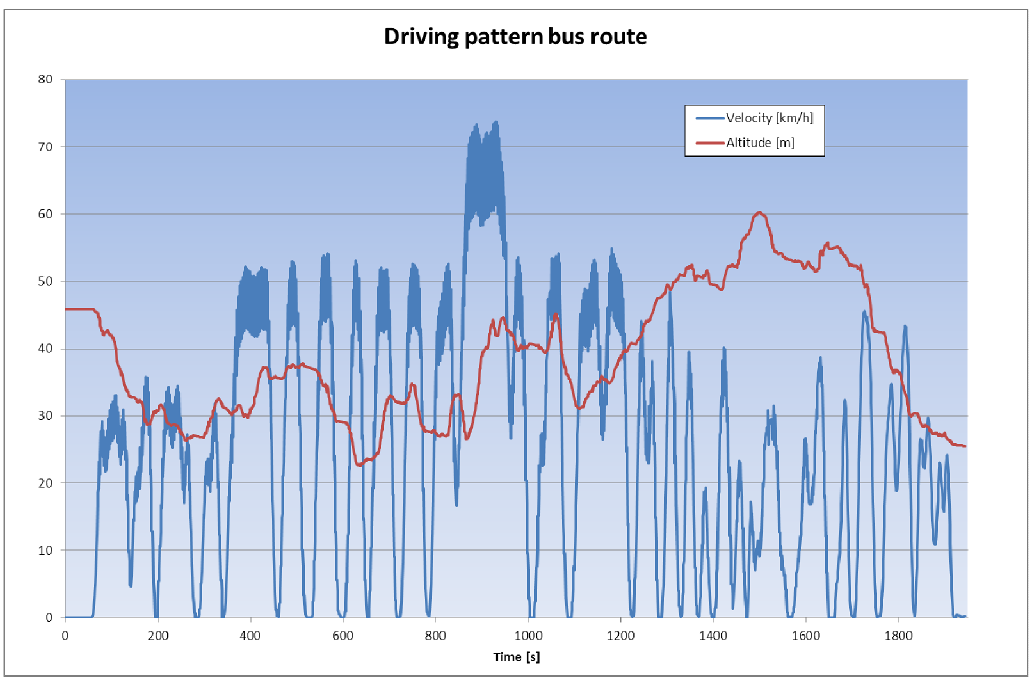


Figure 5. Bus route driving pattern.

Table 4. Route data.

Test route data		
	PEMS route	**Bus route**
Trip duration (s)	4500	1900
Trip distance (km)	77	13.5
Average speed (km/h)	55	26
Urban (%)	43	90
Rural (%)	17	10
Highway (%)	40	0
Accelerating (%)	18	37
Decelerating (%)	18	40
Cruising (%)	57	11
Idle (%)	7	10

Test Fuel

Commercially available fuels fulfilling the specification of Environmental class 1 diesel (Mk1) has been used. Swedish MK1 fuel is a low sulphur diesel i.e. less than 10 ppm, and has a boiling point interval of 180-290℃. The fuel consists of 50-70% parafines, 30-45% naphtenes and 3-5% aromatics.

CNG (Compressed Natural Gas), commercially available CNG which consists of ~77% methane. CNG has an energy content of 35-39 MJ/Nm^3.

ED95 is an ethanol based fuel adapted for diesel engines. It consists of 95% (at least 92.4%) ethanol and 5% additives such as ignition improvers and denaturation- and corrosion inhibitors. It has a cetane number of approximately 10 and an energy density of ~20,5 MJ/l.

Vehicle A

Vehicle A was a garbage truck of euro standard V equipped with a SCR system. The fuel used during the tests was Mk1 diesel.

Presentation of vehicle:

Table 5 Vehicle data.

Year model	2009
Environmental class	Euro V
Mileage, km	12 820
Date of registration	January 2010
Power, kW (approx.)	200
Test weight, kg	14 900
Exhaust aftertreatment	SCR

Test program

The vehicle was tested on road in the AVL MTC EURO V test route as well as a “start and stop” test route which represented typical driving for the particular vehicle.

Below are the test routes presented

The Pems test route was carried out both clockwise as well as anti-clockwise with one hot start and one cold start in order to evaluate the test route and the engine temperature dependency. In addition one start and stop test were carried out as a representative driving for the particular vehicle. The driving patterns are presented in Figure 6 - 8.

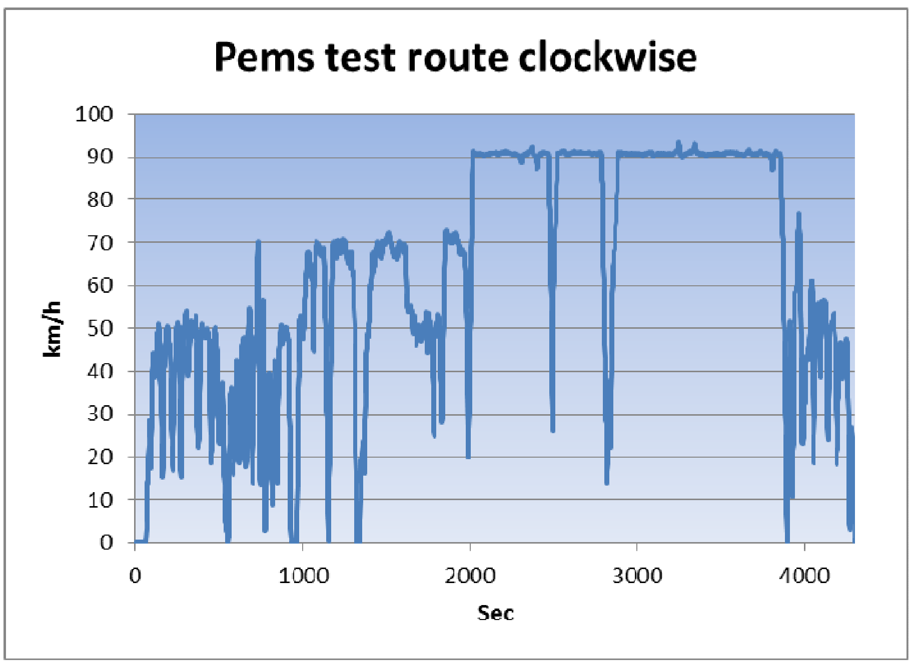


Figure 6. The PEMS test route clockwise.

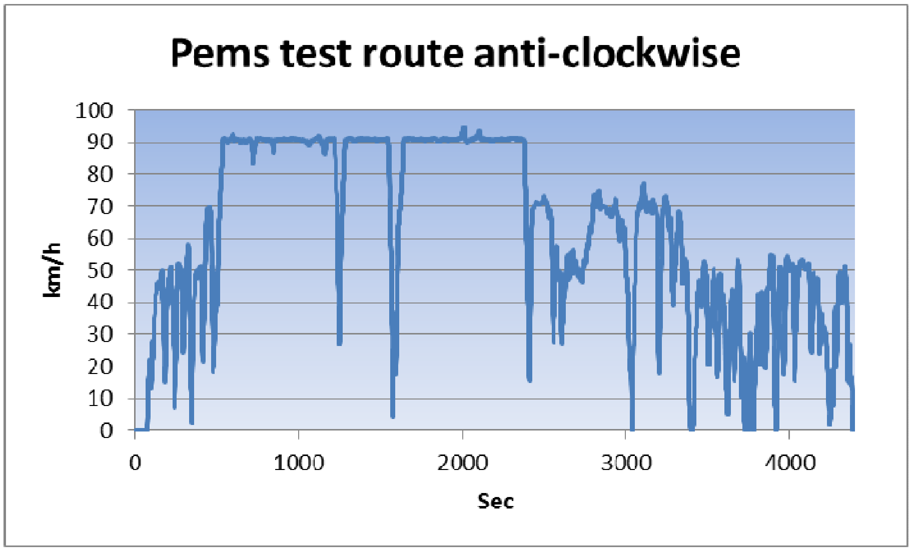


Figure 7. The PEMS test route anti-clockwise.

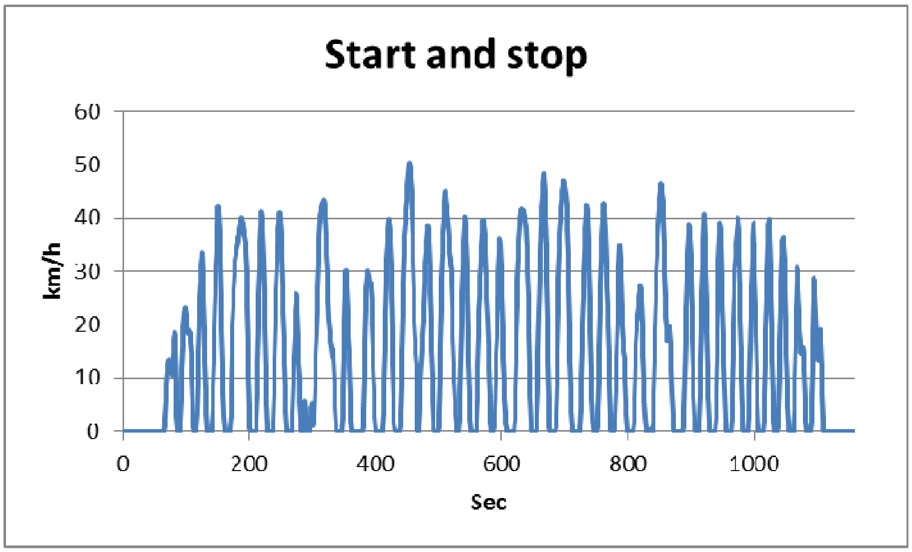


Figure 8. Start and stop.

Test results

The results are presented as distance specific emissions in Figure 9 - 13 and as brake specific emissions in Figure 14 - 19. From the figures some general conclusions can be made. All measured components are lower during cold start testing when driving the anti-clockwise route. This may be due to the fact the SCR catalyst are heated faster during highway driving compared to urban driving. The difference is in the order of 30 % during the first 10 minutes. This implies that sufficient length of the test route is needed in order to reduce the impact of the driving pattern. Highest emission was detected during the start/stop test procedure. During the start/stop testing the exhaust temperature were in average 210 °C compared to 270 C during the PEMS test route. The light off temperature of the catalyst is approximately 250 °C.

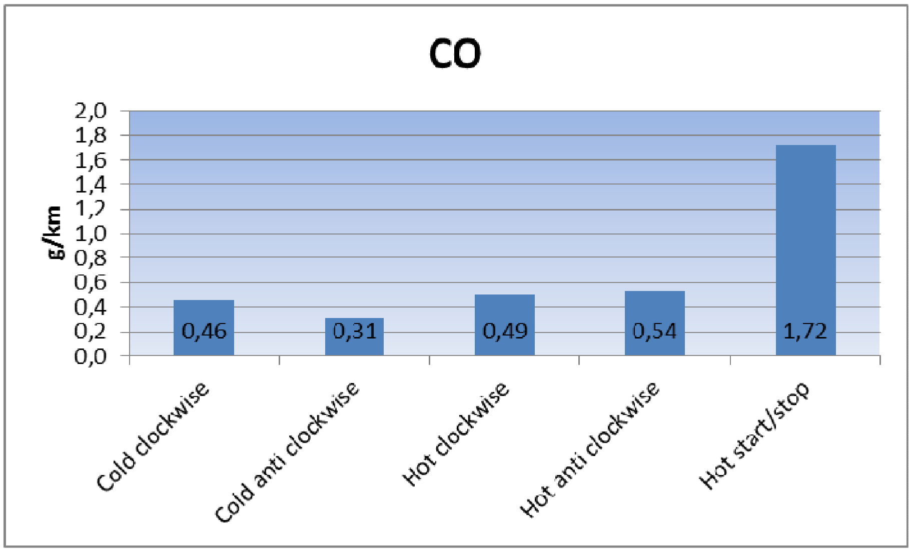


Figure 9. **Distance specific CO mass emission.**

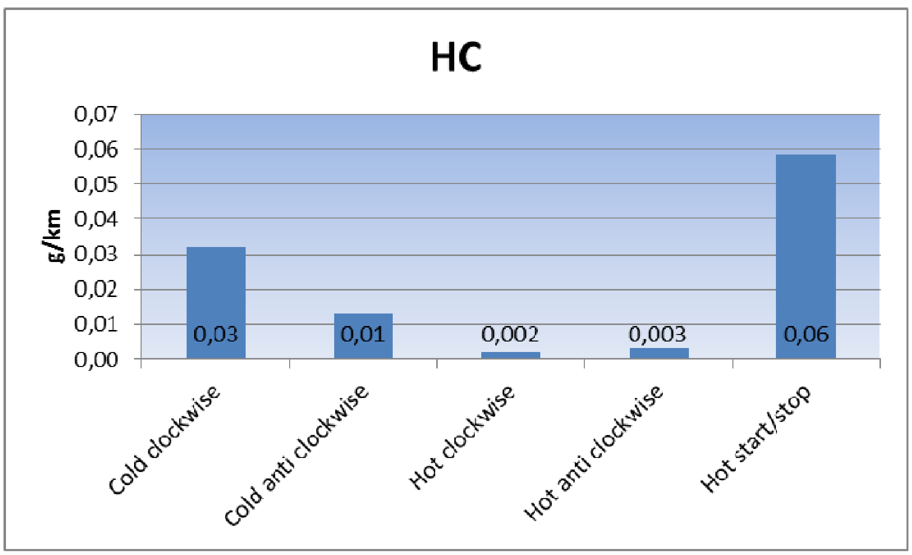


Figure 10. **Distance specific HC emission.**

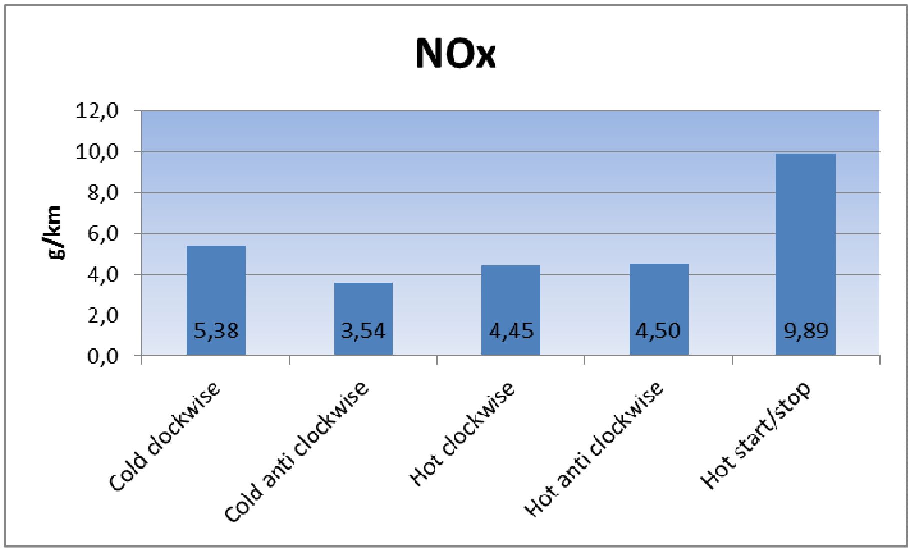


Figure 11. **Distance specific NOx emission.**

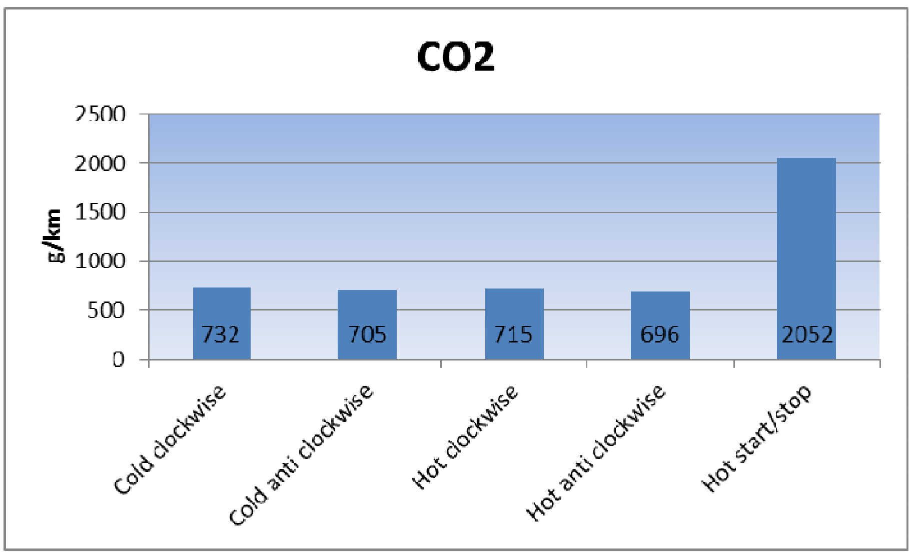


Figure 12. **Distance specific CO_2 emission.**

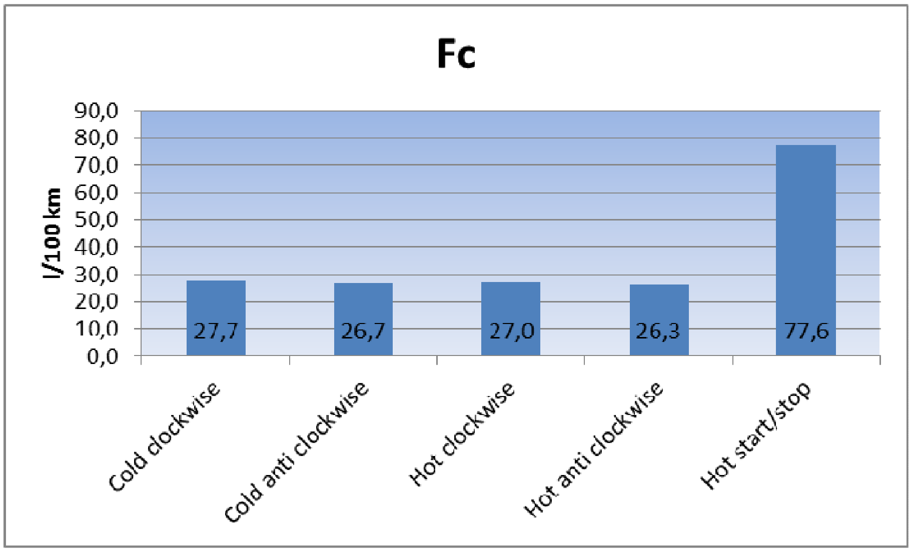


Figure 13. **Distance specific fuel consumption.**

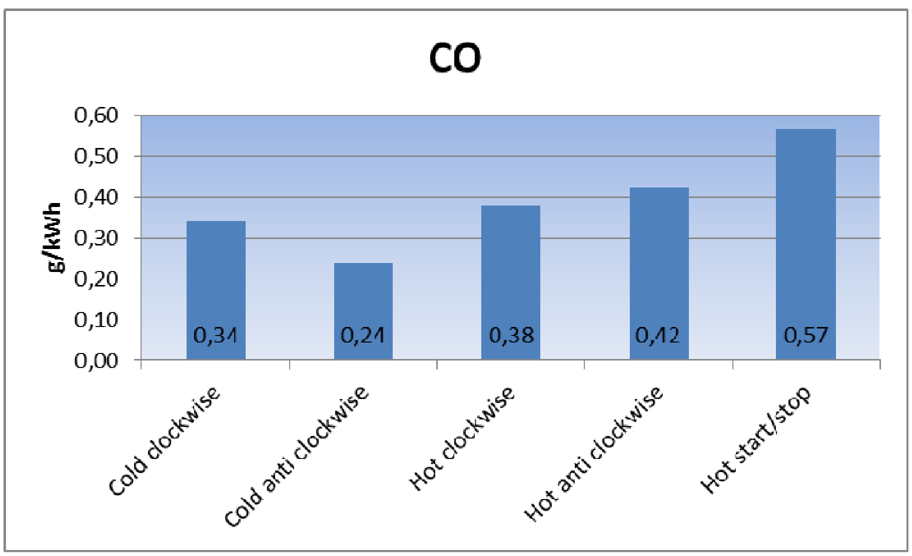


Figure 14. **Brake specific CO emission.**

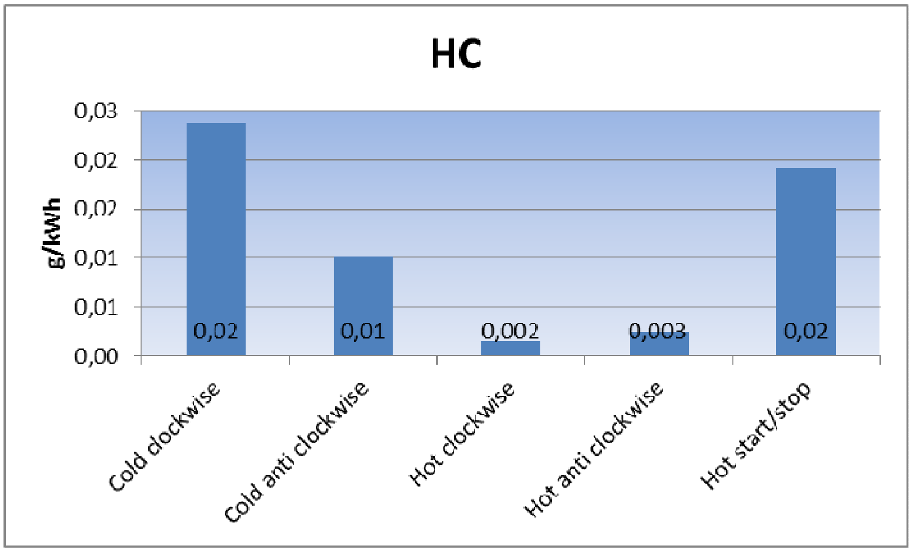


Figure 15. **Brake specific HC emission.**

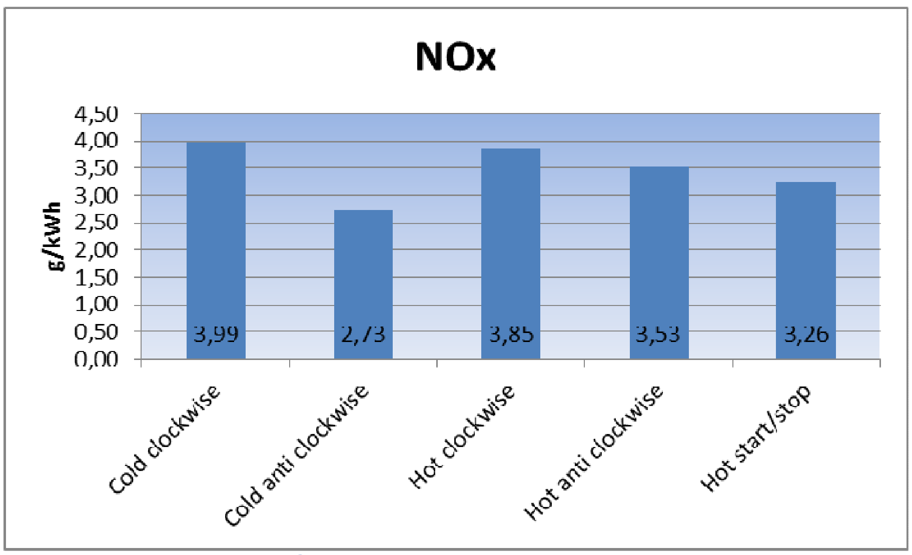


Figure 16. **Brake specific NOx emission.**

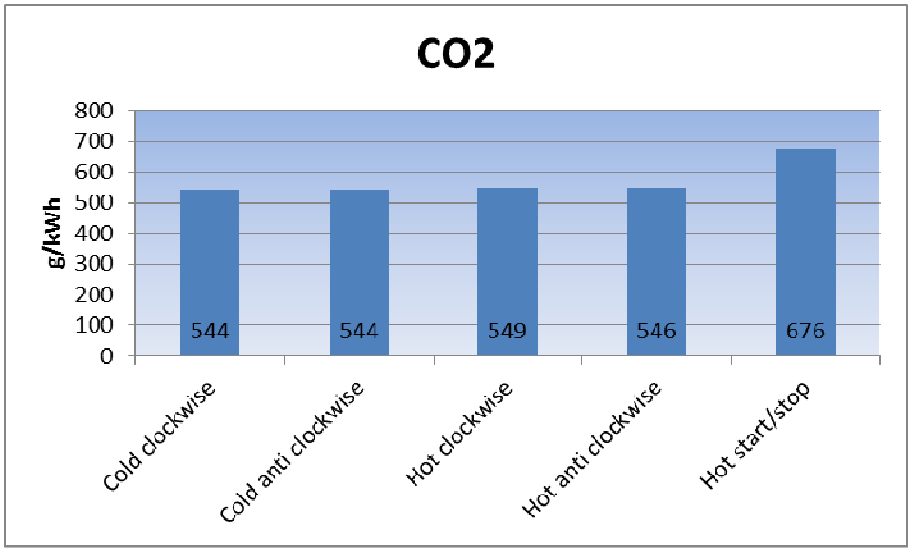


Figure 17. **Brake specific CO_2 emission.**

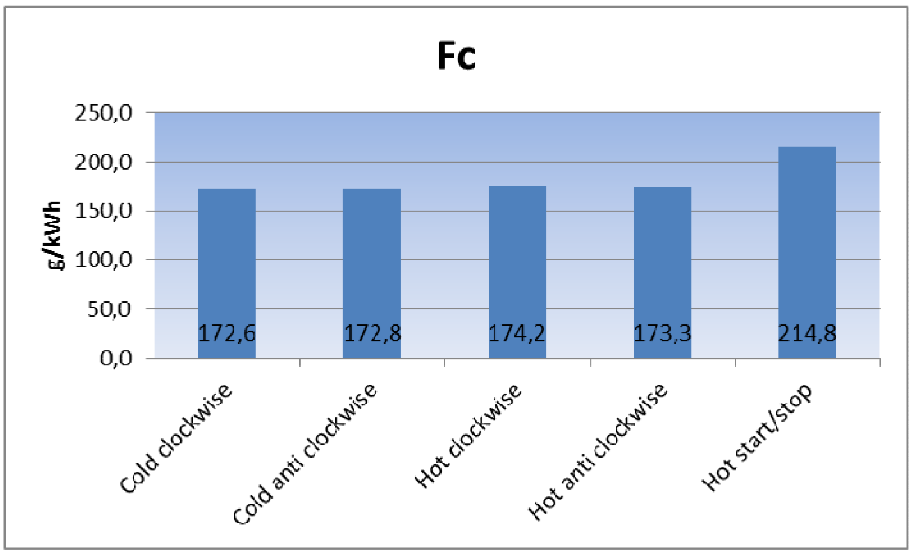


Figure 18. **Brake specific fuel consumption.**

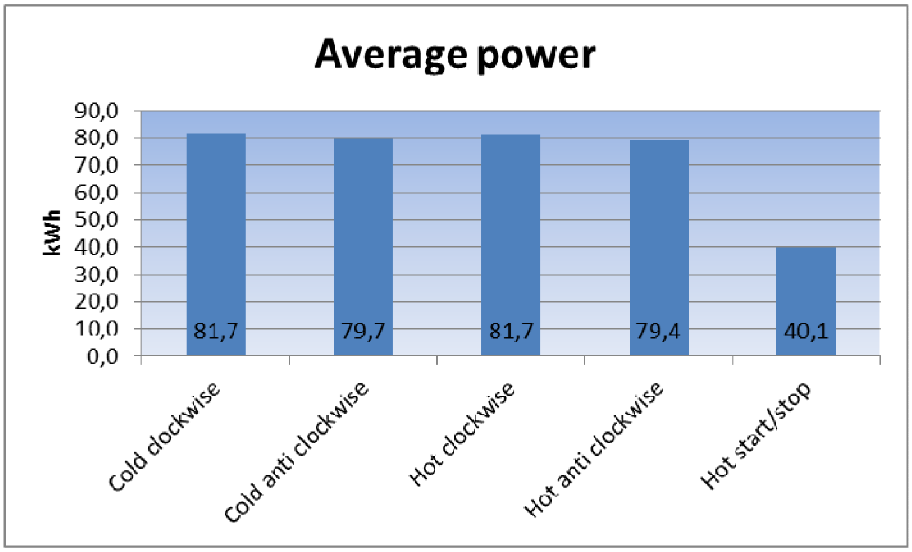


Figure 19. **Brake specific average power.**

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

The exhaust aftertreatment system warms up faster when the high-speed part of the trip comes earlier as in the anti-clockwise driving pattern. This results in lower emissions.

Vehicle B.

Vehicle B was a city bus of euro standard EEV equipped with a three-way catalytic converter. The fuel used during the tests was Compressed Natural Gas (CNG). The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Table 6 Test vehicle data.

Year model	2010
Mileage, km	85793
Date of registration	2010-08-30
Power, kW (approx.)	230
After treatment system	Three-way catalytic converter
Test weight, kg	13800
Euro standard	EEV

Test program

The Chassis dynamometer tests were:

- 2 WHVC (Worldwide Harmonized Vehicle Cycle, chassis dynamometer version of WHTC - Worldwide harmonized Transient Cycle) cold start
- 3 WHVC hot start
- 2 Fige (chassis dynamometer version of ETC – European Transient Cycle)

The test routes selected for this vehicle was bus line 835 in Haninge, Sweden, and AVL MTC's PEMS pilot study test route which has been inspected and accepted by JRC.

Several test runs were carried out in the bus route and in the PEMS route. The routes where performed both forwards and backwards and with cold start and warm start.

Test results

The results are presented in figure 20 - 24. From the figures some general conclusions can be made. When comparing the brake specific emissions with the Euro V certification values the vehicle is below the limit with regard to CO and NOx except during cold start PEMS measurements. However, high emissions of HC (methane) is detected.

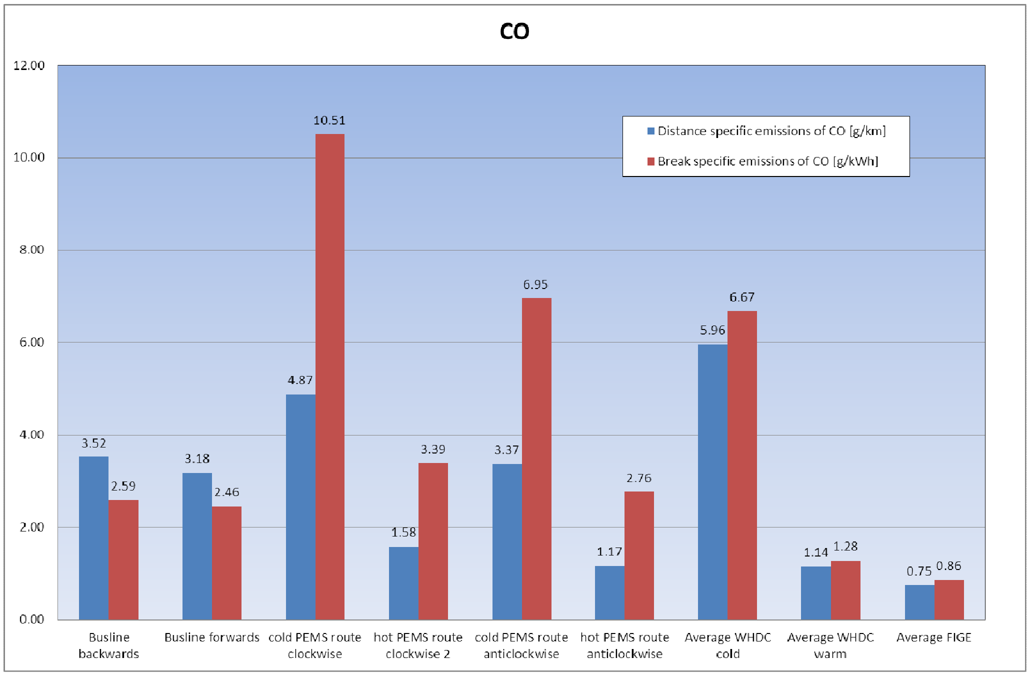


Figure 20. Emissions of CO

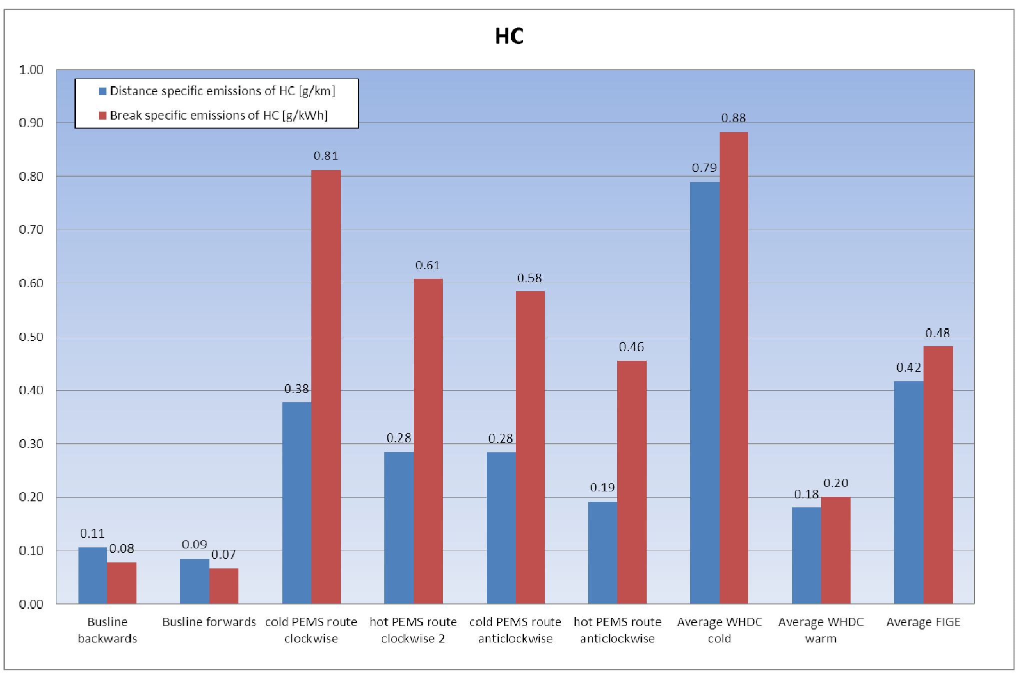


Figure 21. Emissions of HC.

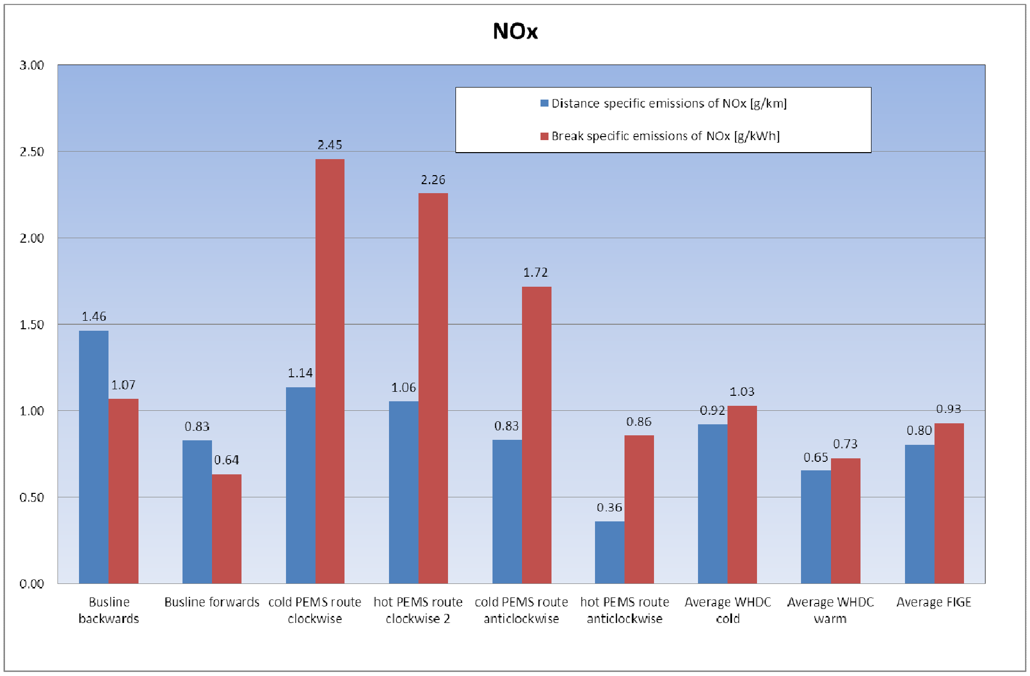


Figure 22. Emissions of NOx.

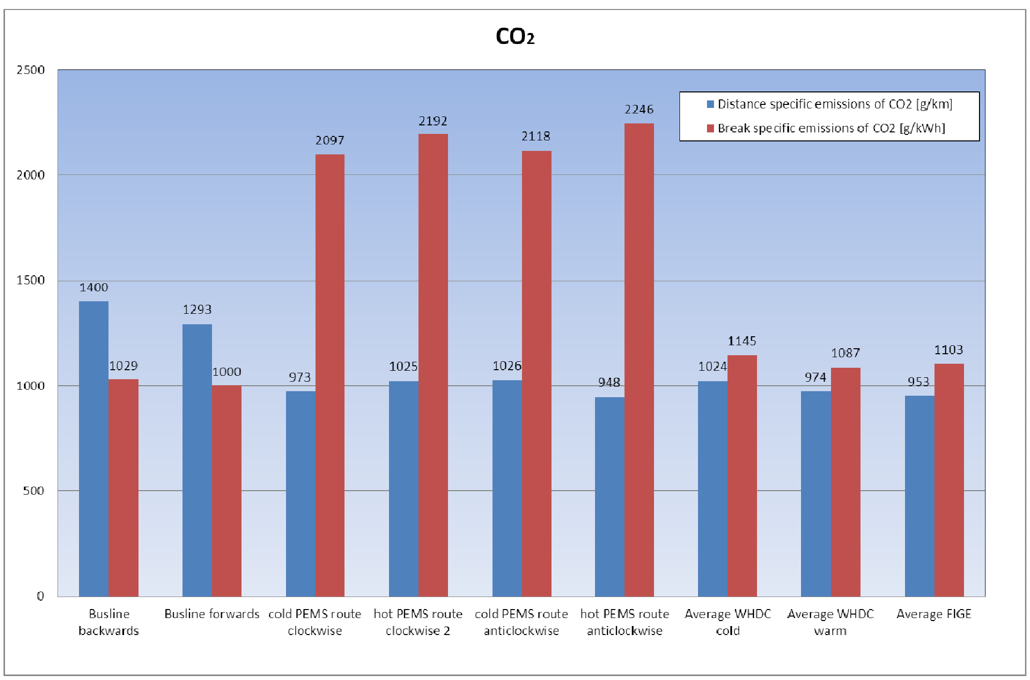


Figure 23. Emissions of CO_2.

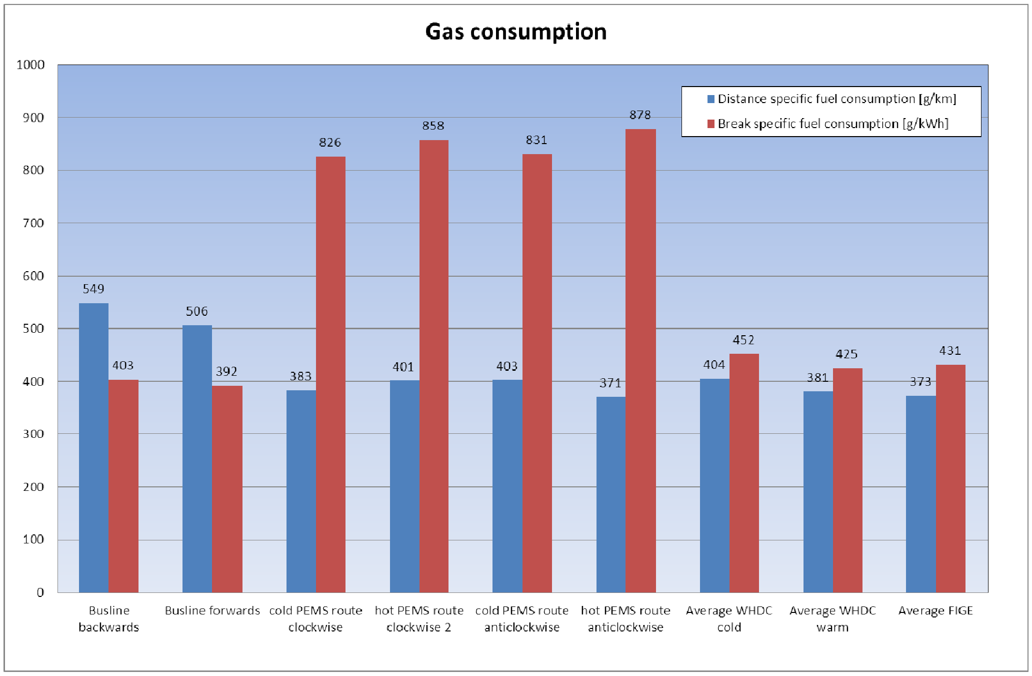


Figure 24. Fuel consumption.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

The exhaust aftertreatment system warms up faster when the high-speed part of the trip comes earlier as in the anti-clockwise driving pattern. This results in lower emissions.

Vehicle C.

Test vehicle C was a distribution truck of emission standard Euro IV, equipped with a SCR system. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road with a cargo load varying between unloaded and approximately 13 500 kg

Presentation of vehicle:

Table 7 Test vehicle data.

Year model	2007
Mileage, km	270239
Date of registration	December 2006
Power, kW (approx.)	230
After treatment system	SCR
Test weight, kg	11520-25000
Euro standard	IV

Test program

The Chassis dynamometer tests were:

- 2 WHVC (World harmonized vehicle chassisdynamometer test) cold start
- 2 WHVC (warm start)
- 3 Fige (chassis dynamometer version of ETC – European Transient Cycle)

The vehicle was tested on road in a test route that represented a normal working day of the particular vehicle divided into several sub trips, some with load and some without load. Presented in this report are one trip with load and one trip without load. Emission results from an idle test run are also presented.

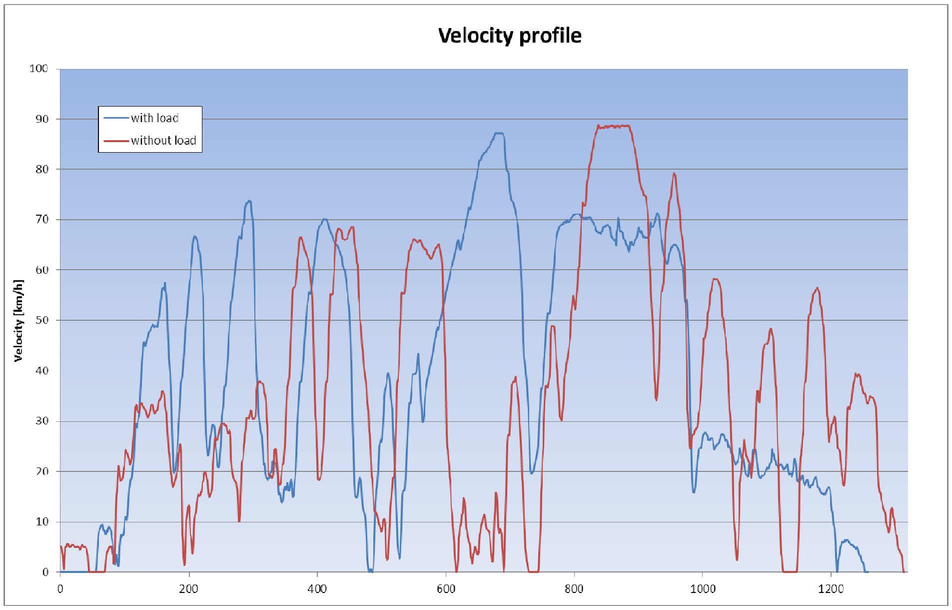


Figure 25. Velocity profile in trips with and without load

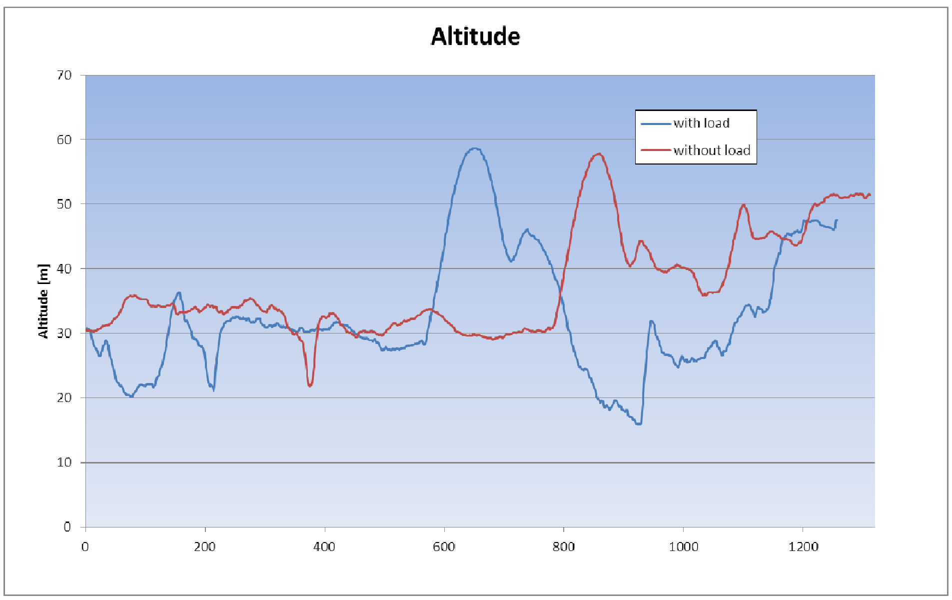


Figure 26. Vehicle altitude in trips with and without load

Test results

The results are presented in Figure 27 - 33. From the figures some general conclusions can be made. Emissions of CO, NO_x, CO_2 and fuel consumption are higher during PEMS measurements with load compared to driving without pay load while HC emissions decreases with approximately 10%. The emissions are generally higher on road compared to chassisdynamometer testing.

The emissions are increasing when comparing FIGE, WHVC-hot and WHVC-cold testing.

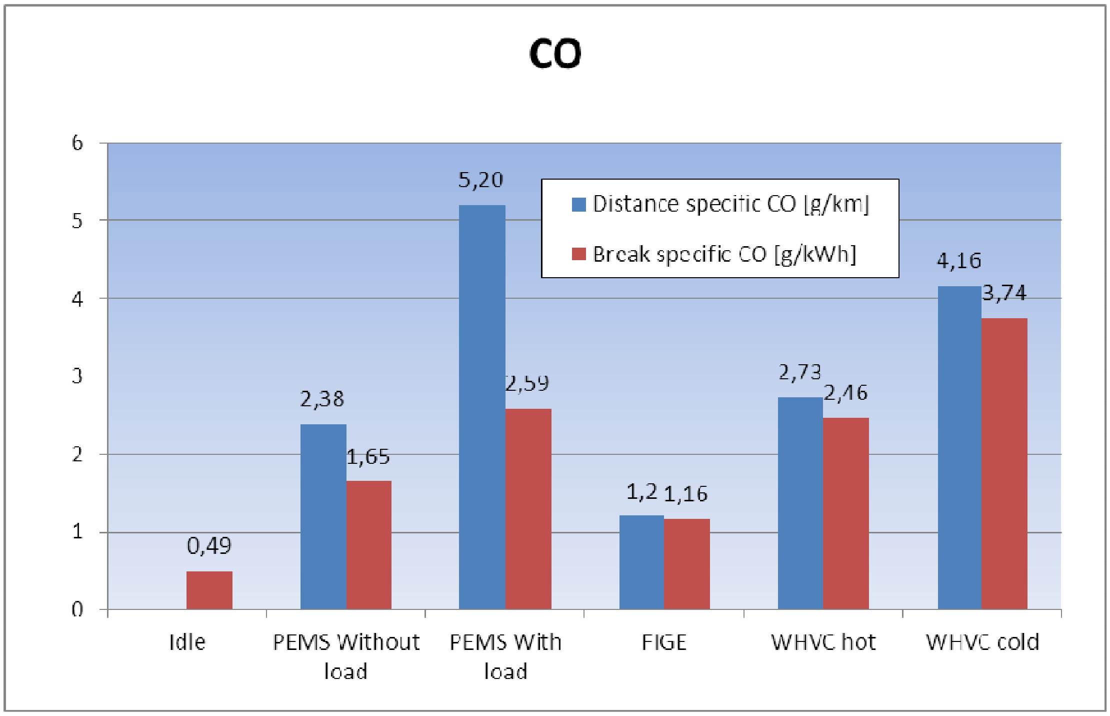


Figure 27 Emissions of CO

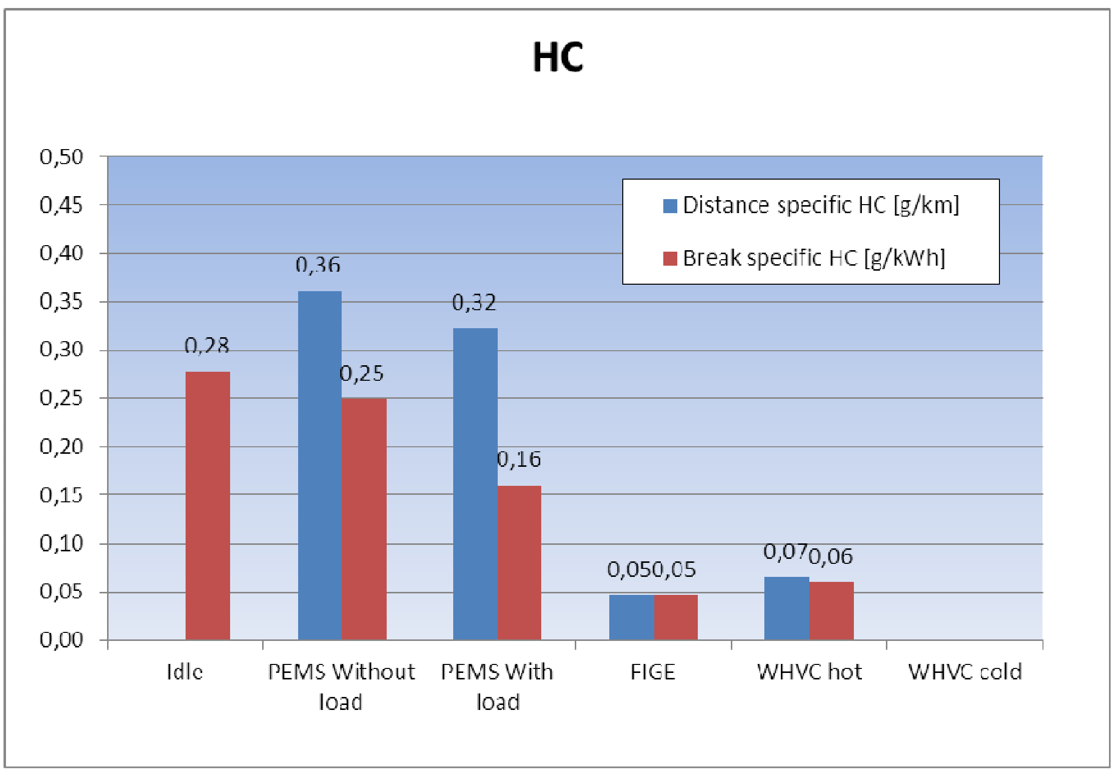
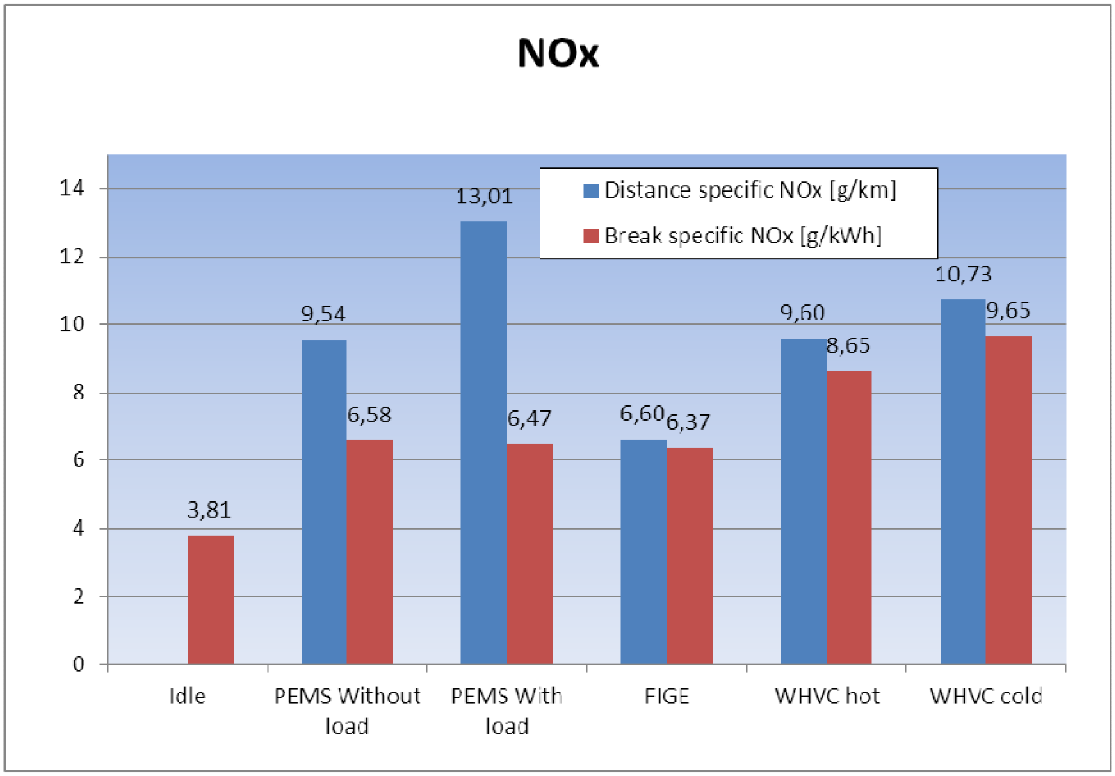


Figure 28. Emissions of HC.



F§igure 29. Emissions of NOx.

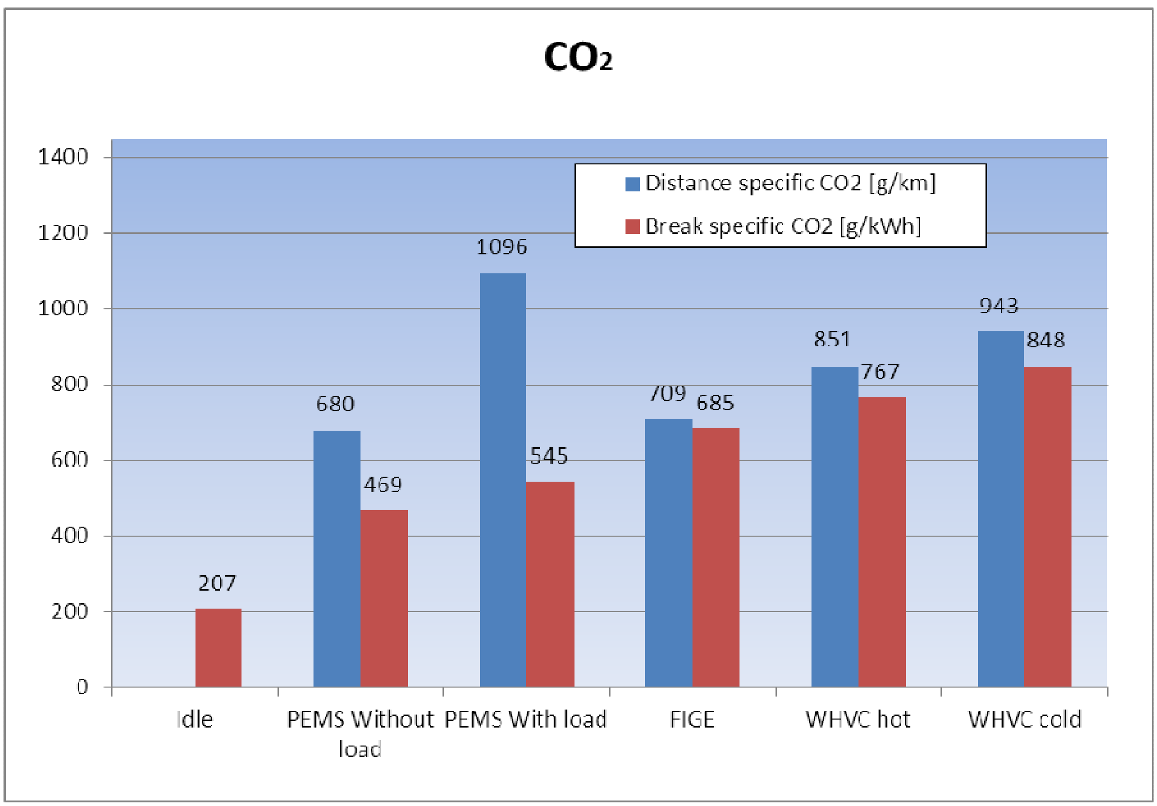


Figure 30. Emissions of CO_2.

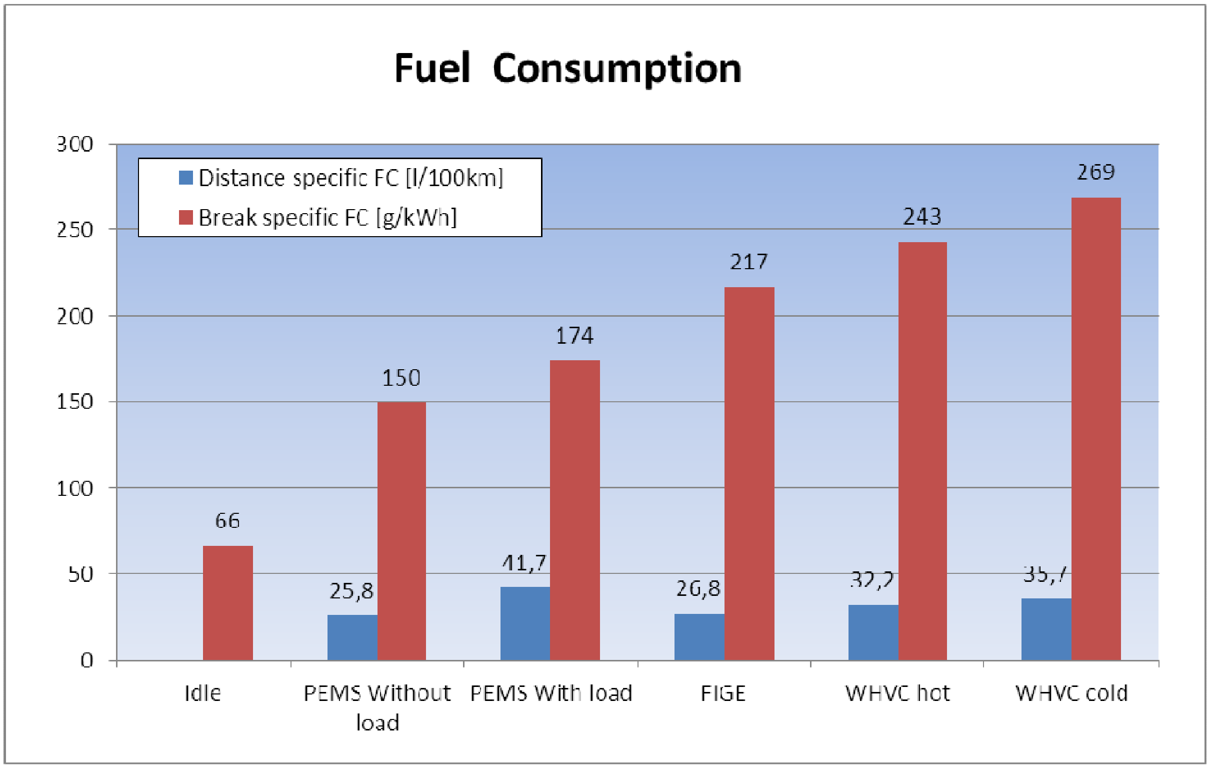


Figure 31. Fuel consumption.

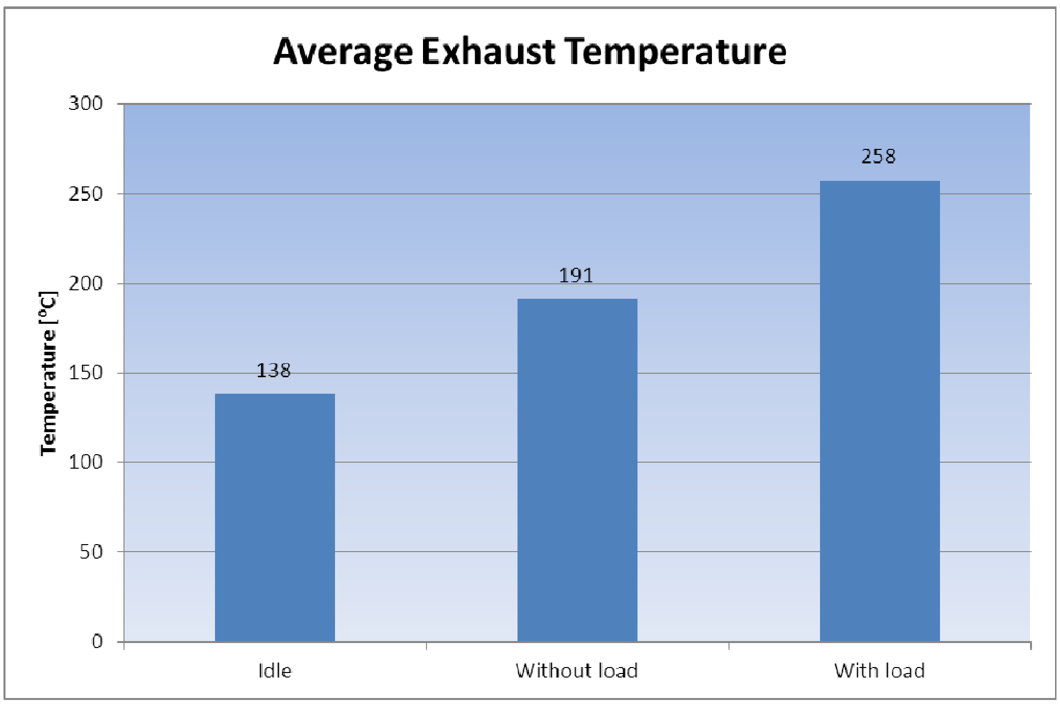


Figure 32. Average exhaust gas temperature during the PEMS measurements.

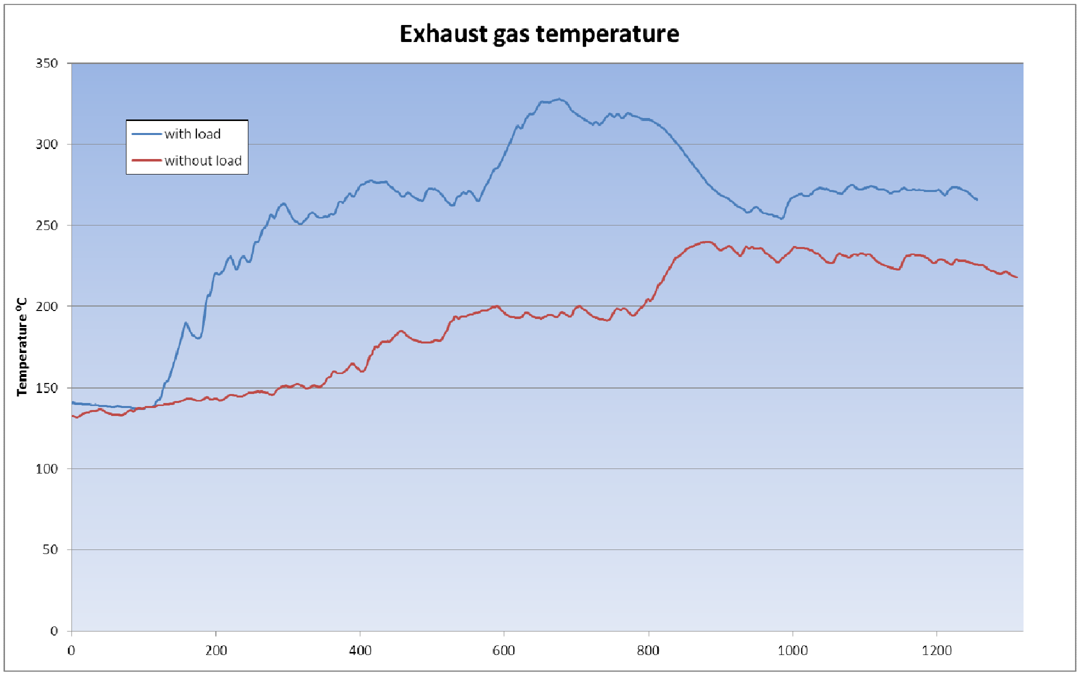


Figure 33. Exhaust gas temperature during the PEMS measurements.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle D

Vehicle D was a long distance steel girder truck. The vehicle was tested on roads during driving conditions and loads representing a normal working day with a cargo load between 12 100 and 20 000 kg.

The tests were carried out with commercially available Environmental class 1 diesel (MK1). The vehicle was served in accordance to the manufacturer specification. The vehicle was tested at an average ambient temperature of approximately 14^{0}C.

Presentation of vehicle:

Table 8 Test vehicle data.

Year model	2010
Mileage, km	136217
Date of registration	April 2010
Power, kW (approx.)	300
After treatment system	SCR
Test weight, kg	12 100-20 000 load +9715kg truck + 13000kg trailer
Euro standard	V

Test program

The test run carried out on the test vehicle represented a normal working day and was divided into four sub trips. The first three sub trips with approximately the same (medium) load and the fourth fully loaded. Sub trip number one and three consisted of mainly highway driving while sub trip number two and four represented urban and suburban driving.

Table 9 Sub trip data

Sub trip		Load
1	Arboga - Örebro	12,3 tons
2	City of Örebro	12,2 tons
3	Örebro – Kolbäck	12,1 tons
4	Kolbäck – Västerås	20 tons

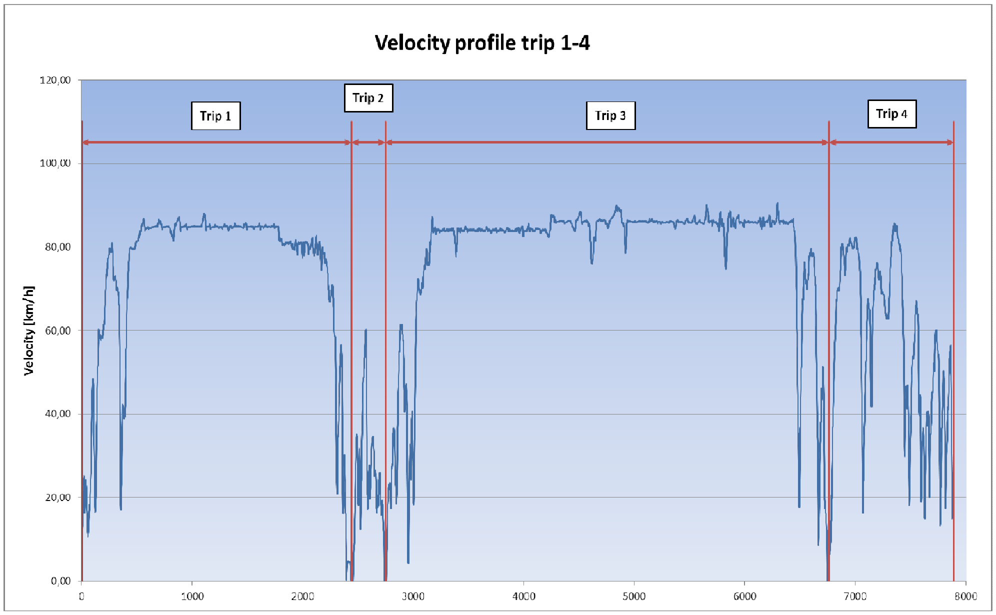


Figure 34. Velocity profile in sub trip 1-4

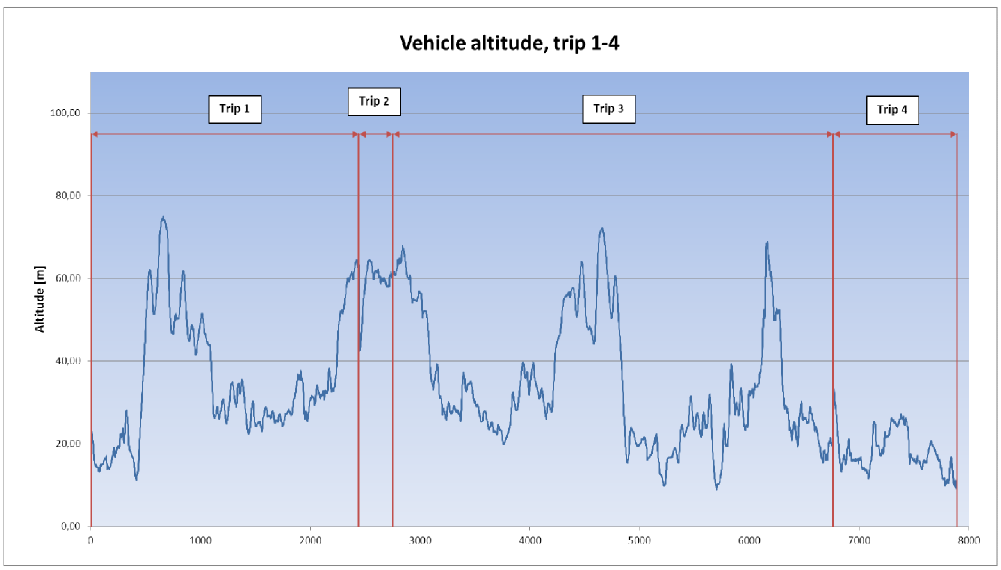


Figure 35. Vehicle altitude, sub trip 1-4

Test results

The results are presented in Figure 36 - 43. From the figures some general conclusions can be made. All measured components are higher during urban driving i.e. trip 2 and 4. This may be due to the fact the exhaust temperature is lower and the SCR catalyst is not functioning as well as when the exhaust temperature is higher.

During the urban driving sub trip the exhaust temperature was in average 179 ^{o}C compared to 237-245 ^{o}C during other sub trips. The light off temperature of the catalyst is approximately 230 -250 ^{o}C.

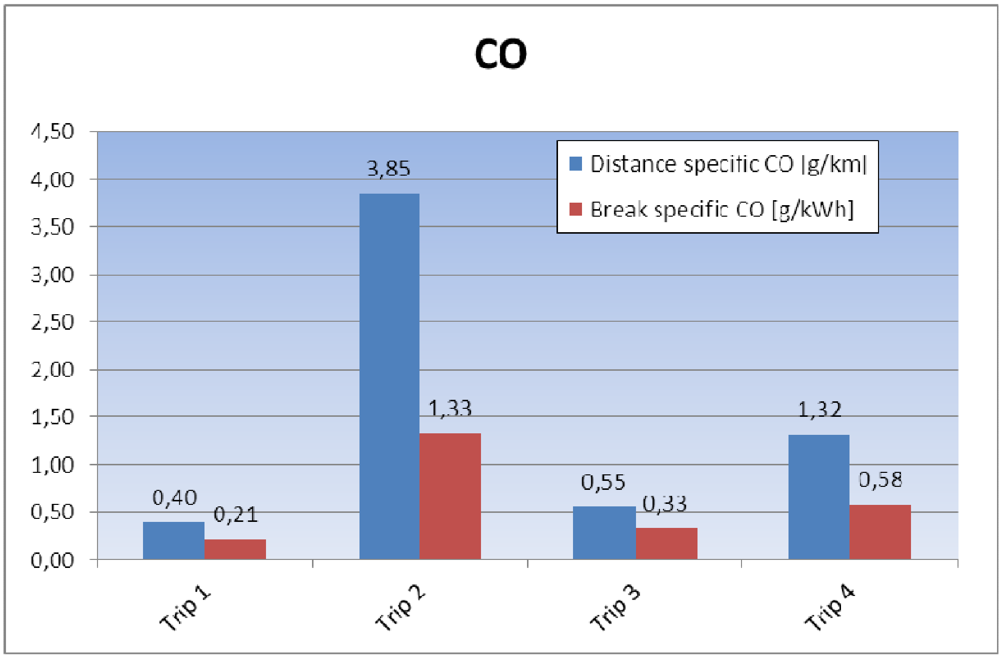


Figure 36. Emissions of CO

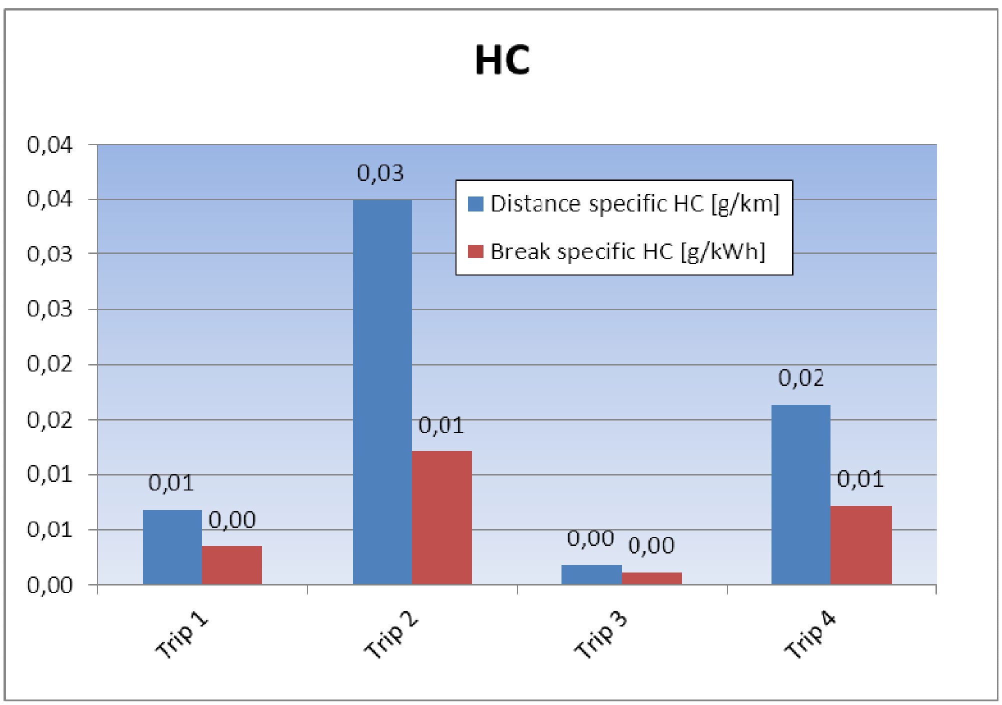


Figure 37. Emissions of HC.

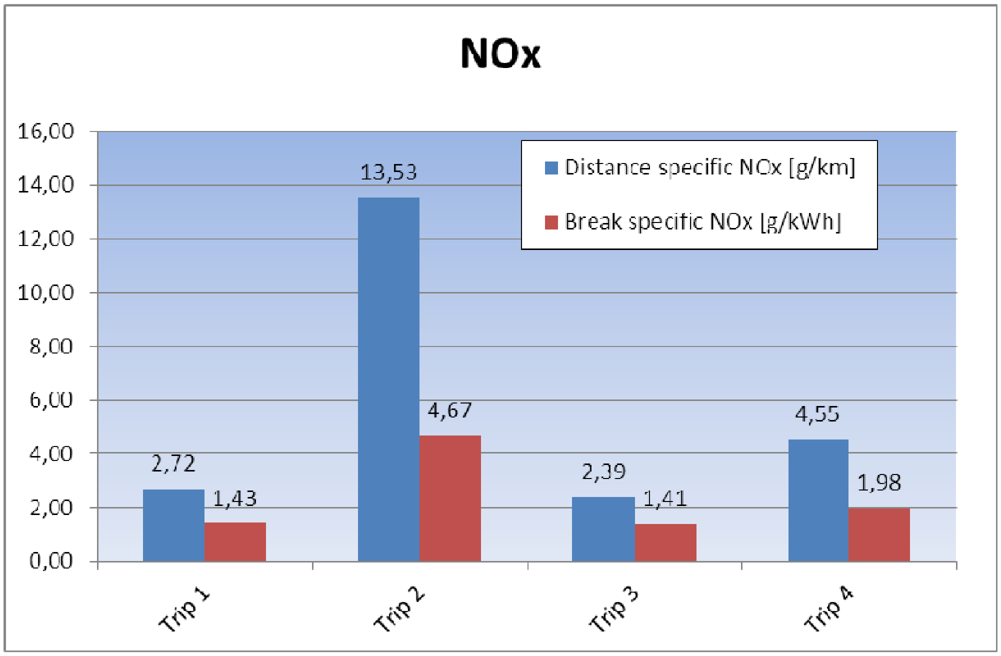


Figure 38. Emissions of NOx.

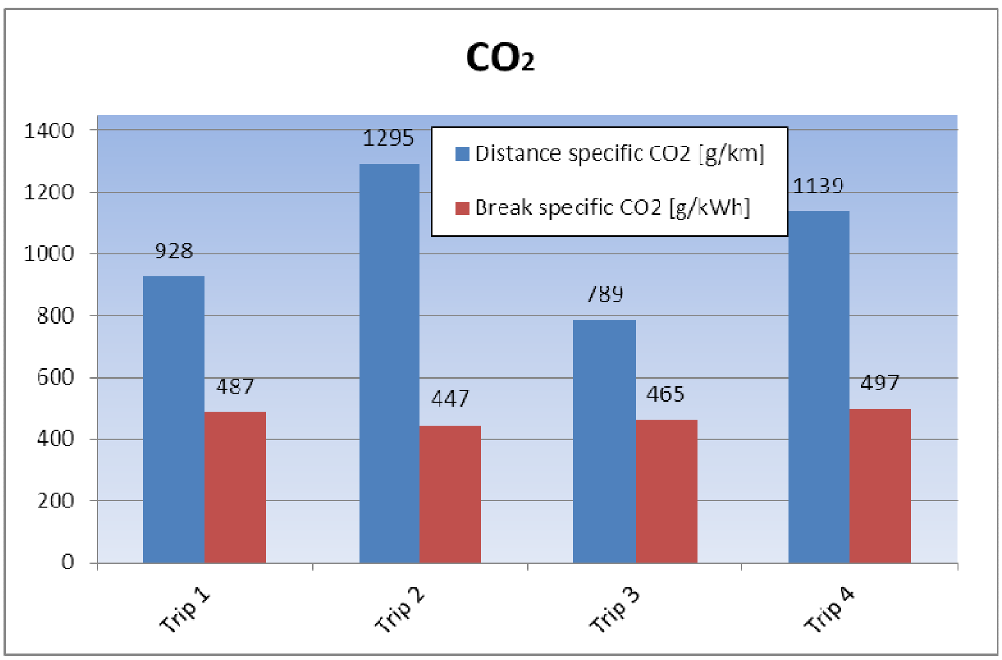


Figure 39. Emissions of CO_2.

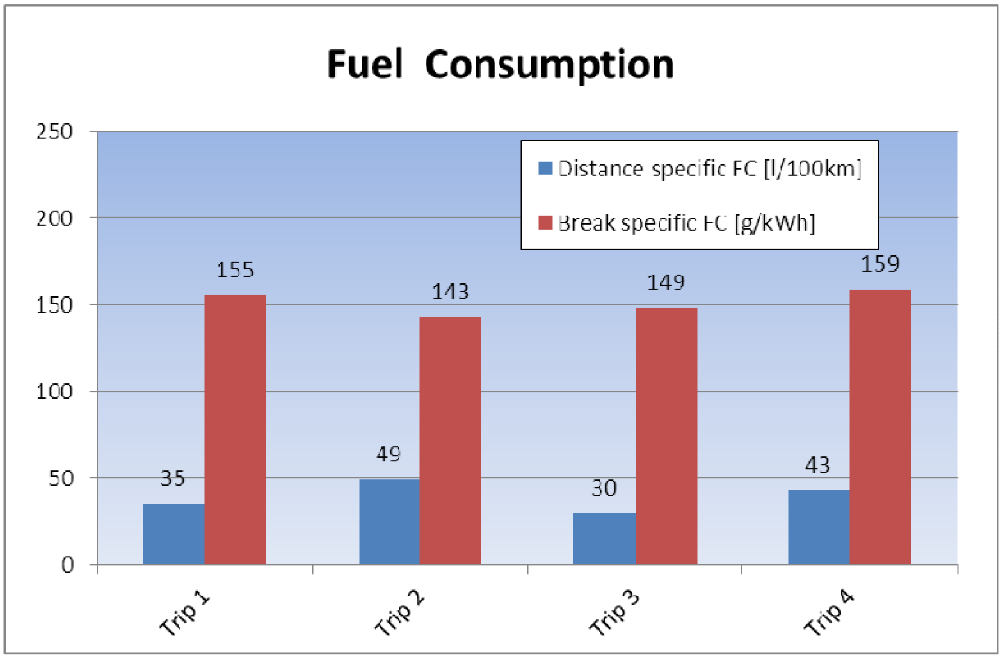


Figure 40. Fuel consumption.

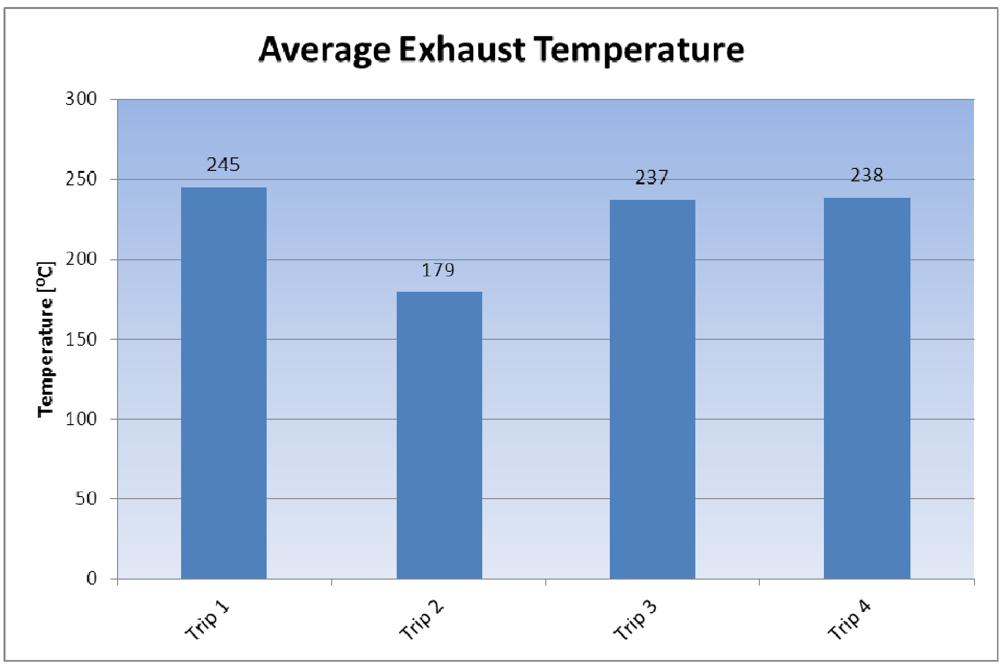


Figure 41. Average exhaust gas temperature.

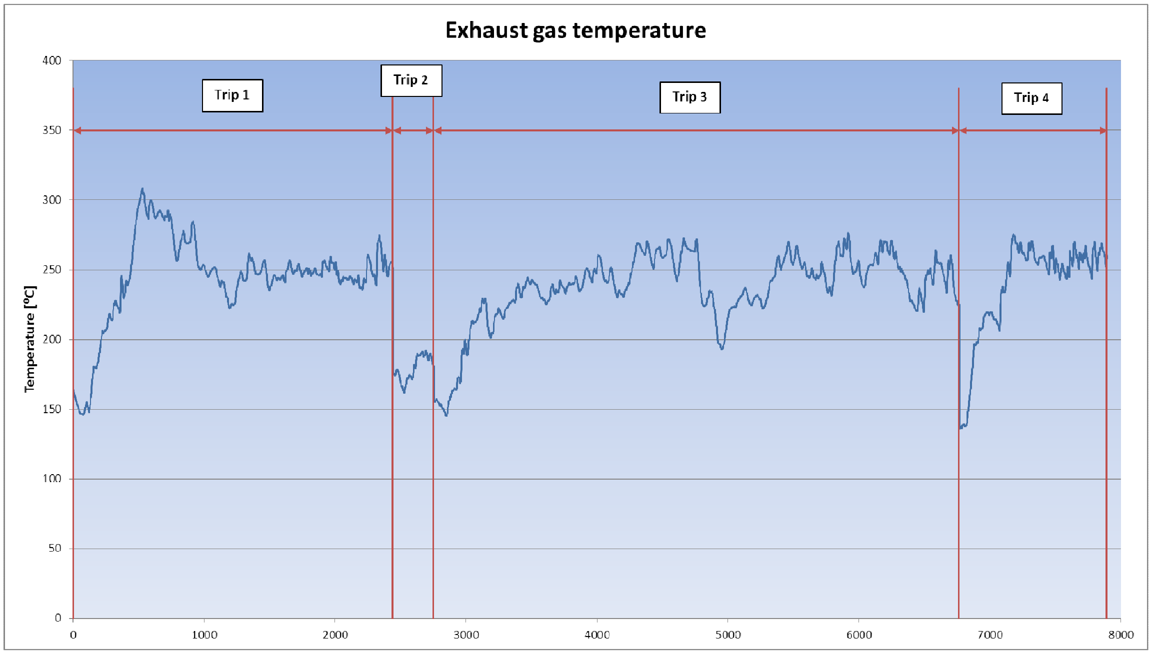


Figure 42. Exhaust gas temperature, trip 1-4.

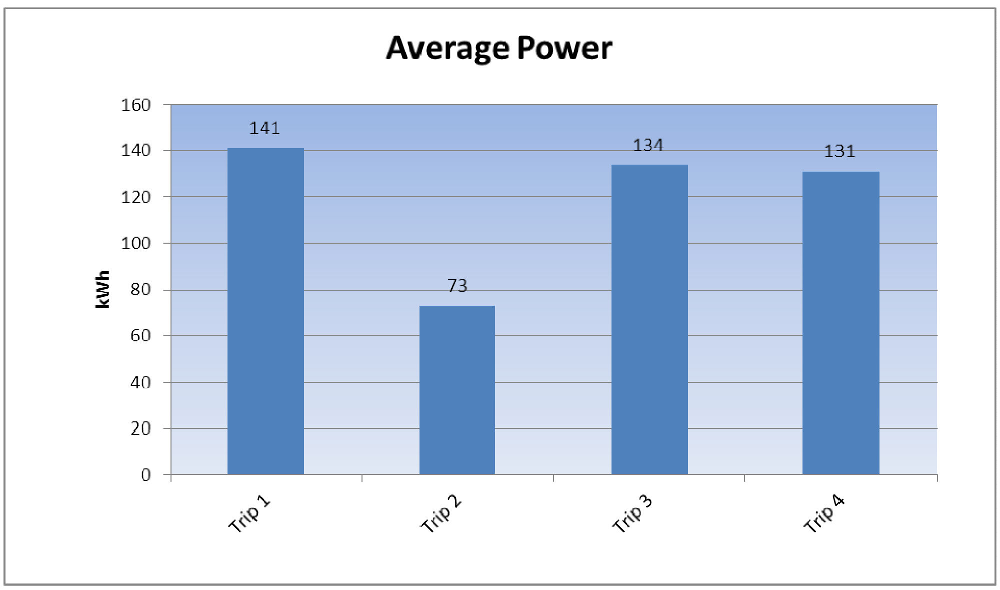


Figure 43. Average brake specific power.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle E

Test vehicle E was a distribution truck of emission standard Euro IV, equipped with a EGR system. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road with a cargo load varying between unloaded and approximately 10 000 kg

Presentation of vehicle:

Table 10. Test vehicle data.

Mileage, km	270 000
Date of registration	May 2007
Power, kW (approx.)	350
After treatment system	EGR
Test weight, kg	10860-20860
Euro standard	IV

Test program

The Chassis dynamometer tests were:

- 2 FIGE (chassis dynamometer version of ETC – European Transient Cycle) cold start
- 2 FIGE (warm start)
- 3 WHVC (World harmonized vehicle chassisdynamometer test) (warm start)

The vehicle was tested on road in a test route that represented a normal working day of the particular vehicle divided into several sub trips, some with load and some without load. Presented in this report is one trip with load and one trip without load.

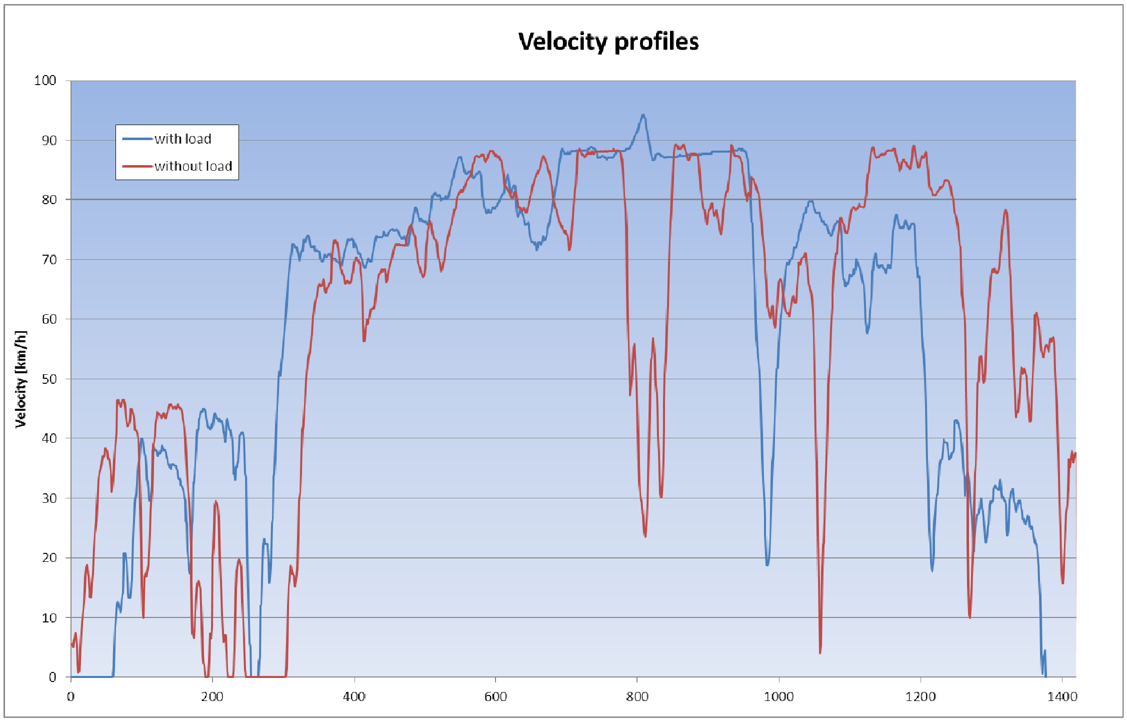


Figure 44 Velocity profile during PEMS testing.

Test results

The results are presented in Figure 45 – 51. From the figures some general conclusions can be made. The emissions of CO and HC are generally higher when driving on road compared to chassisdynamometer testing while NO_x and CO_2 are in the same order of magnitude on a distance specific emission basis. High engine load reduces the brake specific emissions during on road testing. Slightly increased emission values can be seen when comparing FIGE-warm, FIGE-cold and WHVC respectively.

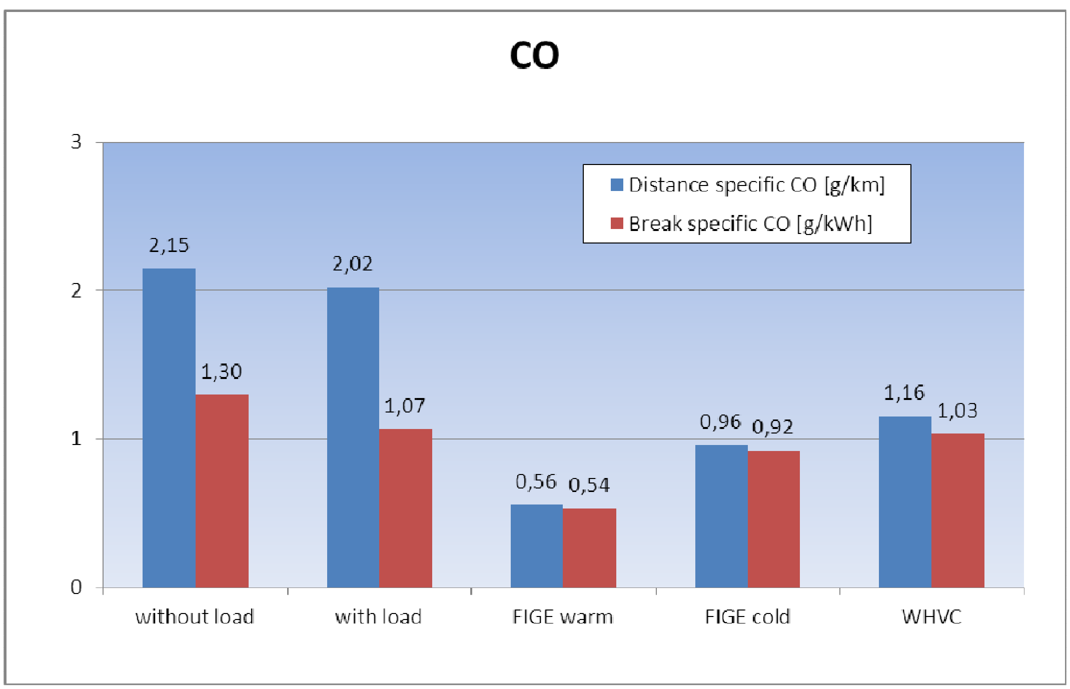


Figure 45. Emissions of CO

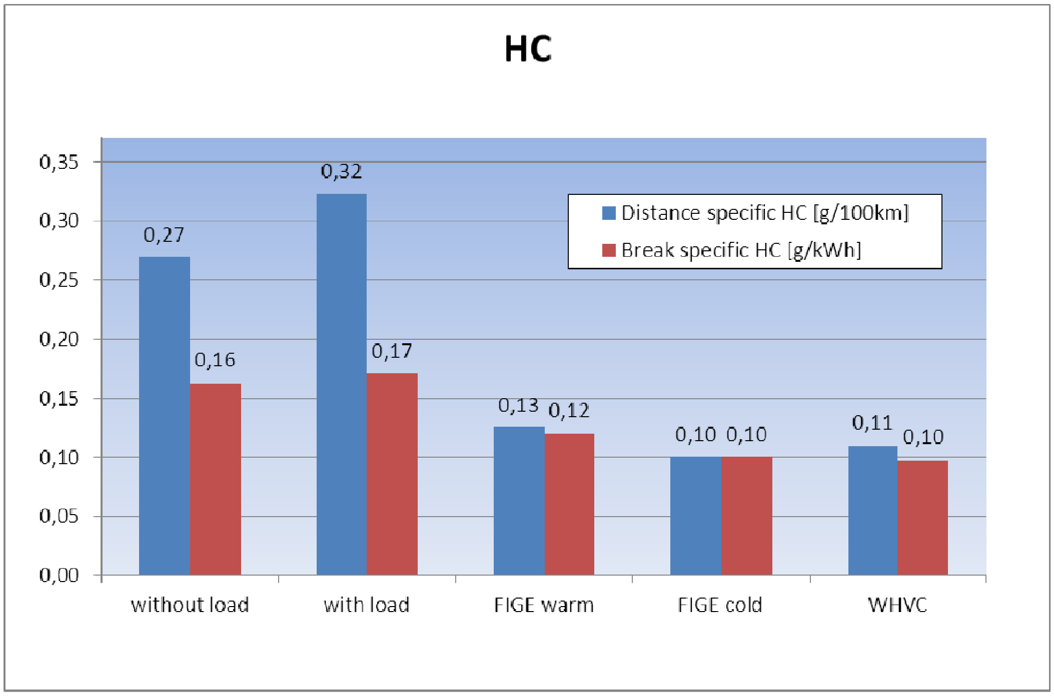


Figure 46. Emissions of HC.

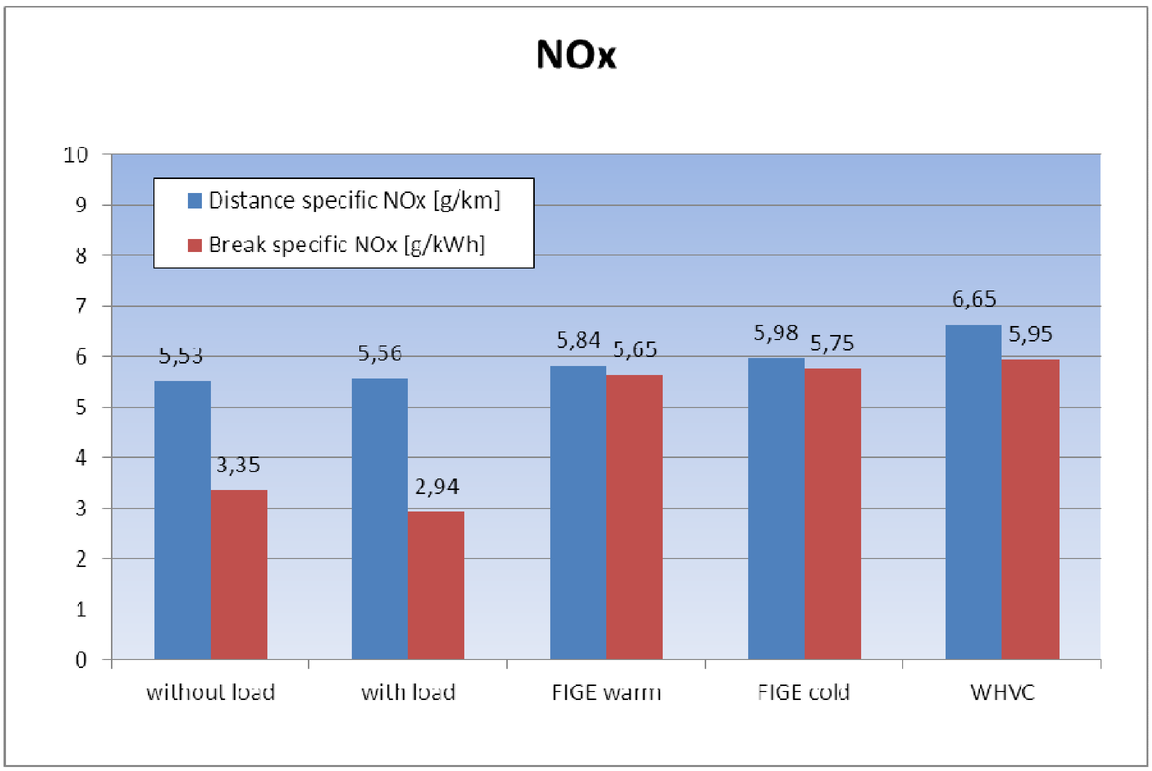


Figure 47. Emissions of NOx.

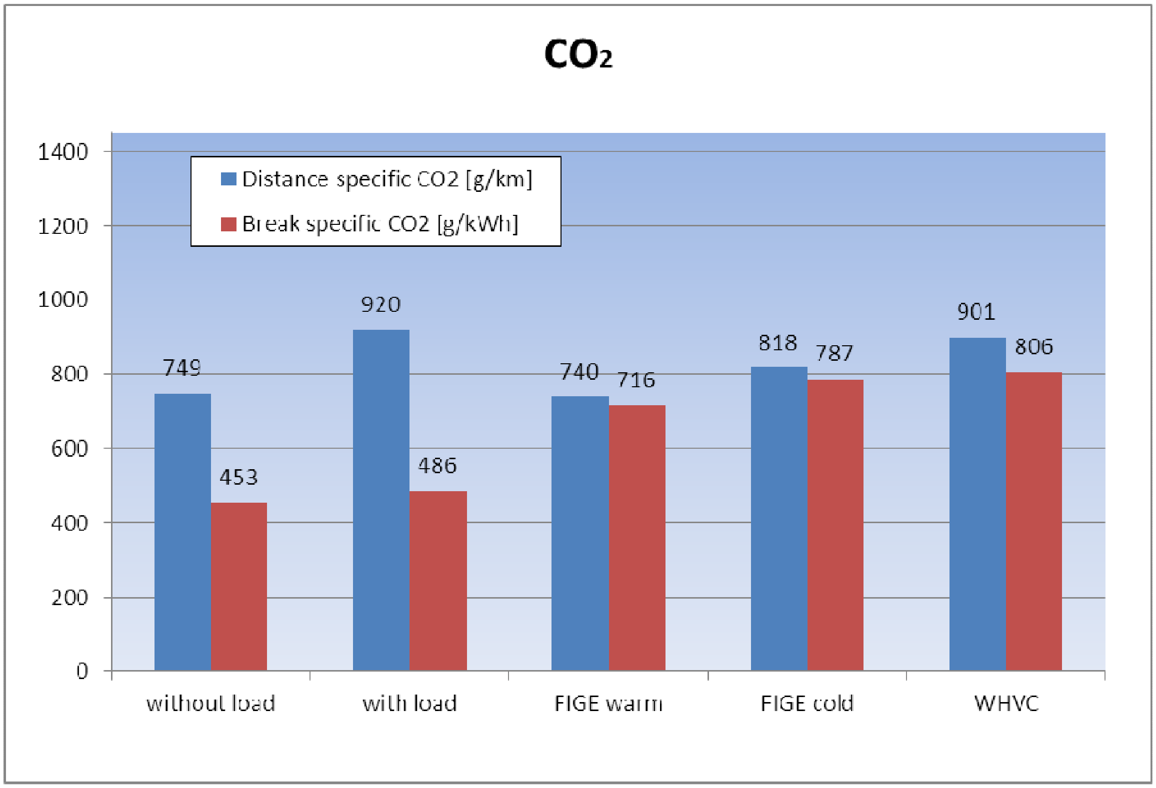


Figure 48 Emissions of CO_2.

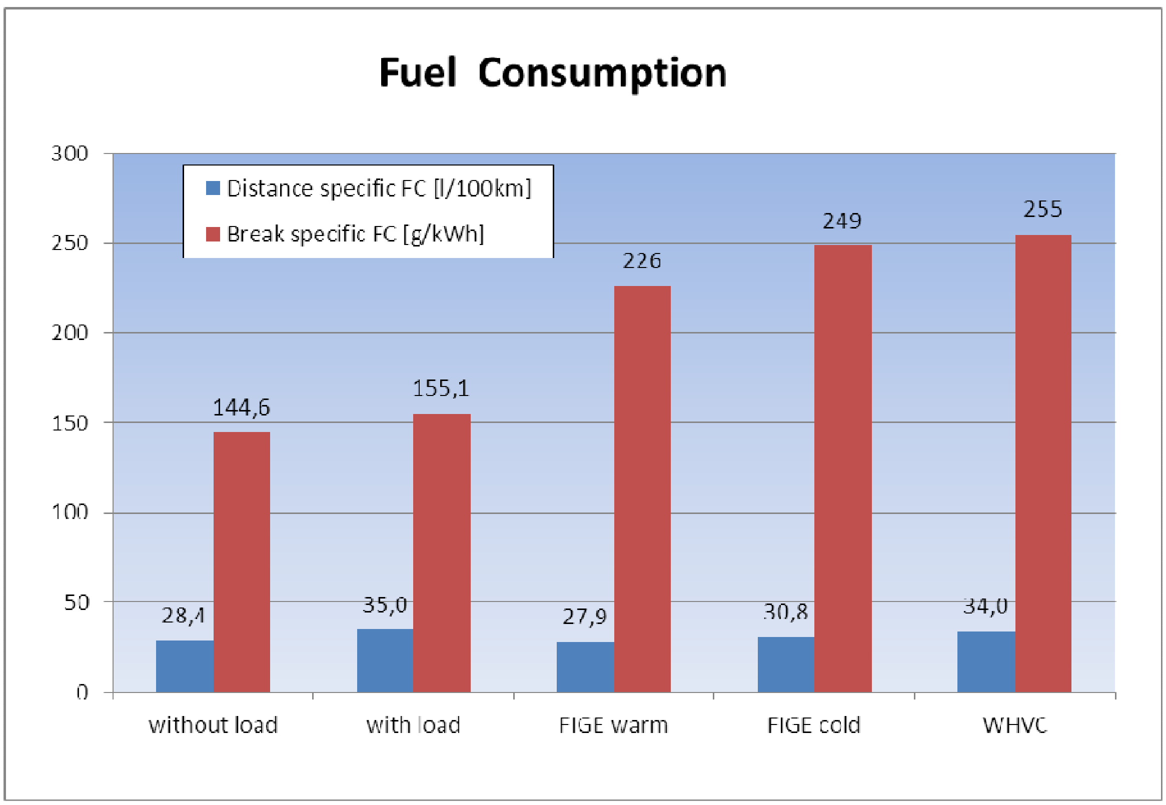


Figure 49. Fuel consumption.

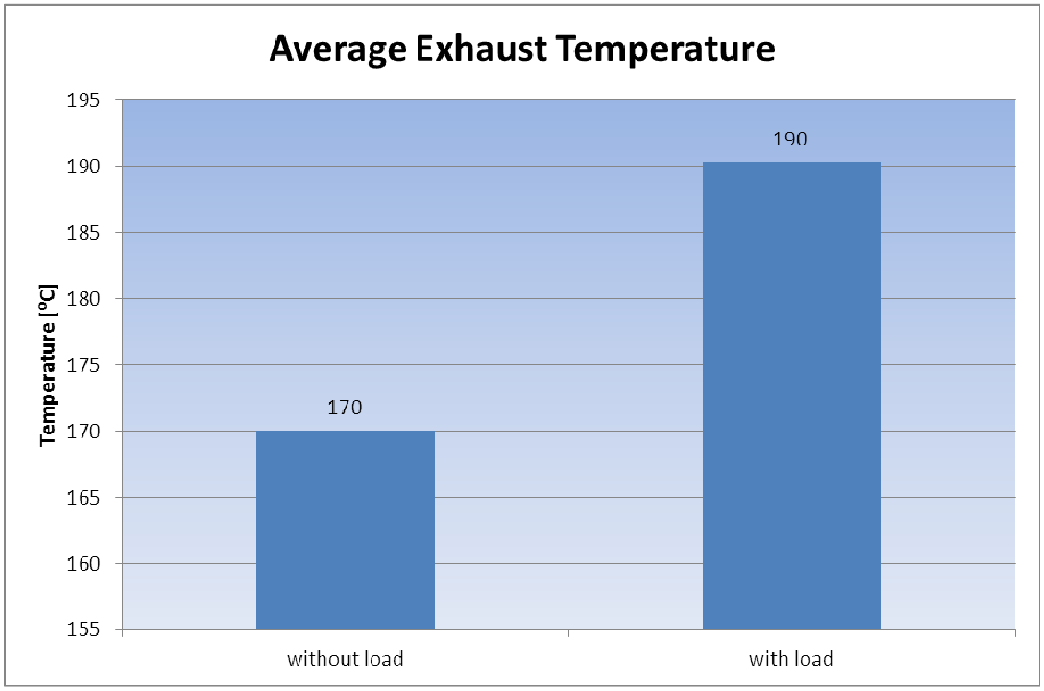


Figure 50 Average exhaust gas temperature during PEMS testing.

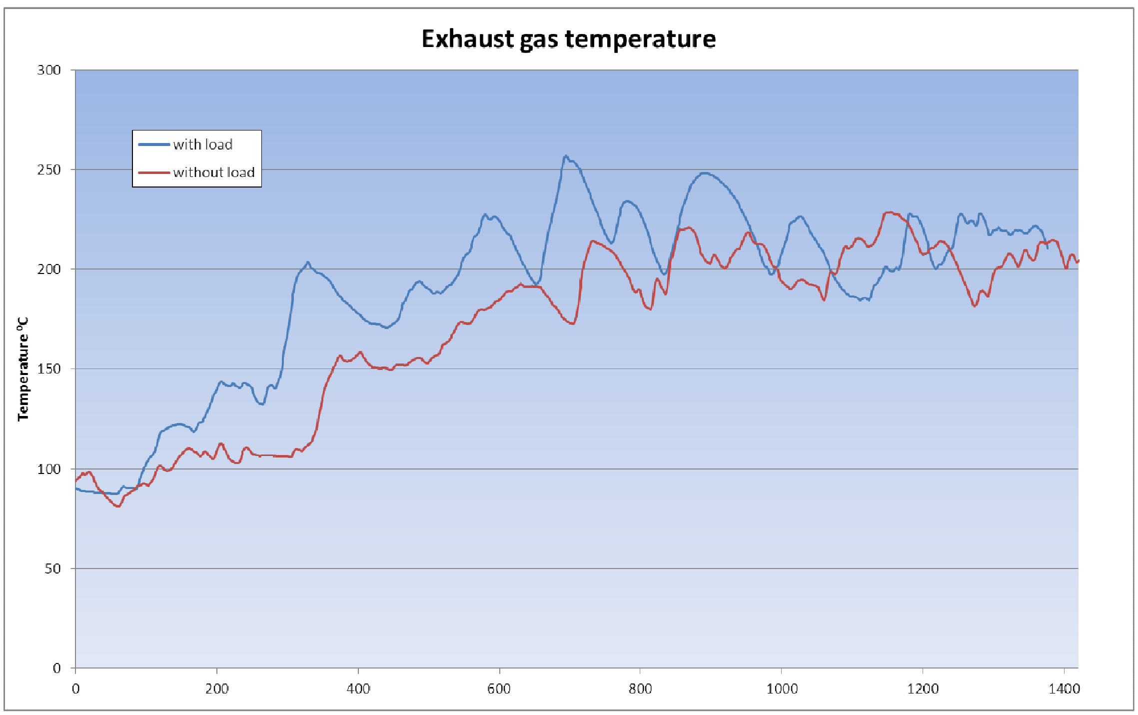


Figure 51 Exhaust gas temperature during PEMS testing.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle F

Vehicle F was a city bus equipped with a retrofitted SCRT system, which according to the supplier upgrades the Euro III vehicle to a vehicle of Euro V emission standard. The vehicle was tested was tested on road in the previous described bus route which represented typical driving for the particular vehicle. The fuel used during the tests was Mk1 diesel

The vehicle was tested on roads during driving conditions and loads representing a normal working day with a cargo load of 1370 kg. The extra net weight is corresponding to approximately 20 passengers and three test runs were carried out.

The tests were carried out with commercially available Environmental class 1 diesel (MK1). The vehicle was serviced in accordance to the manufacturer's specifications. The vehicle was tested at an average ambient temperature of approximately 11^{0}C

Presentation of vehicle:

Table 11 Test vehicle data.

Year model	2002
Mileage, km	270 000
Date of registration	May 2007
Power, kW (approx.)	190
After treatment system	SCRT
Test weight, kg	17700kg +1370kg load
Euro standard	III converted to V

Test program

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

According to the PEMS protocol the driving routes should include urban, suburban, and highway driving and if possible, also include:

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

The selected test route for this vehicle was the previous described bus line 835 in Haninge. Sweden.

Test results

The results are presented in Figure 52 - 59. From the figures some general conclusions can be made. Figure 52 - 56 has emission values corresponding to a well-functioning after treatment system. Trip1 starts with lower exhaust temperature which results in a higher HC value.

The SCRT catalyst with its particulate filter combined with the SCR catalyst reduces all regulated emissions (Pm, NOx, HC and CO). However, figure 54 shows a relatively high NO_2 proportion of the total NOx (~40%). In Table 12 are the Euro III and V standards as well as the average test results presented. However, it must be emphasised that PEMS measurement differs from the certification test procedure and can thus not be used as a pass or fail criteria. According to the test results, the retrofit system reduces the emissions as expected.

Table 12. Euro III and V limit values, g/kWh.

g/kWh	CO	HC	NOx	PM
Euro III	2.1	0.66	5.0	0.1
Euro V	1.5	0.46	2.0	0.02
Average results	0.07	0.001	2.46	NA

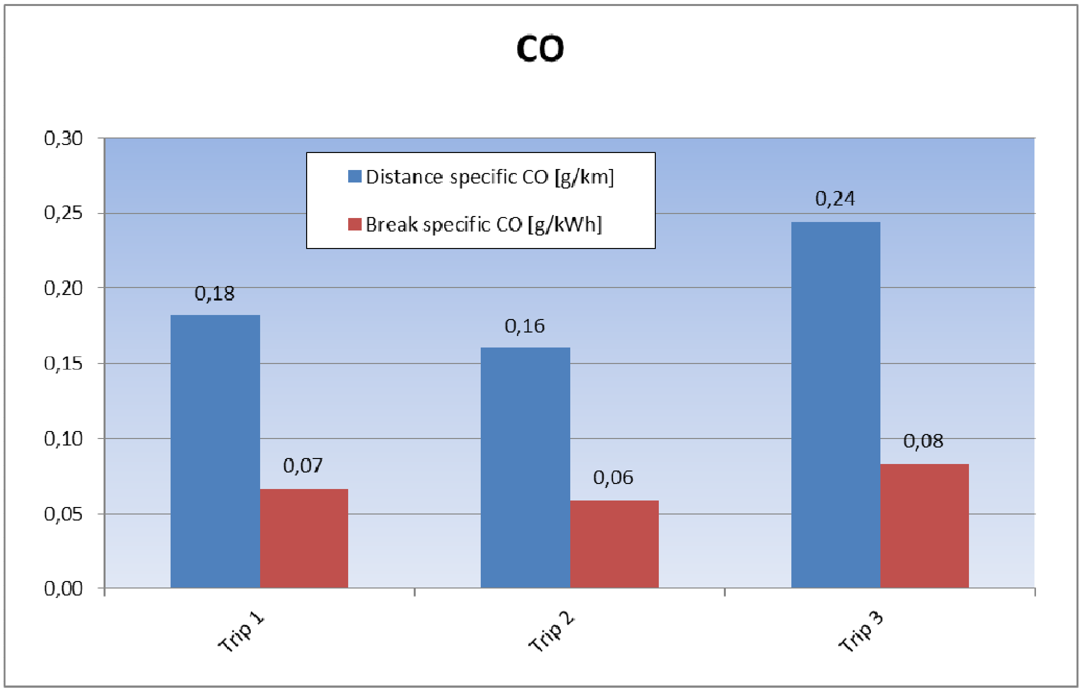


Figure 52 Emissions of CO

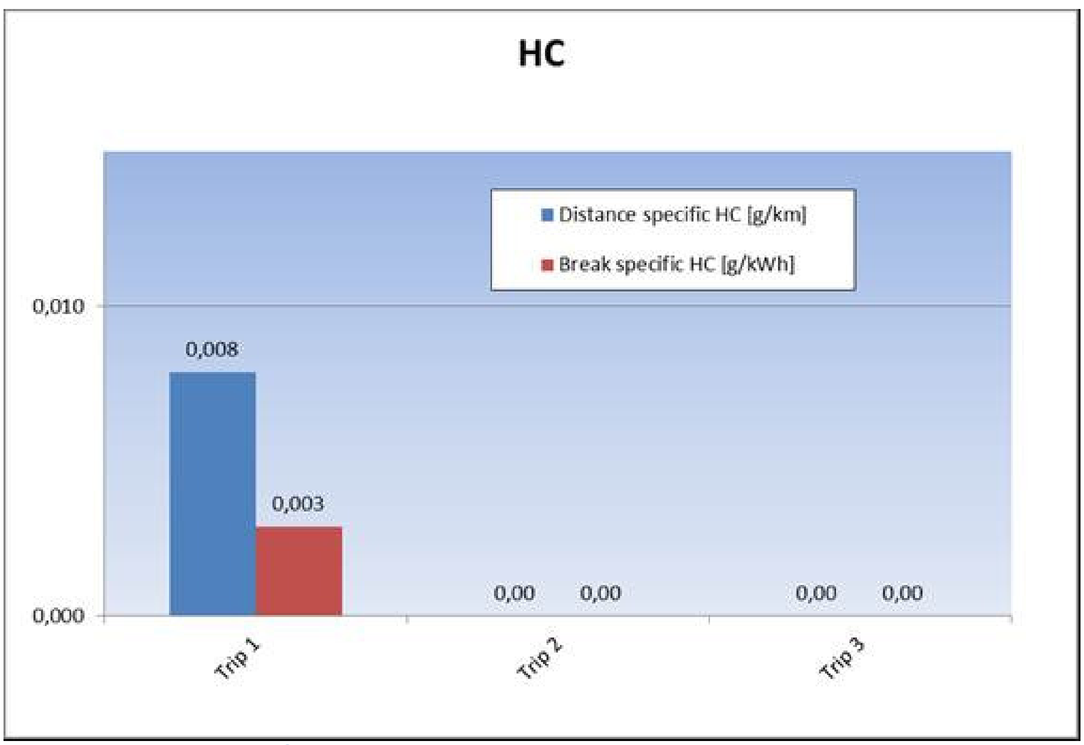


Figure 53. Emissions of HC.

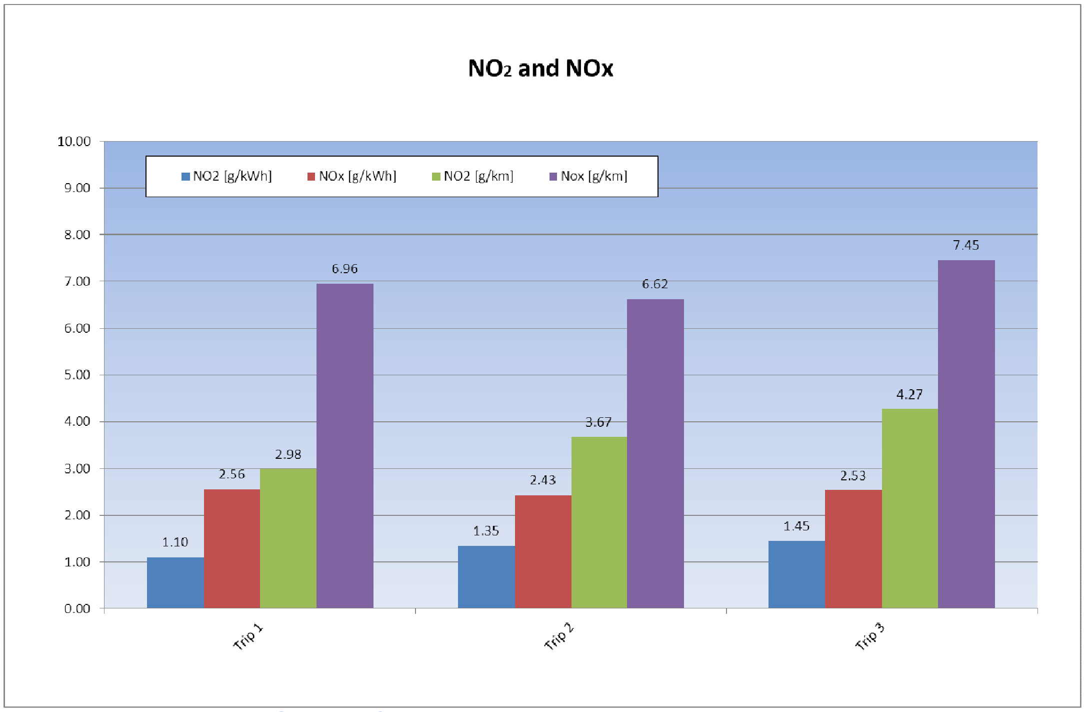


Figure 54 Emissions of NOx and NO_2

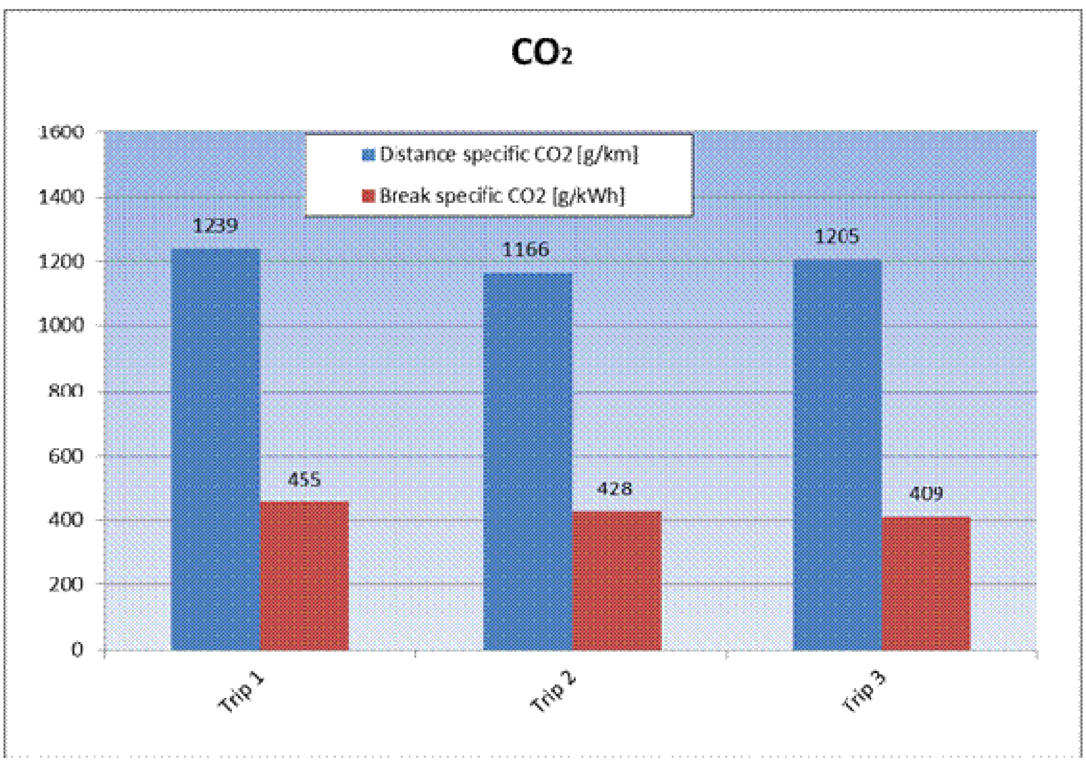


Figure 55 Emissions of CO_2.

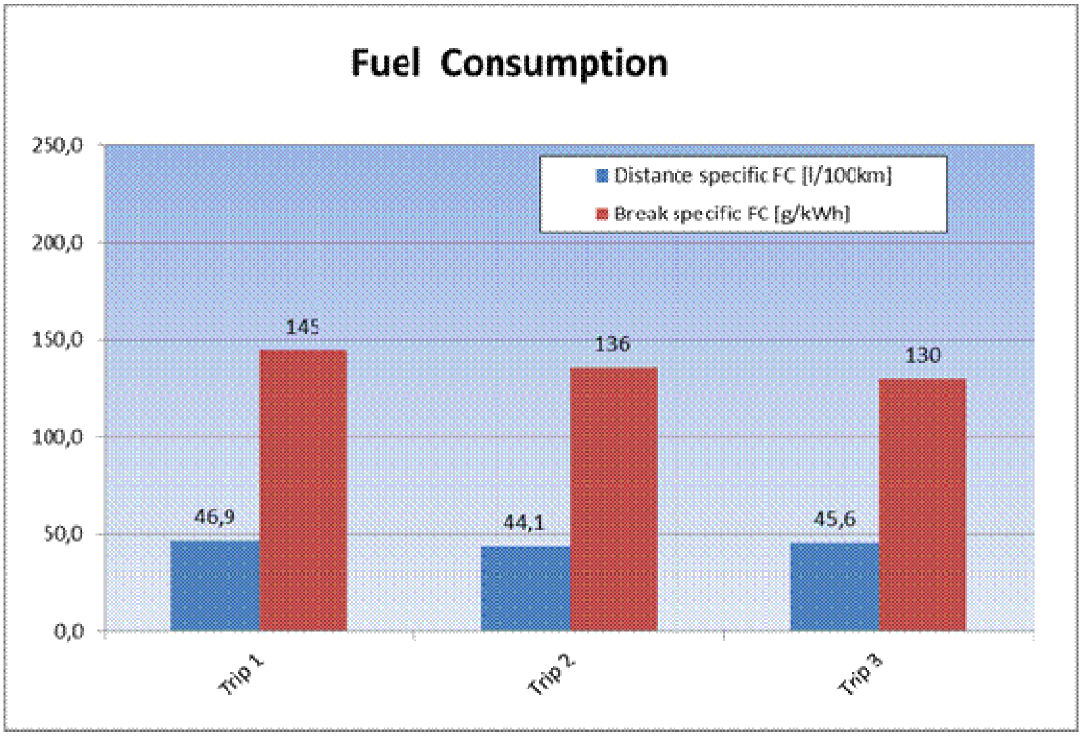


Figure 56. Fuel consumption.

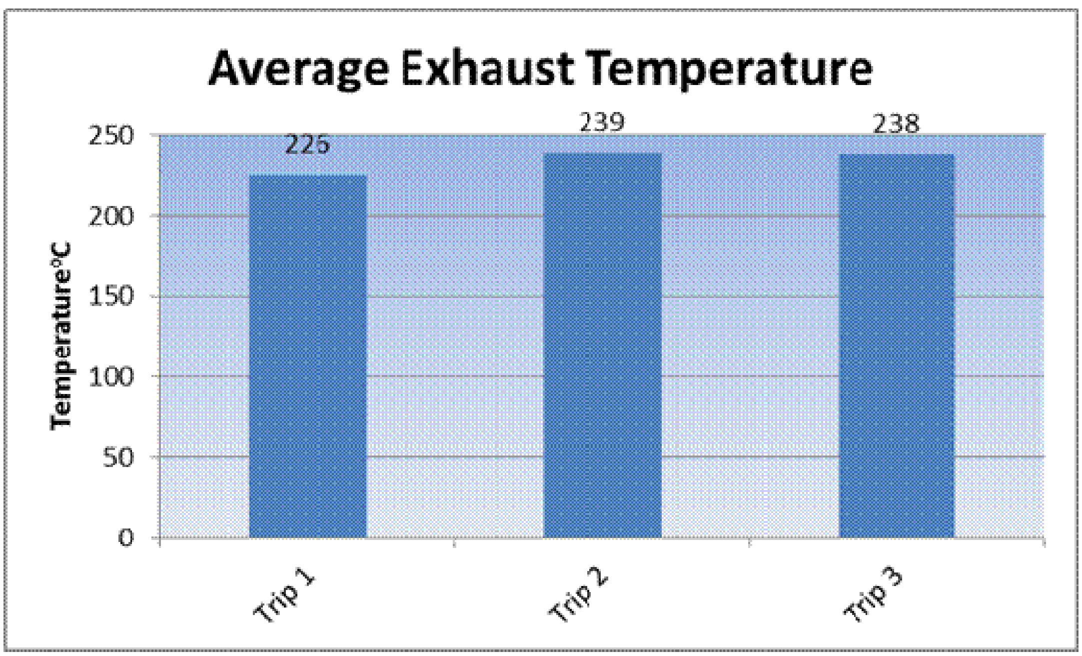


Figure 57 Average exhaust gas temperature.

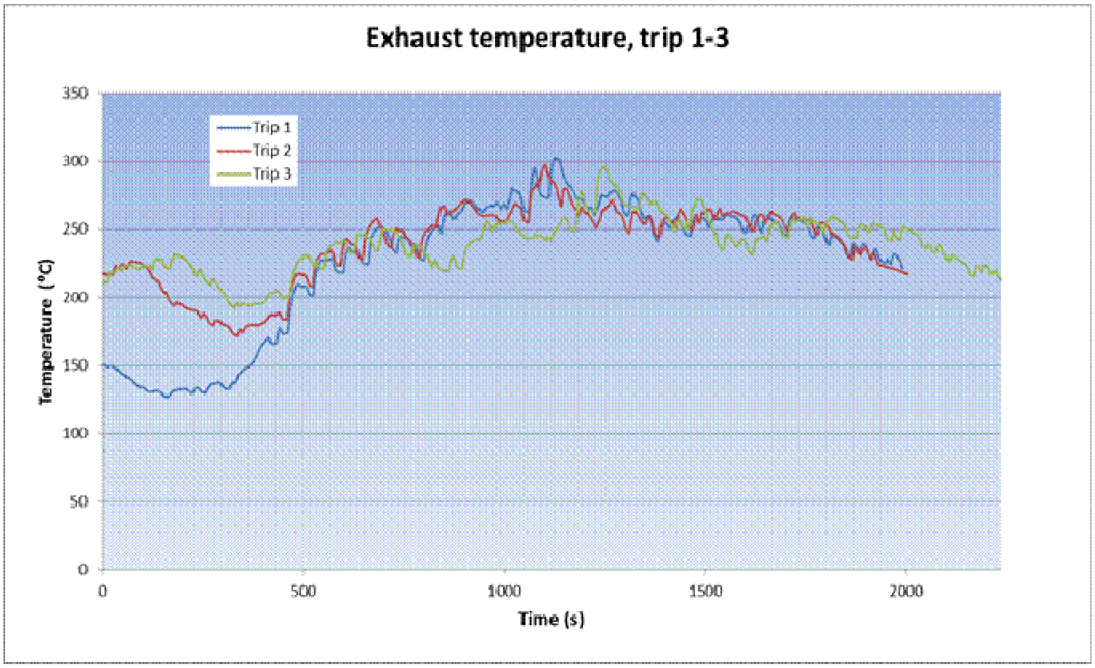


Figure 58. Exhaust gas temperature, trip 1-3.

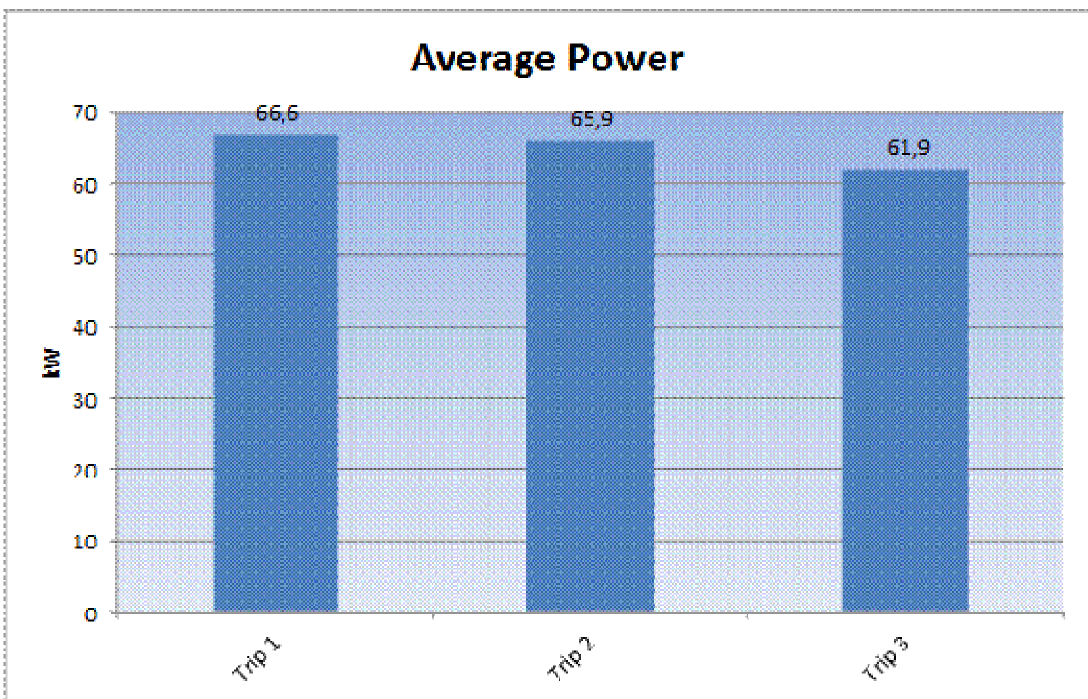


Figure 59. Average brake specific power.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure

Vehicle G

Vehicle G was a distribution truck with trailer which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. The vehicle was of euro standard V, equipped with a SCR system and the fuel used during the tests was Mk1 diesel.

The vehicle was tested on roads during driving conditions and loads representing a normal working day with a cargo load between 2 500 and 27 000 kg.

vehicle was served in accordance to the manufacturer specification. The vehicle was tested at an average ambient temperature of approximately 2ºC.

Presentation of vehicle:

Table 13. Test vehicle data.

Year model	2006
Mileage, km	263794
Date of registration	Aug 2010
Power, kW (approx.)	330
After treatment system	SCR
Test weight, kg	2 500-26 950kg load + 8545kg truck + 13500kg trailer
Euro standard	V

Test program

The test run carried out on the test vehicle represented a normal working day and was divided into four sub trips. The first three sub trips with approximately the same (medium) load and the fourth fully loaded. Sub trip number one and three consisted of mainly highway driving while sub trip number two and four represented urban and suburban driving.

Table 14 Sub trip data

Sub trip	Load
1 Södertälje – Strängnäs Mainly motorway	27 tons
2 Strängnäs- Kopparberg Mainly country road	27 tons
3 Kopparberg – Västerås 60% country road and 40% motorway	2,5 tons
4 Västerås – Eskilstuna 40% country road and 60% motorway	0 tons

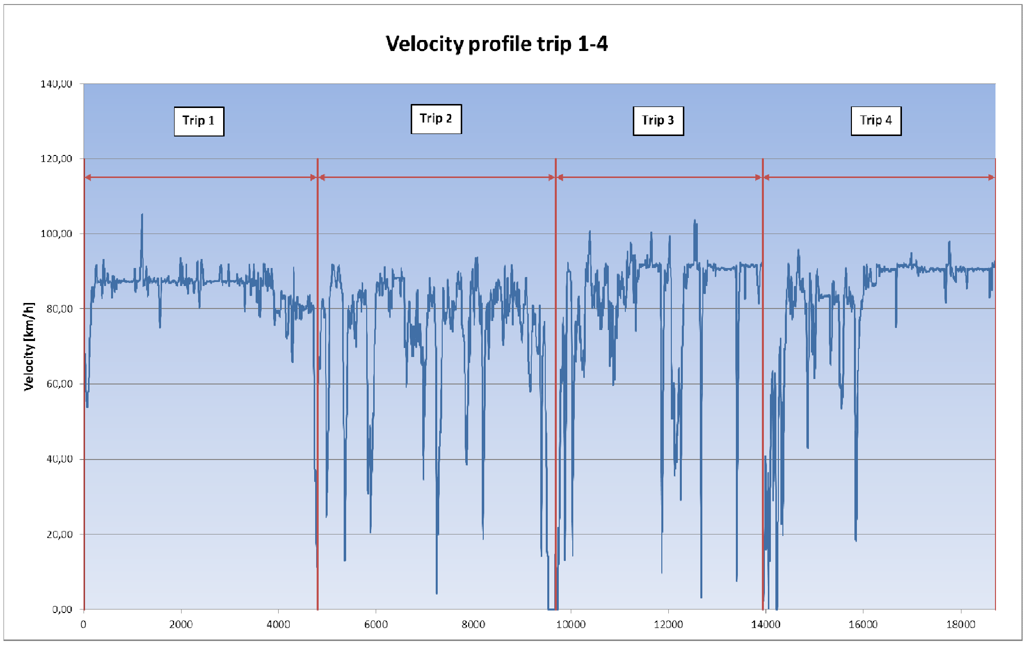


Figure 60. Velocity profile in sub trip 1-4

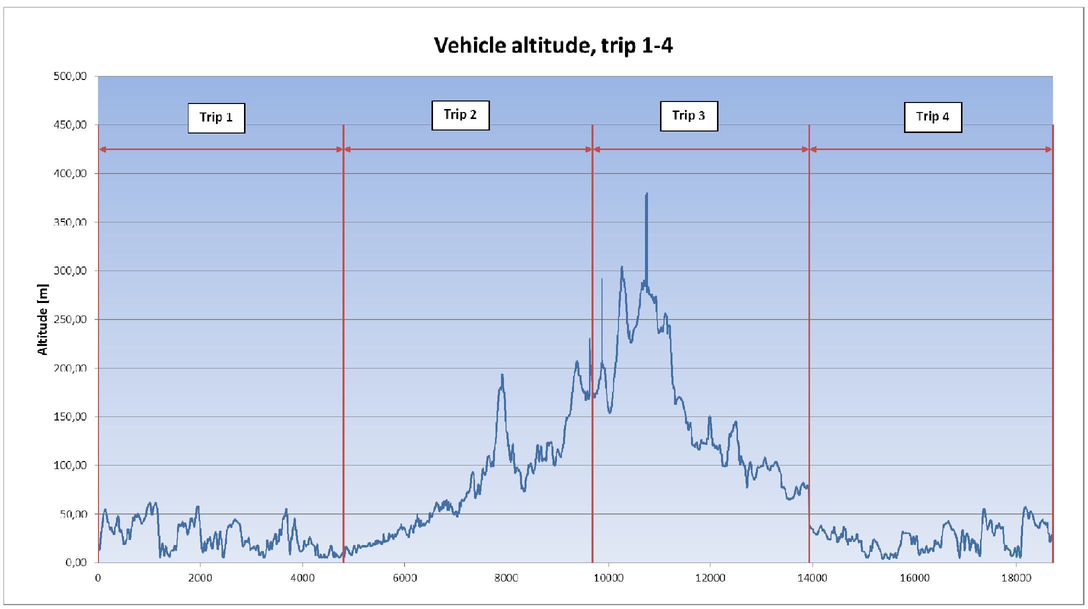


Figure 61. Vehicle altitude, sub trip 1-4

Test results

The results are presented in Figure 62 – 69. From the figures some general conclusions can be made.

There is no significant difference between the emissions on full load compared to no load. When comparing trip 1 and trip 2 it can be seen that the fuel consumption is higher when the driving pattern is more transient. It can also be seen that emissions of NOx are slightly higher when the exhaust gas temperature is lower. Higher load gives higher exhaust gas temperatures, lower emissions and increased CO_2 and fuel consumption.

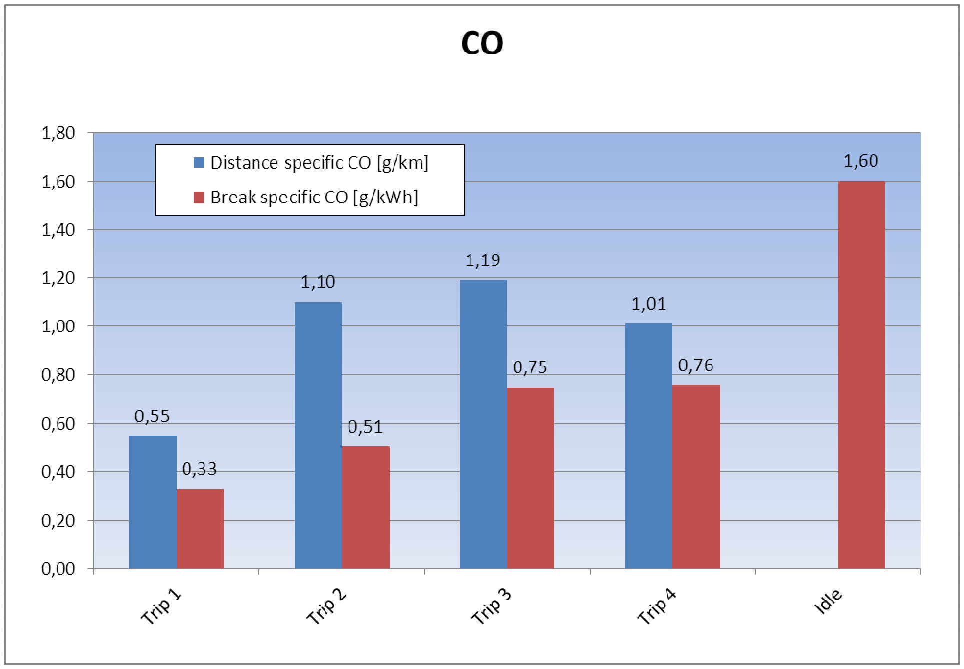


Figure 62. Emissions of CO

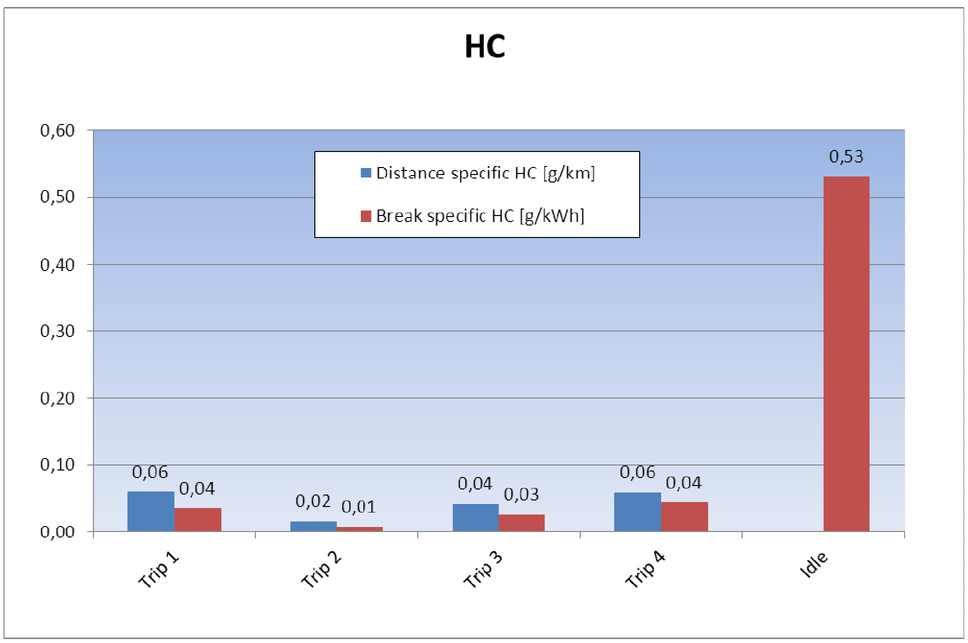


Figure 63. Emissions of HC.

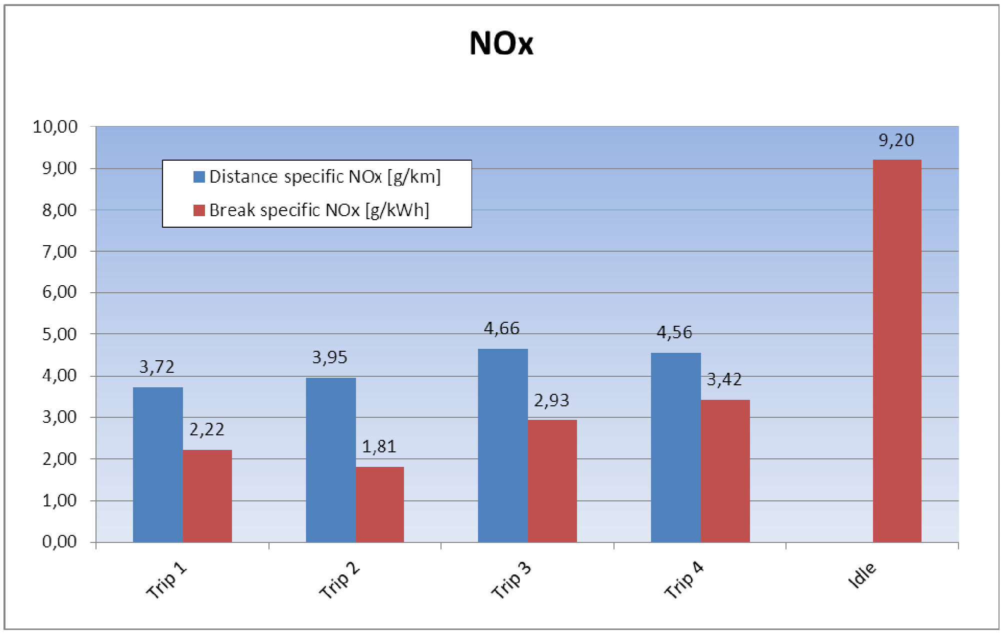


Figure 64. Emissions of NOx.

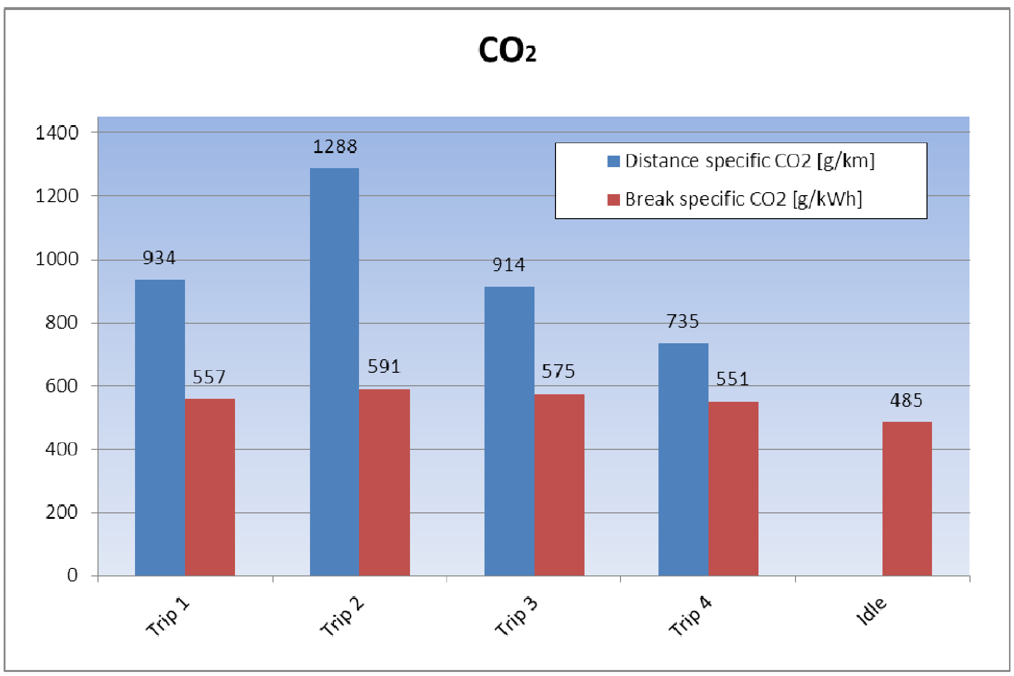


Figure 65. Emissions of CO_2.

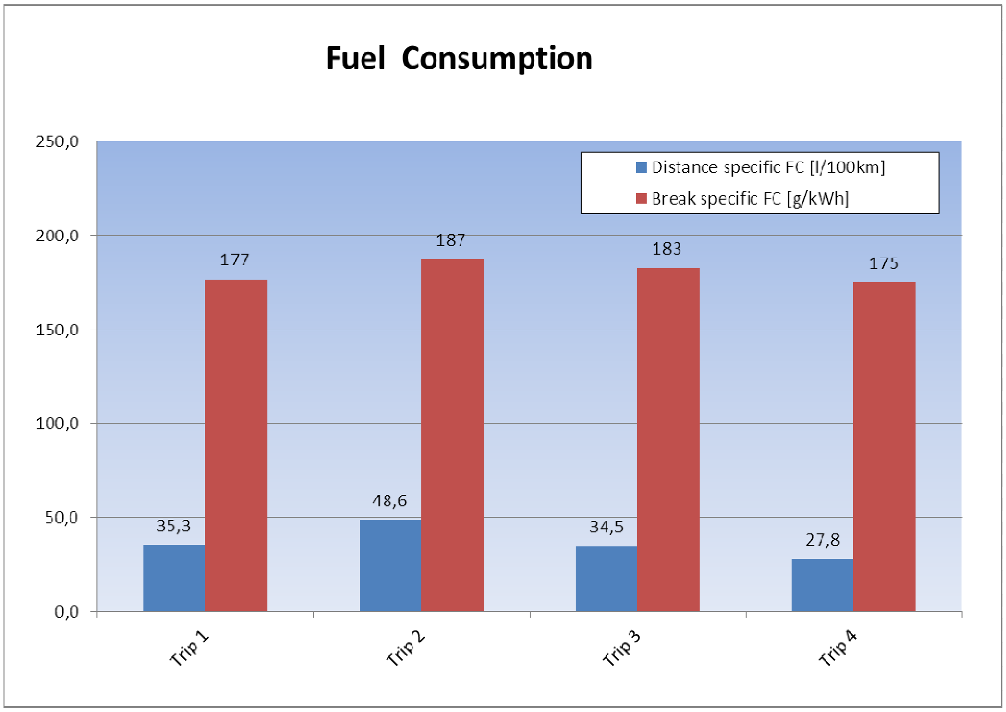


Figure 66. Fuel consumption.

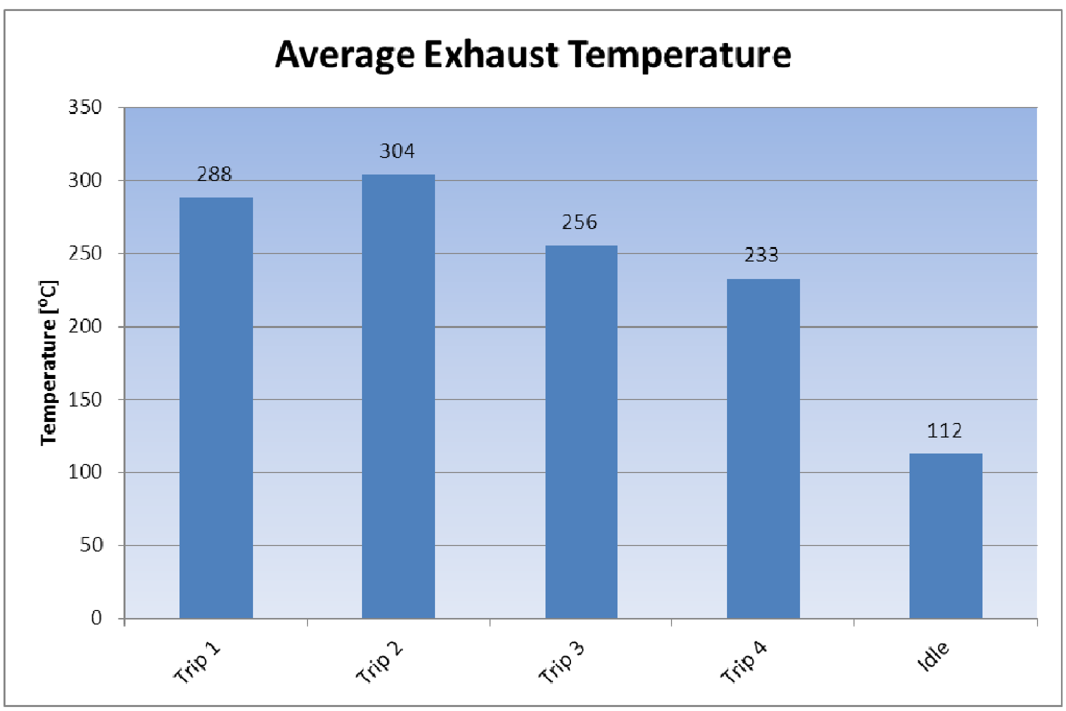


Figure 67. Average exhaust gas temperature.

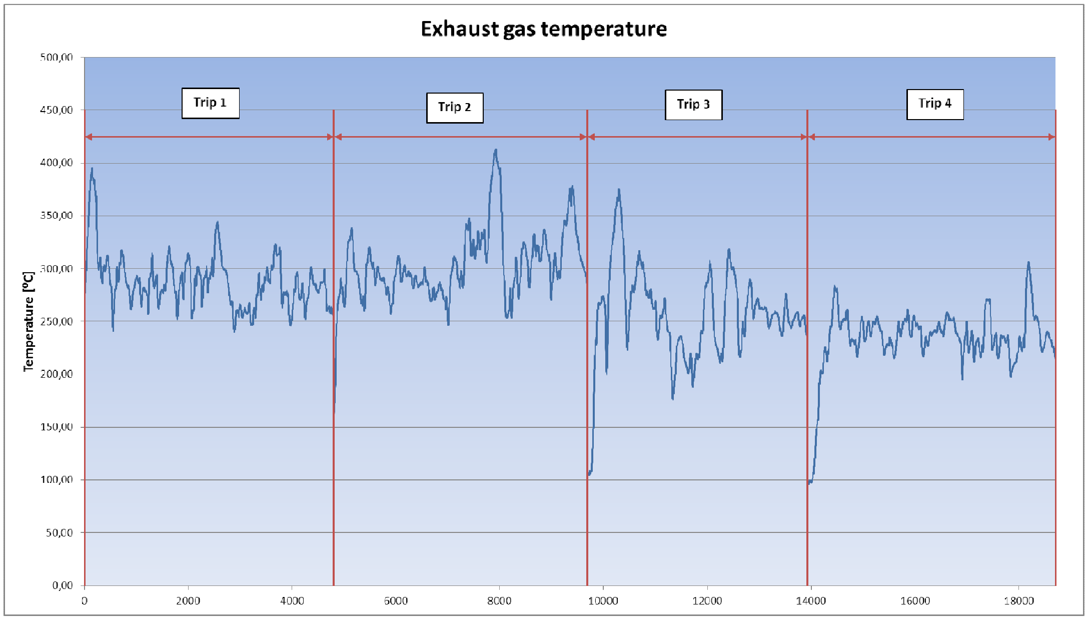


Figure 68. Exhaust gas temperature, trip 1-4.

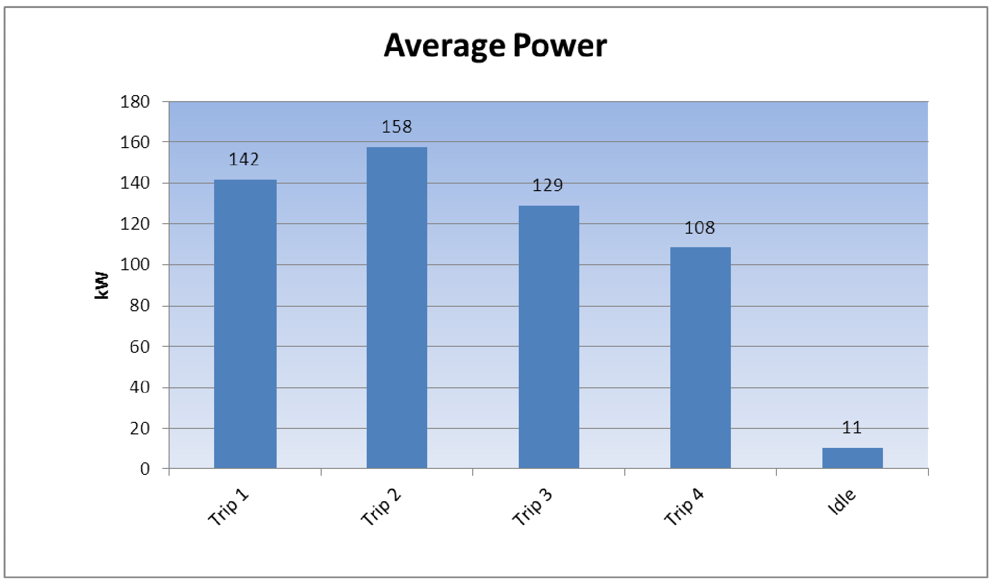


Figure 69. Average brake specific power.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle H

Vehicle H was a hybrid garbage truck which was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. The vehicle was of euro standard V, equipped with a SCR system and the fuel used during the tests was Mk1 diesel.

The tests were carried out with commercially available Environmental class 1 diesel (Mk1). The vehicle was served in accordance to the manufacturer specification. The vehicle was tested at an average ambient temperature of 11 °C.

Presentation of vehicle:

Table 15. Vehicle data.

Year model	2011
Mileage, km	2500
Power, kW (approx.)	250
Test weight, kg	20 000
Euro standard	V

Test program

The vehicle was tested during a normal working day in rural areas outside Stockholm.

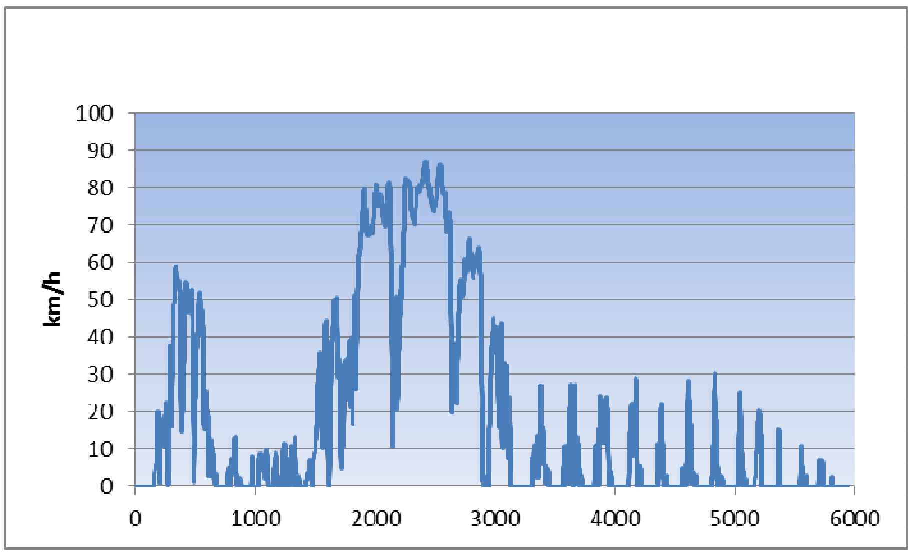


Figure 70. Distance specific CO mass emission.

Test results

The results are presented as distance specific emissions in Figure 70 and as brake specific emissions in Figure 71. From the figures some general conclusions can be made. During the start/stop testing the exhaust temperature was in average 160°C. The light off temperature of the catalyst is approximately 250°C. This implies that despite a good functioning exhaust after treatment system reduction of NOx was only obtained during urban and highway driving, thus generating brake specific emission higher than Euro V limits. However, it must be emphasised that PEMS measurement differs from the certification test procedure and can thus not be used as a pass or fail criteria

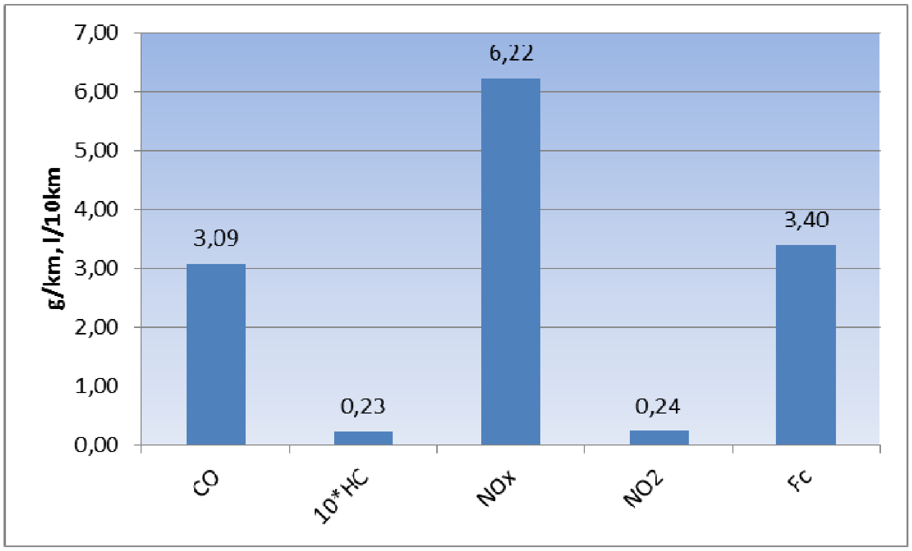


Figure 70. Distance specific CO mass emission.

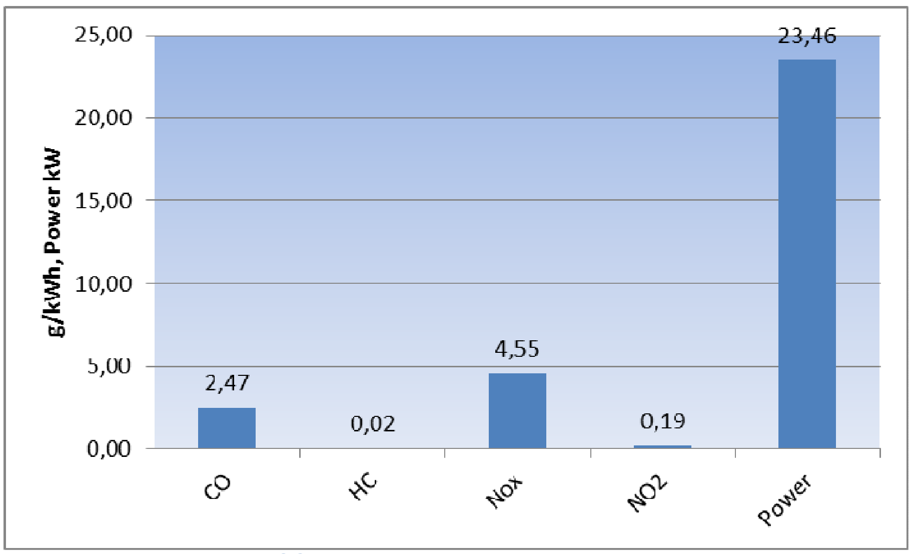


Figure 71. Brake specific CO mass emission.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle I

Vehicle I was a tractor trailer truck of Euro standard EEV equipped with a EGR system. The test fuel used during the tests was commercially available ethanol (ED95).

The vehicle was tested on roads during driving conditions and loads representing a normal working day with an unloaded trailer (6700 kg) as well as with a trailer loaded with 21 000 kg (+trailer weight 6700 kg).

Presentation of vehicle:

Table 16 Test vehicle data.

Year model	2012
Mileage, km	8121
Date of registration	February 2012
Power, kW (approx.)	200
After treatment system	EGR
Test weight, kg	13286-34286
Euro standard	IV/EEV

Test program

The vehicle was tested on road in a test route that represented a normal working day of the particular vehicle and with different loads throughout the day. In addition, the vehicle was tested on chassis dynamometer. The tests were carried out with commercially available Ethanol (ED95).

The Chassis dynamometer tests were:

- 2 WHVC (World harmonized vehicle chassisdynamometer test) cold start
- 3 WHVC hot start
- 2 Fige (chassis dynamometer version of ETC – European Transient Cycle)

On-board measurement

The test run was divided into three sub trips. The first two sub trips with the same load (34 tonnes) and the third without load.

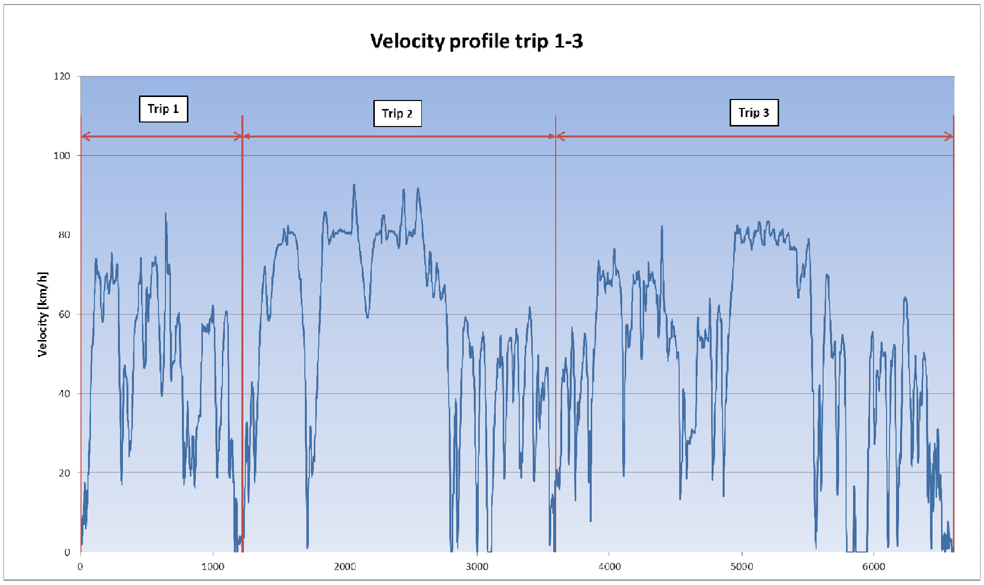


Figure 72. Velocity profile in sub trip 1-3

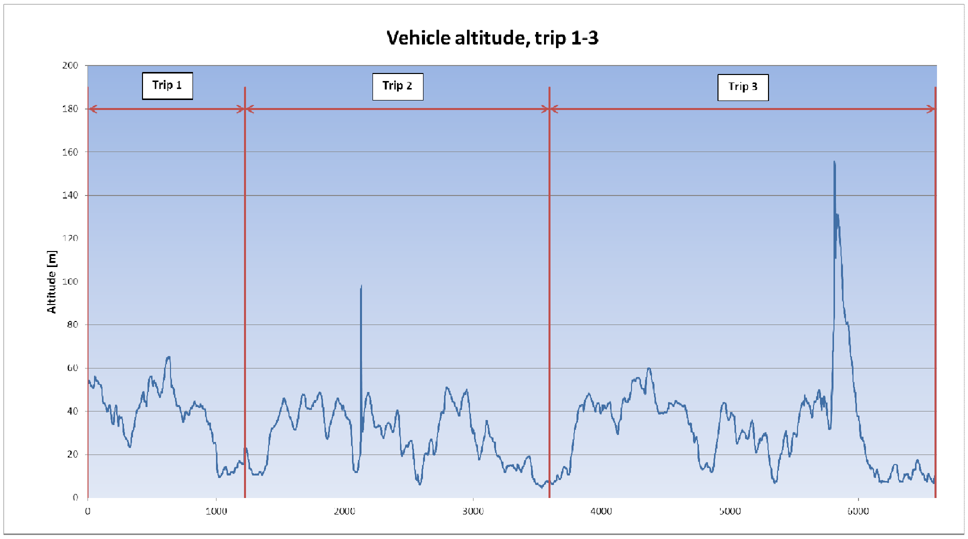


Figure 73. Vehicle altitude, sub trip 1-3

Test results

The results are presented in Figure 74 – 81. From the figures some general conclusions can be made. All regulated emissions are higher during cold start (+22 ºC). Distance specific emissions and fuel consumption are generally higher during on-board measurements compared to chassisdynamometer testing except the emissions of NOx (in average +30%). This may due to the higher load on the road testing, thus implying higher exhaust temperature and higher formation of NOx.

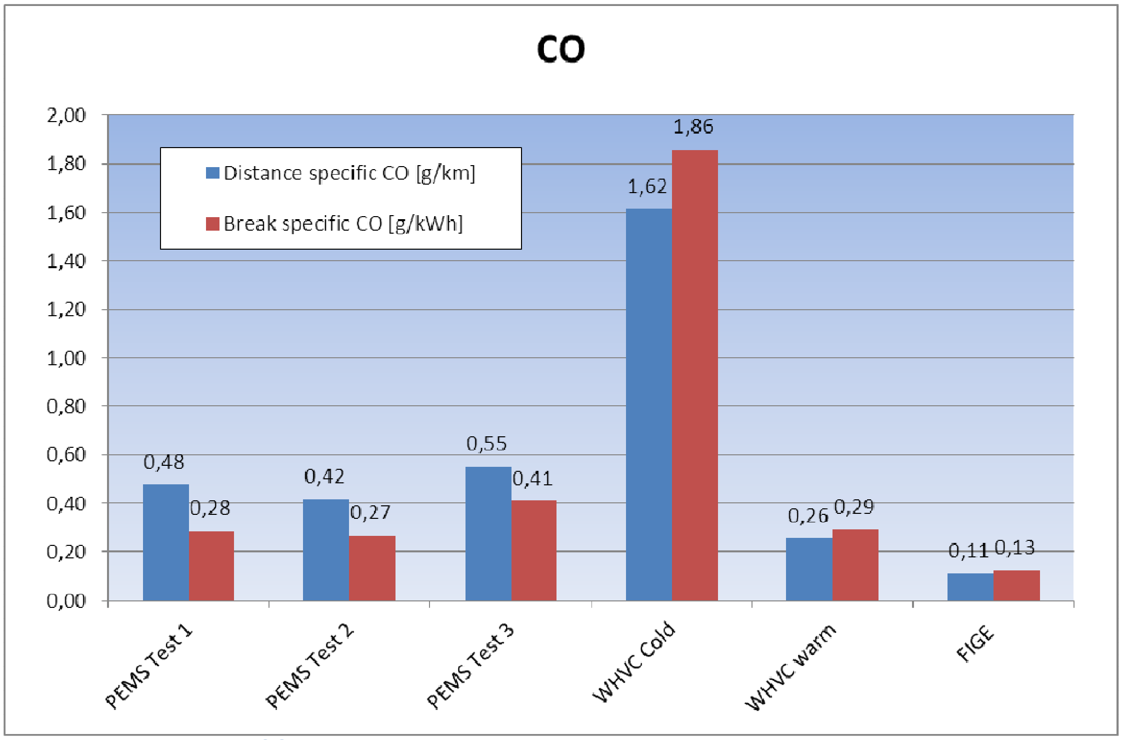


Figure 74 Emissions of CO

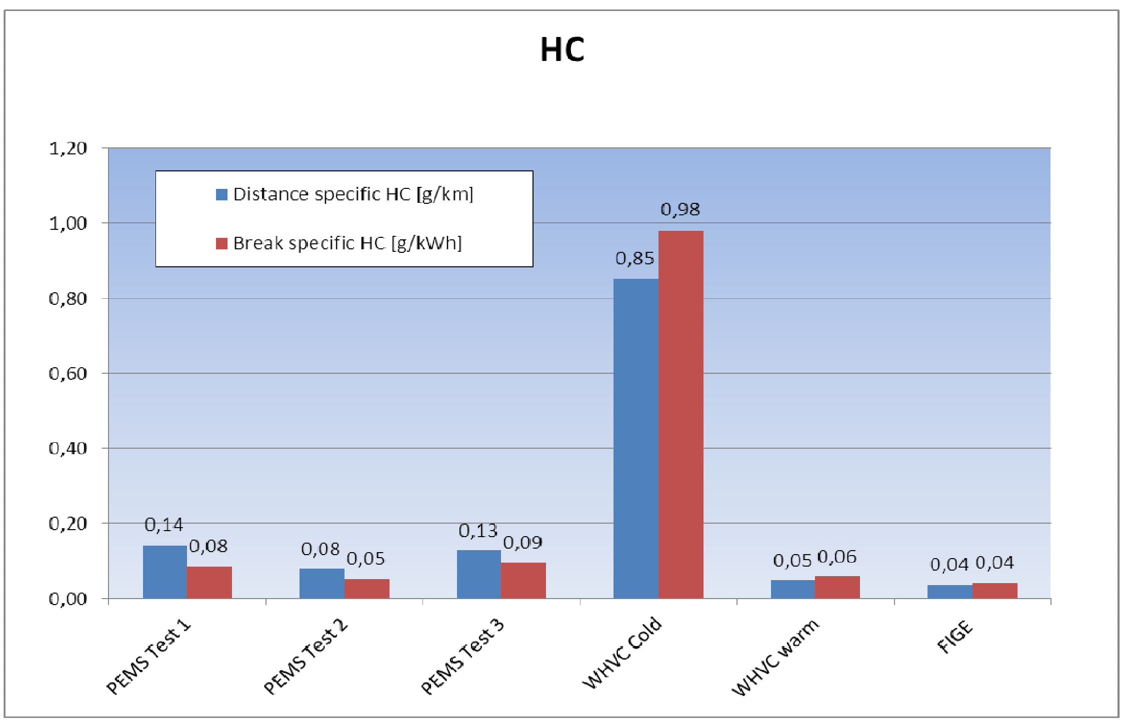


Figure 75. Emissions of HC.

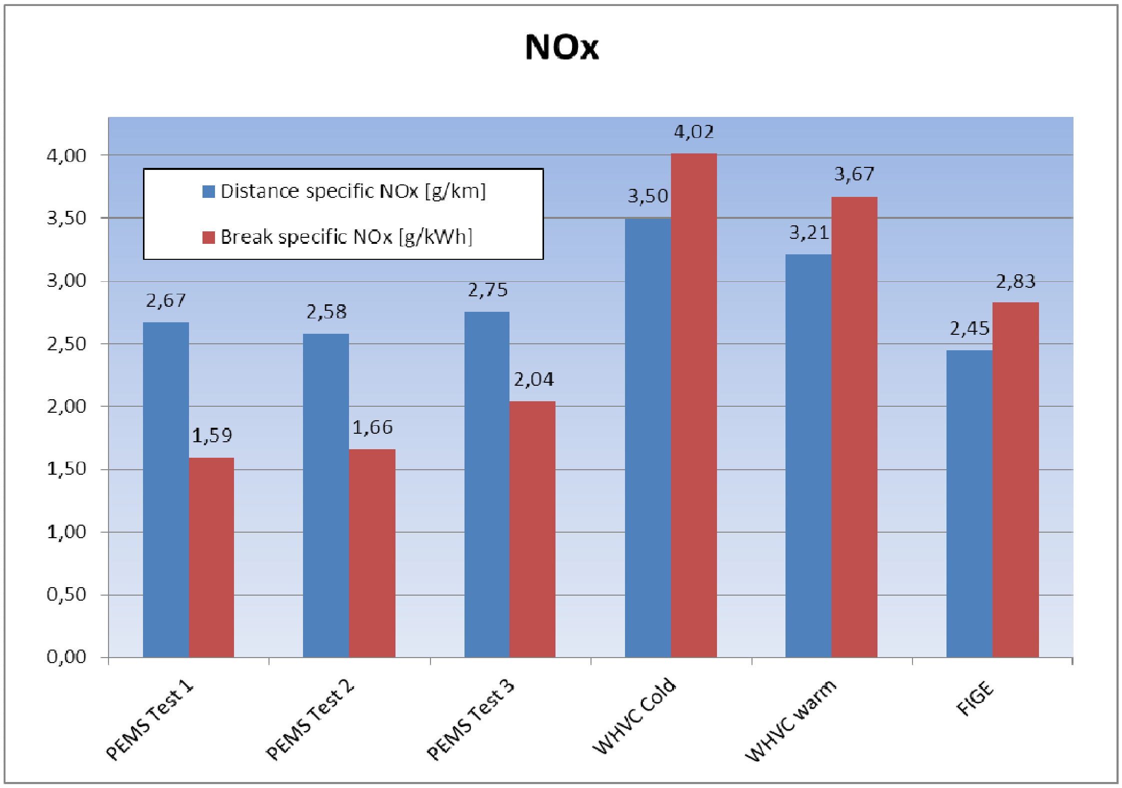


Figure 76. Emissions of NOx.

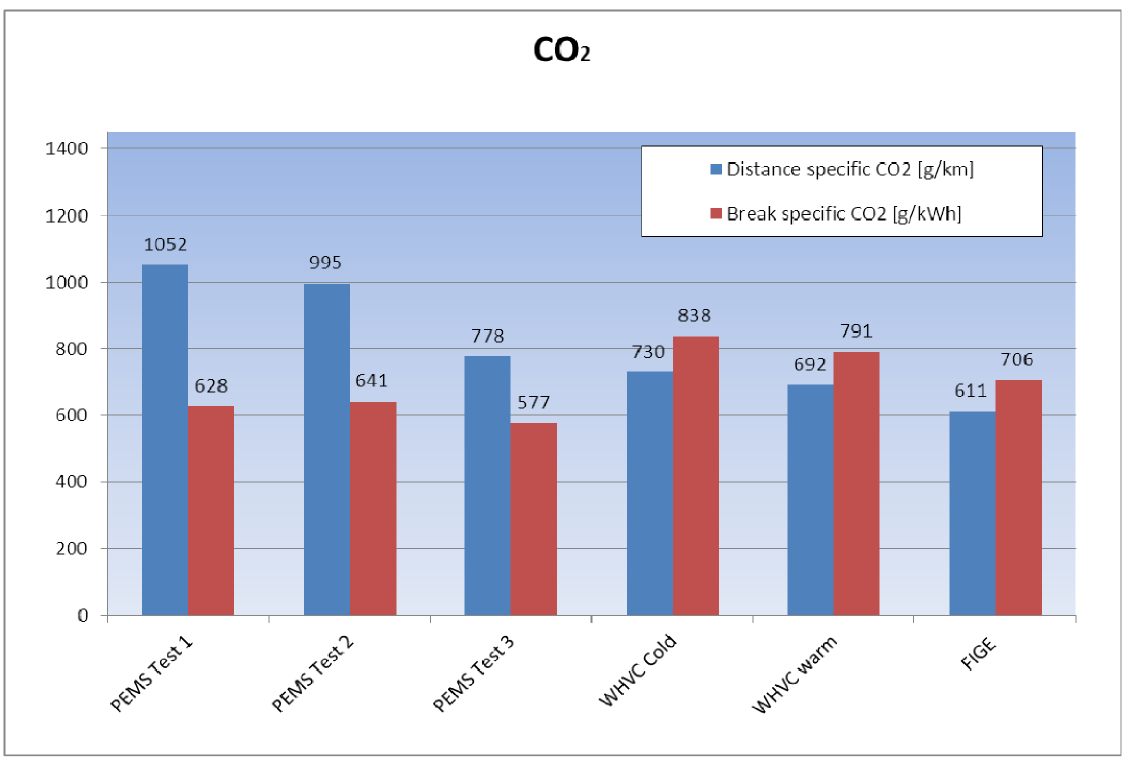


Figure 77 E.missions of CO_2.

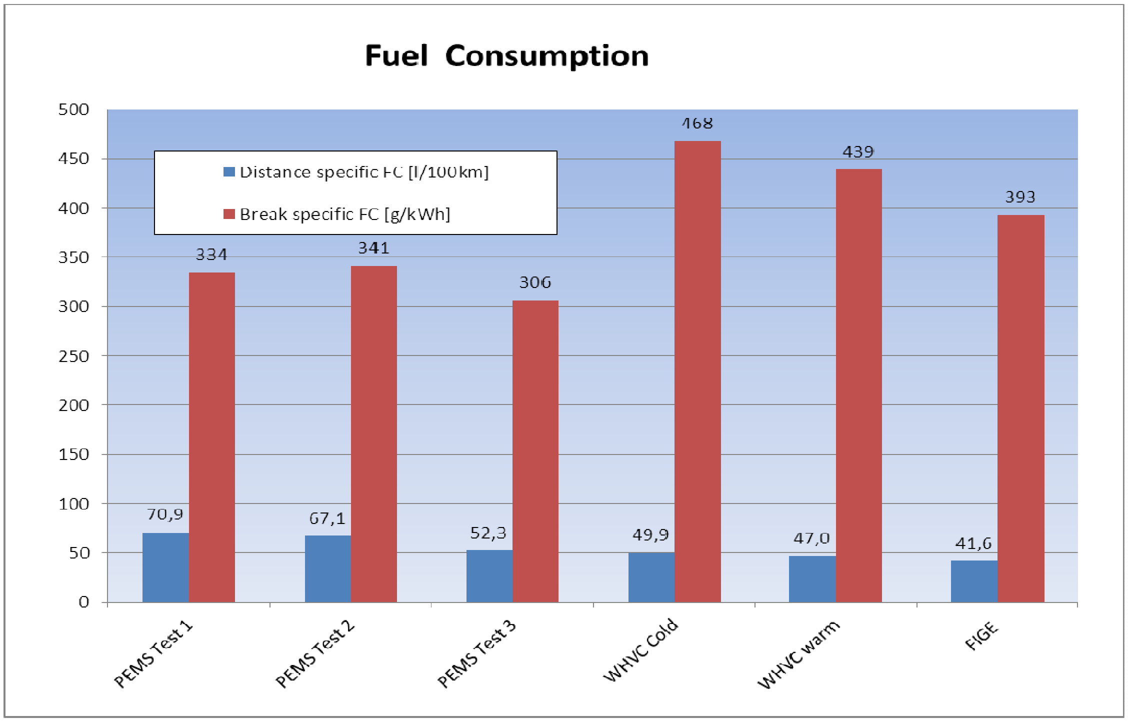


Figure 78. Fuel consumption.

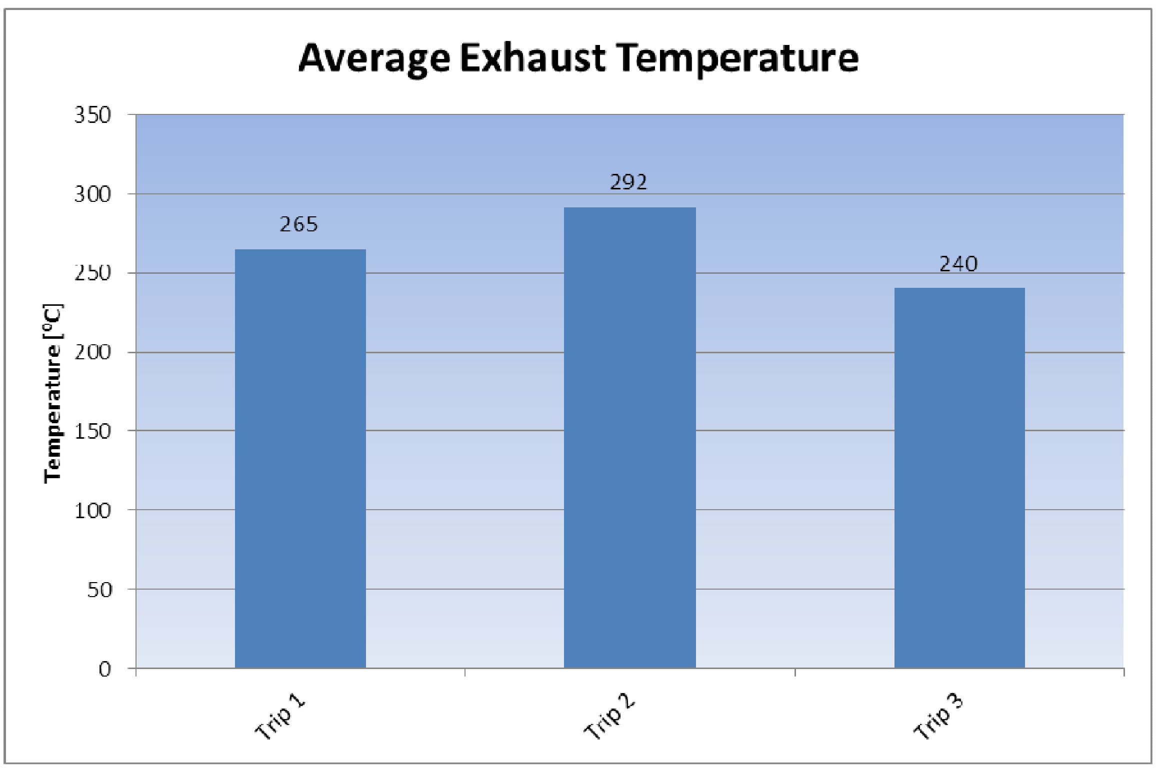


Figure 79. Average exhaust gas temperature.

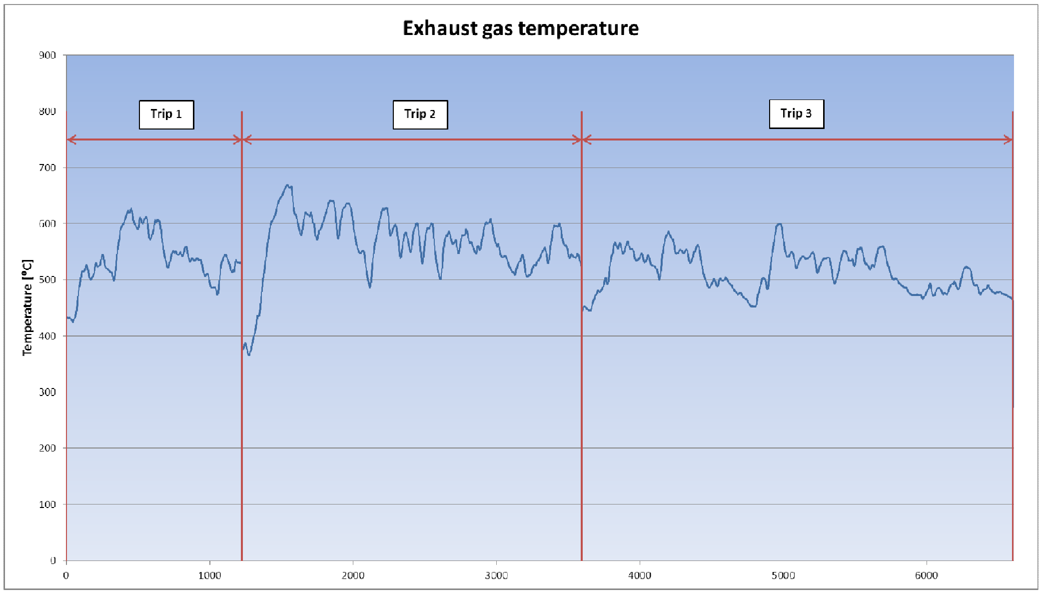


Figure 80 Exhaust gas temperature, trip 1-4.

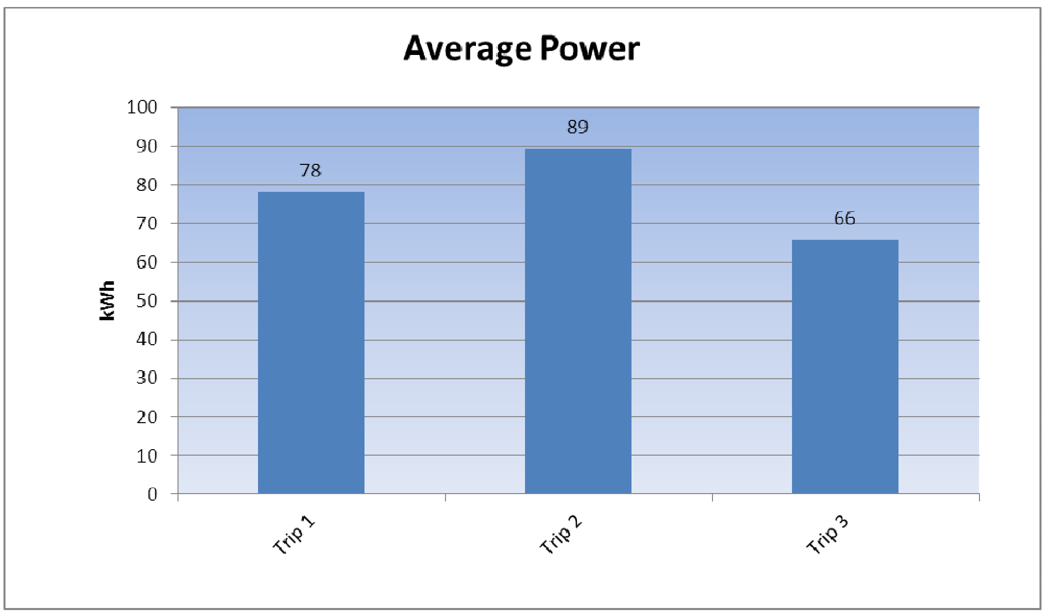


Figure 81 Average brake specific power.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle J

Test vehicle J was a city bus of euro standard EEV equipped with a DOC. The fuel used during the tests was Compressed Natural Gas (CNG). The vehicle has been tested both on chassis dynamometer and on road with a load corresponding to approximately 20 passengers.

Presentation of vehicle:

Table 17 Test vehicle data.

Year model	2010
Mileage, km	15500
Date of registration	2011-01-26
Power, kW (approx.)	199
Test weight, kg	14200
Euro standard	EEV

Test program

The Chassis dynamometer tests were:

- 2 WHVC (Worldwide Harmonized Vehicle Cycle, chassis dynamometer version of WHTC - Worldwide harmonized Transient Cycle) cold start
- 3 WHVC hot start
- 1 Fige (chassis dynamometer version of ETC – European Transient Cycle)

The test routes selected for this vehicle was bus line 835 in Haninge, Sweden, and AVL MTC's PEMS pilot study test route which has been inspected and accepted by JRC.

Three test runs were carried out in the bus route and one test in the PEMS route.

Test results

The test results are presented in Figure 82 – 87 and in Table 18. From the figures some general conclusions can be made. For a vehicle operated with methane, it can be assumed that almost all HC consists of methane. The test results for emissions of THC and CH_4 are higher during cold start than during warm start on chassis dynamometer. On road, bus route 1-3 where performed subsequent to each other. Bus route 1 and 2 shows rather high emissions of THC, whereas bus route 3 shows considerable lower THC emissions. This phenomenon may be explained in Figure 90 which shows a slightly higher exhaust gas temperature in bus route 3. Similar behaviour is shown for emissions of NOx on road although the start temperature on chassis dynamometer do not show the same influence.

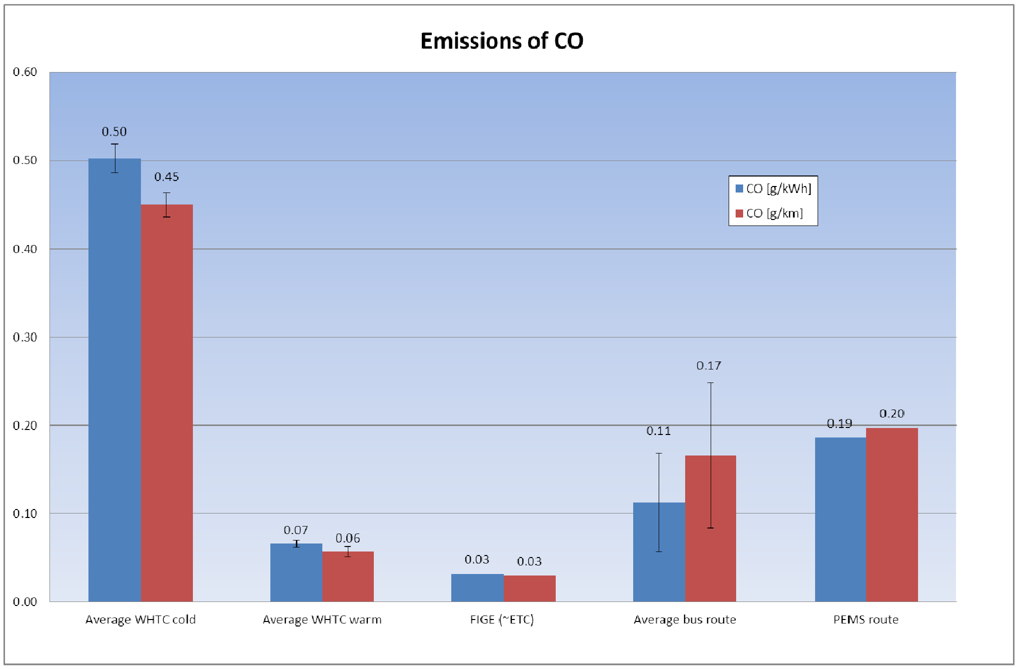


Figure 82. Emissions of CO

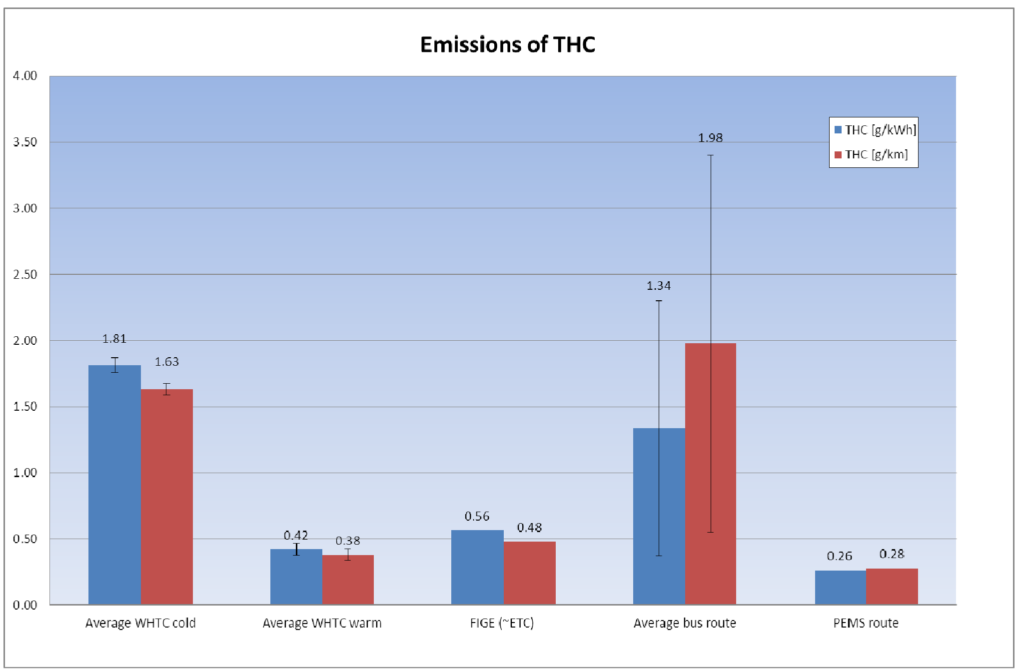


Figure 83. Emissions of THC

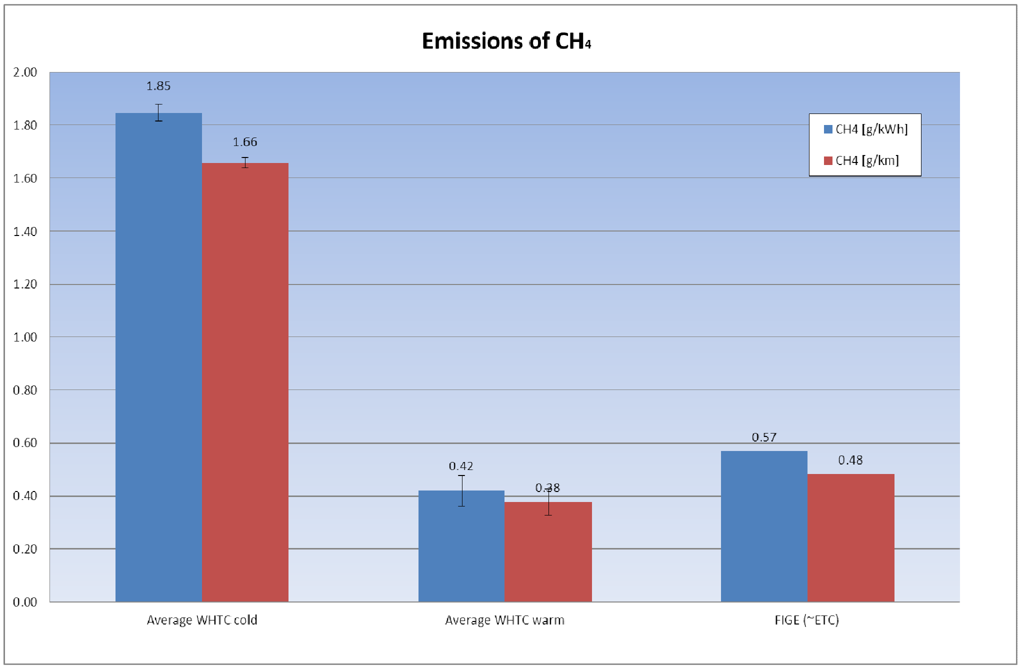


Figure 84. Emissions of CH_4

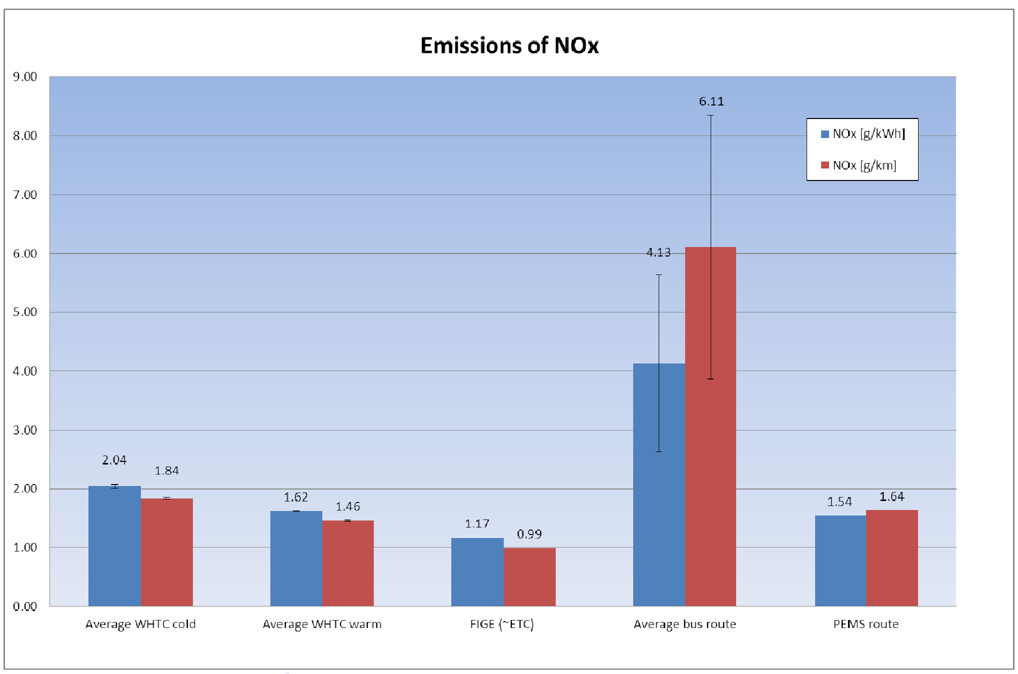


Figure 85. Emissions of NOx

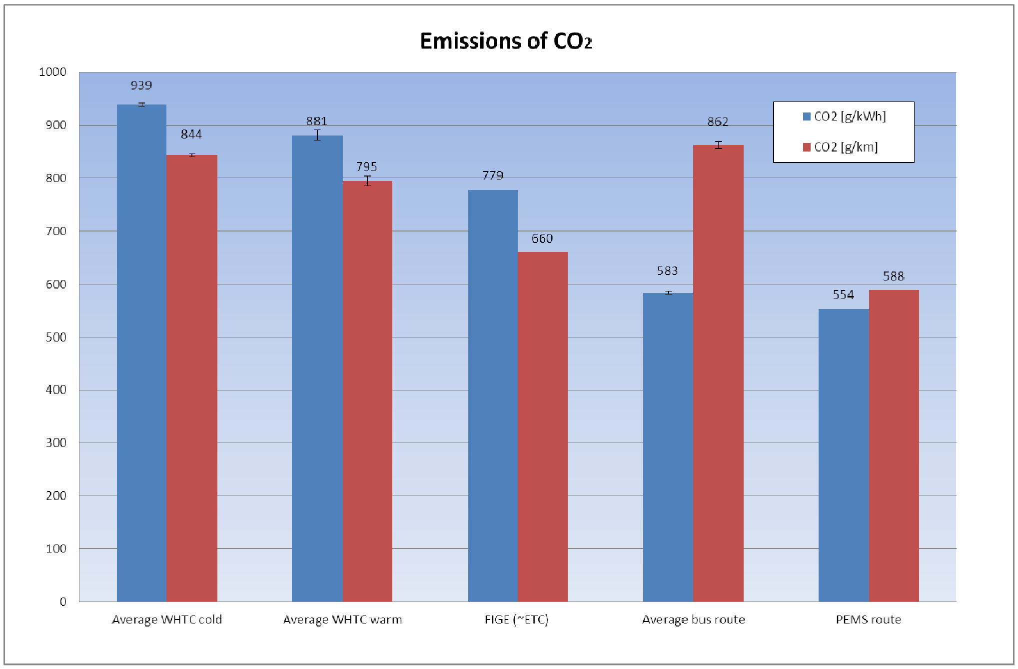


Figure 36. Emissions of CO_2

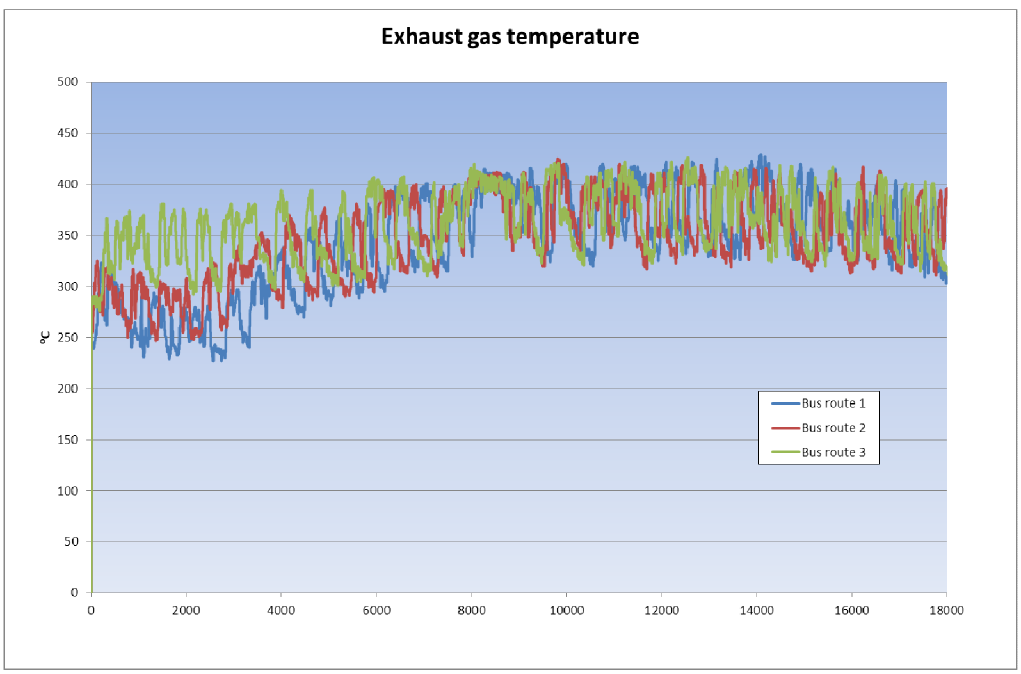


Figure 87. Exhaust gas temperatures during the bus routes

Table 18 Emission results

Chassi dyno testing	CO	THC	CH4	NOX	CO2	PM		CO	THC	CH4	NOX	CO2	PM
	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh		g/km	g/km	g/km	g/km	g/km	g/km
WHTC 1 (cold)	0.51	1.78	1.83	2.02	937	0.004		0.46	1.60	1.65	1.82	846	0.003
WHTC 2 (cold)	0.49	1.85	1.87	2.07	941	0.003		0.44	1.66	1.67	1.85	841	0.002
Average WHTC cold	0.50	1.81	1.85	2.04	939	0.003		0.45	1.63	1.66	1.84	844	0.003
Standard dev	0.02	0.05	0.03	0.03	3	0.001		0.01	0.04	0.02	0.02	3	0.001
WHTC 1 (warm)	0.06	0.48	0.49	1.62	887	0.005		0.05	0.43	0.43	1.45	794	0.005
WHTC 3 (warm)	0.07	0.40	0.39	1.62	886	0.002		0.06	0.36	0.35	1.47	805	0.002
WHTC 4 (warm)	0.07	0.39	0.39	1.63	871	0.001		0.06	0.35	0.35	1.47	787	0.001
Average WHTC warm	0.07	0.42	0.42	1.62	881	0.003		0.06	0.38	0.38	1.46	795	0.002
Standard dev	0.00	0.05	0.06	0.01	9	0.002		0.01	0.04	0.05	0.01	9	0.002
FIGE (~ETC)	0.03	0.56	0.57	1.17	779	0.004		0.03	0.48	0.48	0.99	660	0.004
Limit EURO EEV (ETC)	**3.0**		**0.65**	**2.0**		**0.020**							
PEMS testing													
Bus route 1	0.17	1.77	n.m.	3.59	580	n.m.		0.25	2.61	n.m.	5.30	854	n.m.
Bus route 2	0.11	2.01	n.m.	5.84	585	n.m.		0.17	2.98	n.m.	8.65	867	n.m.
Bus route 3	0.06	0.23	n.m.	2.97	586	n.m.		0.08	0.34	n.m.	4.39	865	n.m.
Average bus route	0.11	1.34		4.13	583			0.17	1.98		6.11	862	
Standard dev	0.06	0.96		1.51	3			0.08	1.43		2.24	7	
PEMS route	0.19	0.26	n.m.	1.54	554	n.m.		0.20	0.28	n.m.	1.64	588	n.m.

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle K

Vehicle K was a long haul truck equipped with a Diesel Dual Fuel (DDF) system.

Dual-Fuel technology enables a diesel engine to operate on a proportion of natural (or bio) gas. The diesel engine is unchanged and operates according to the Diesel Cycle, using a small “pilot” diesel injection to ignite a controlled mixture of gas and air. For this vehicle, the Dual-Fuel control system is interfaced with the OEM engine control system, giving the Dual-Fuel system control of the engine.

The vehicle was tested on chassis dynamometer and roads with a cargo load of approximately 20 tonnes (CD and on road) and 40 tonnes (on road).

The tests were carried out with Mk1 diesel and Liquefied Bio Gas (LBG). The vehicle was equipped with a SCR system and a DOC optimized for methane slip.

Presentation of vehicle:

Table 19. Test vehicle data.

Year model	2011
Power, kW (approx.)	350
After treatment system	DOC, SCR
Test weight, kg	20 tonnes, 40 tonnes
Euro standard (diesel engine)	Euro V

Test program

A DDF vehicle can be operated in diesel only mode as well as Dual Fuel mode (continuously varying mixture of methane gas and diesel). The vehicle was tested in both operating modes. The Chassis dynamometer tests were:

Diesel mode:

- 1 WHVC (Worldwide Harmonized Vehicle Cycle, chassis dynamometer version of WHTC - Worldwide harmonized Transient Cycle) cold start
- 3 WHVC hot start
- 2 Fige (chassis dynamometer version of ETC – European Transient Cycle)

DDF mode:

- 1 WHVC cold start
- 3 WHVC hot start
- 2 Fige

The vehicle was tested on roads in the OEM’s Euro VI test route as well as the AVL MTC Euro V test route.

Table 20. Test route data, PEMS route Gothenburg vs PEMS route Haninge

Test route data		
	PEMS Gbg	PEMS Haninge
Trip duration (s)	14800	5000
Trip distance (km)	220	77
Average speed (km/h)	54	55
Urban (%)	38	43
Rural (%)	22	17
Highway (%)	40	40
Accelerating (%)	15	18
Decelerating (%)	12	18
Cruising (%)	60	57
Idle (%)	13	7

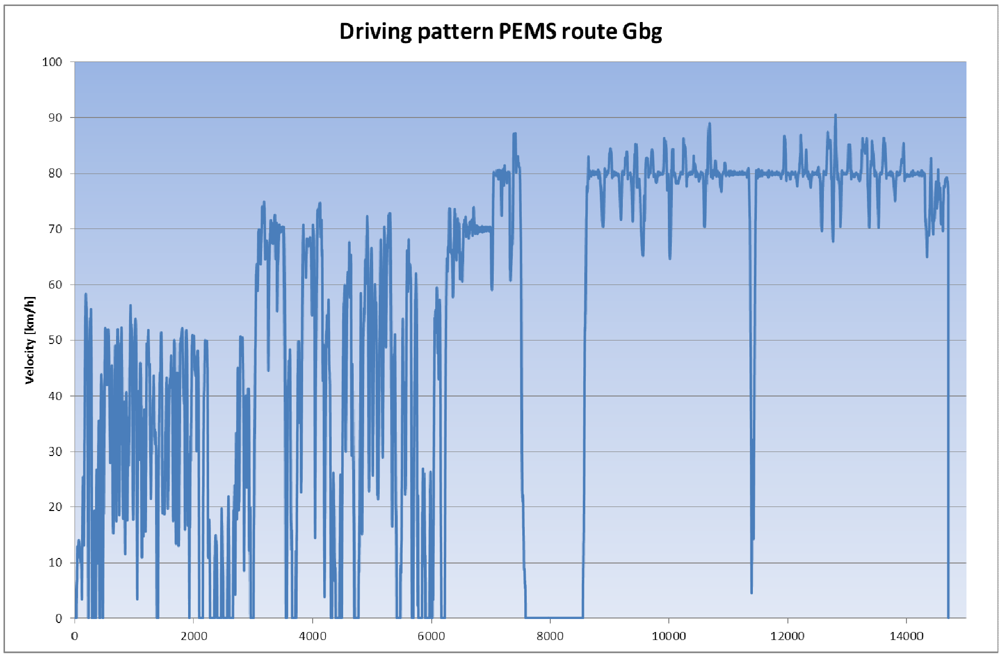


Figure 88. Driving pattern PEMS Euro VI

The vehicle was tested with a cargo load of 40 tonnes and 20 tonnes in DDF mode as well as Diesel mode. Unfortunately the DDF test on 20 tonnes failed, probably due to problems with engine management software.

The route selected for the test in Haninge has been inspected and accepted by JRC.

Test route description:
Start at Armaturvägen in Jordbro, Haninge (AVL MTC) – through Handens centrum – Årsta Havsbad – Ösmo – Armaturvägen (end).

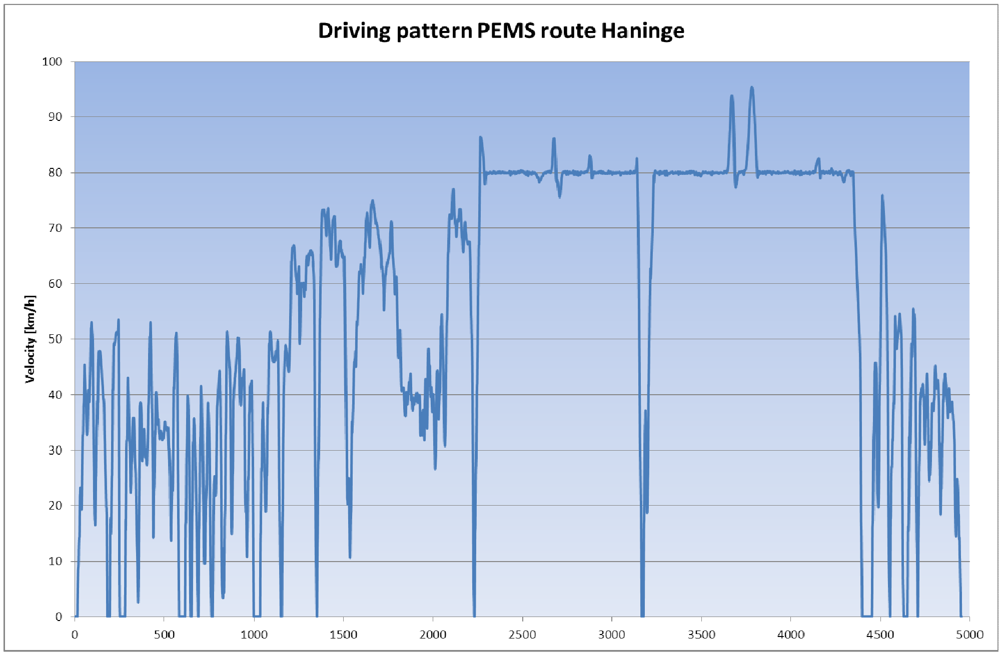


Figure 89. Driving pattern PEMS route in Haninge

In the AVL MTC test route, the vehicle was tested with a cargo load of 20 tonnes in DDF mode as well as Diesel mode. The test in DDF mode, was performed with a different EMS software (as a consequence of the problems that occurred in Gothenburg). Due to problems with logging of ECU signals the test results of the DDF test could only be calculated in g/km.

Test results

The test results are presented in Figure 90- 100.

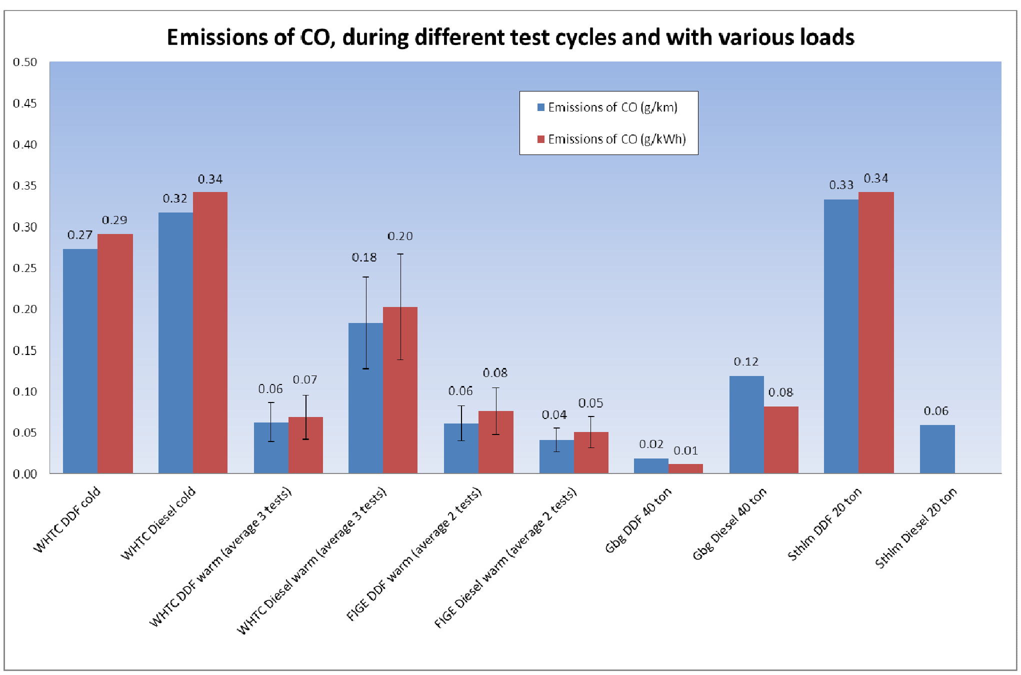


Figure 90. Emissions of CO during the various driving cycles

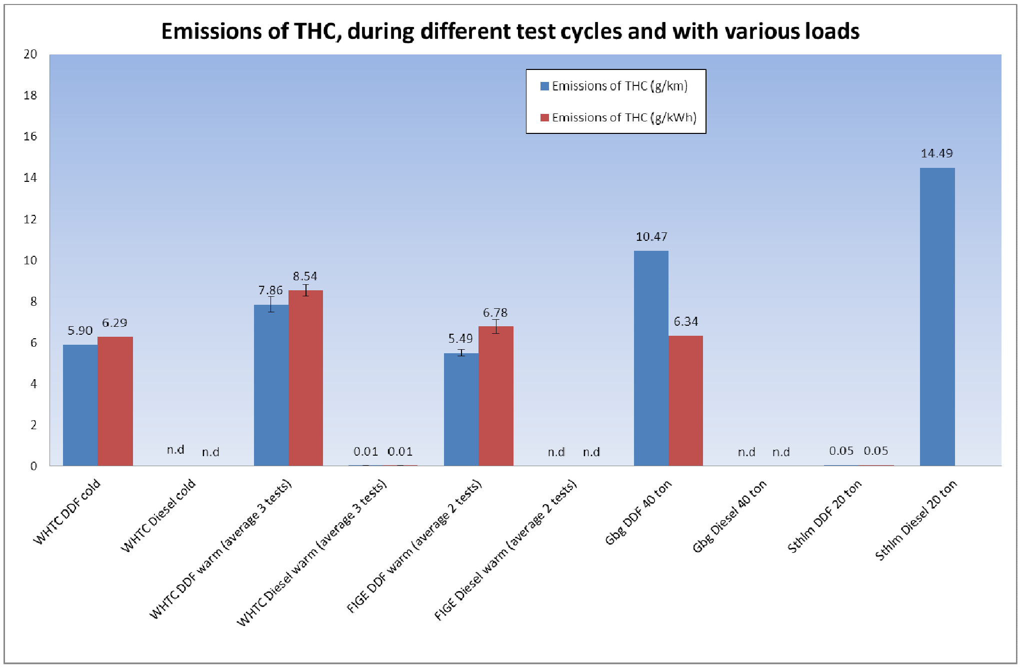


Figure 91. Emissions of THC during the various driving cycles

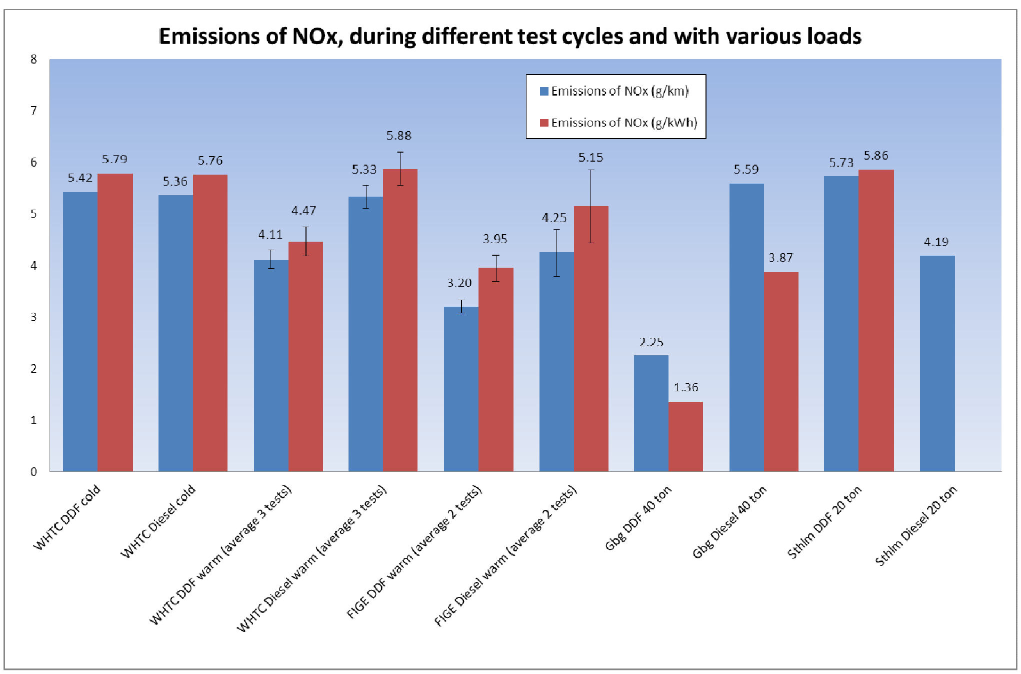


Figure 92. Emissions of NOx during the various driving cycles

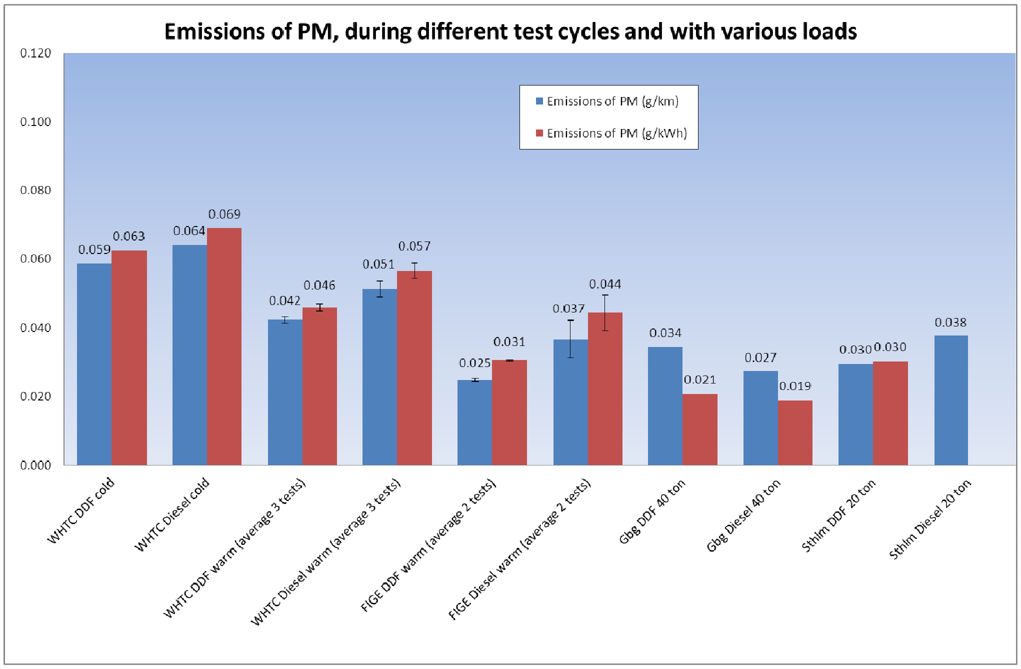


Figure 93. Emissions of PM during the various driving cycles

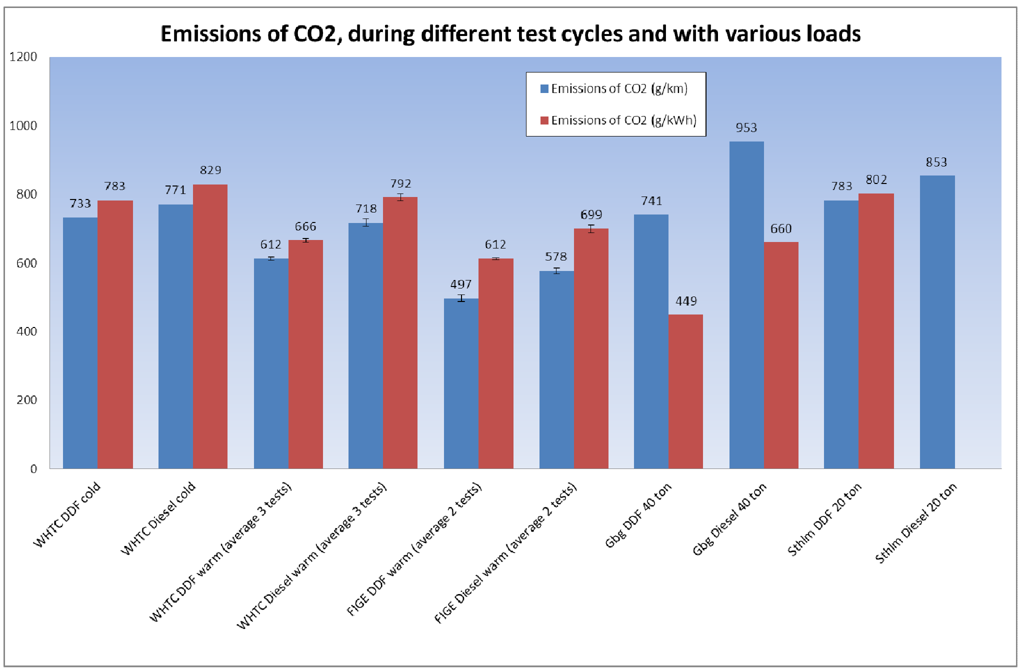


Figure 94. Emissions of CO_2 during the various driving cycles

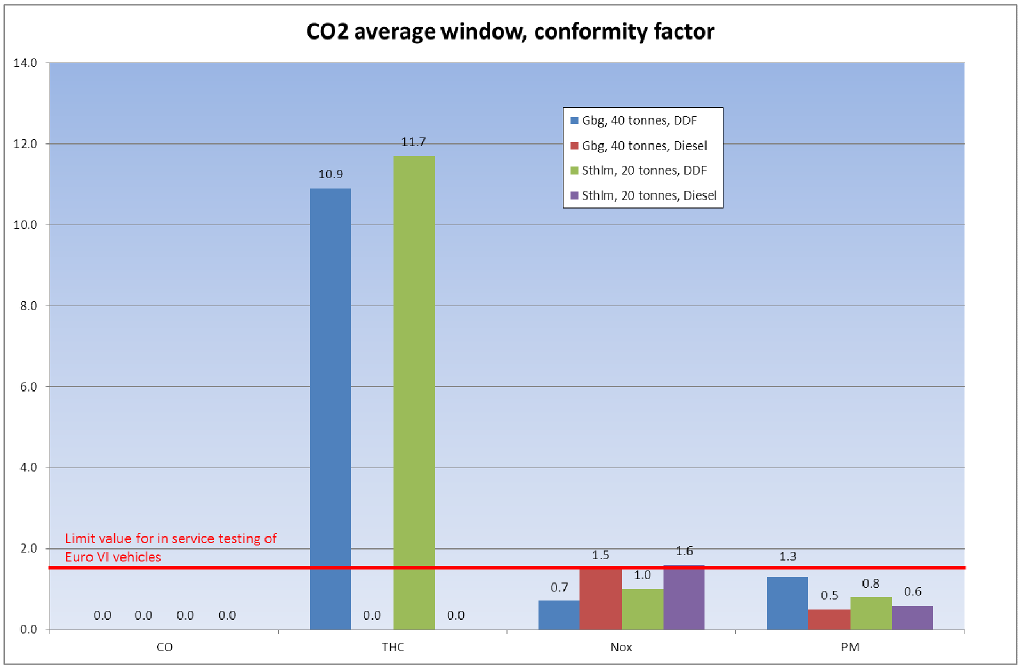


Figure 95. CO_2 average window, conformity factor

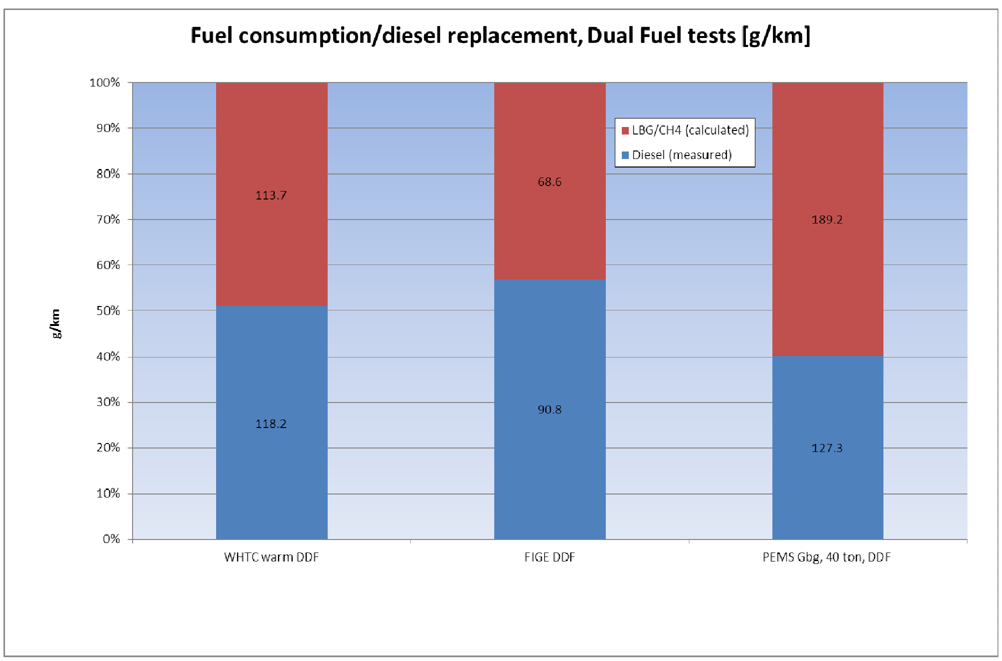


Figure 96. Average fuel consumption/Diesel replacement in g/km

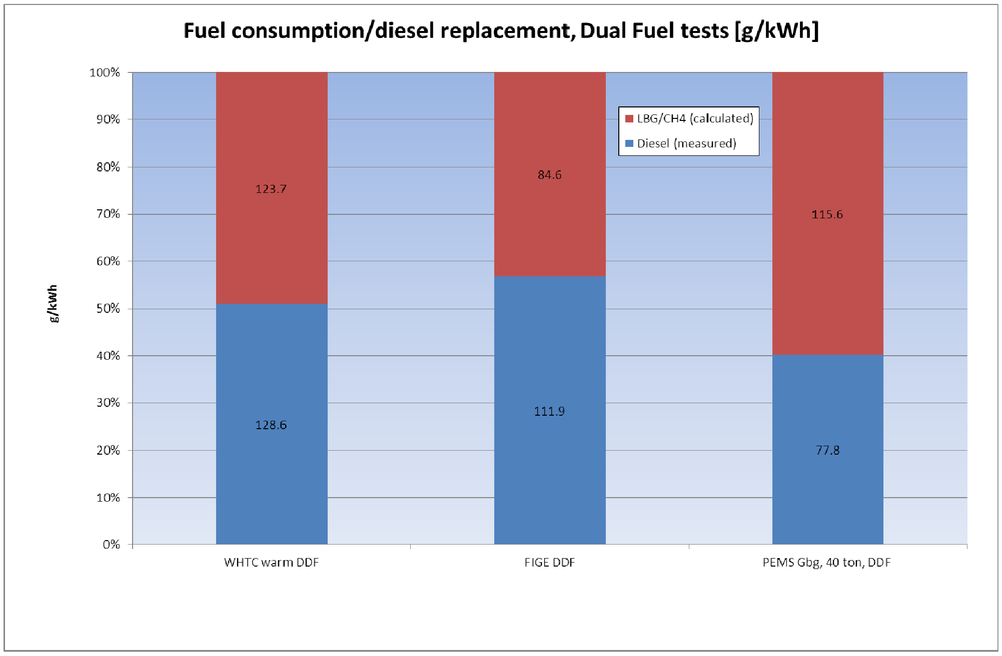


Figure 97. Average fuel consumption/Diesel replacement in g/kWh

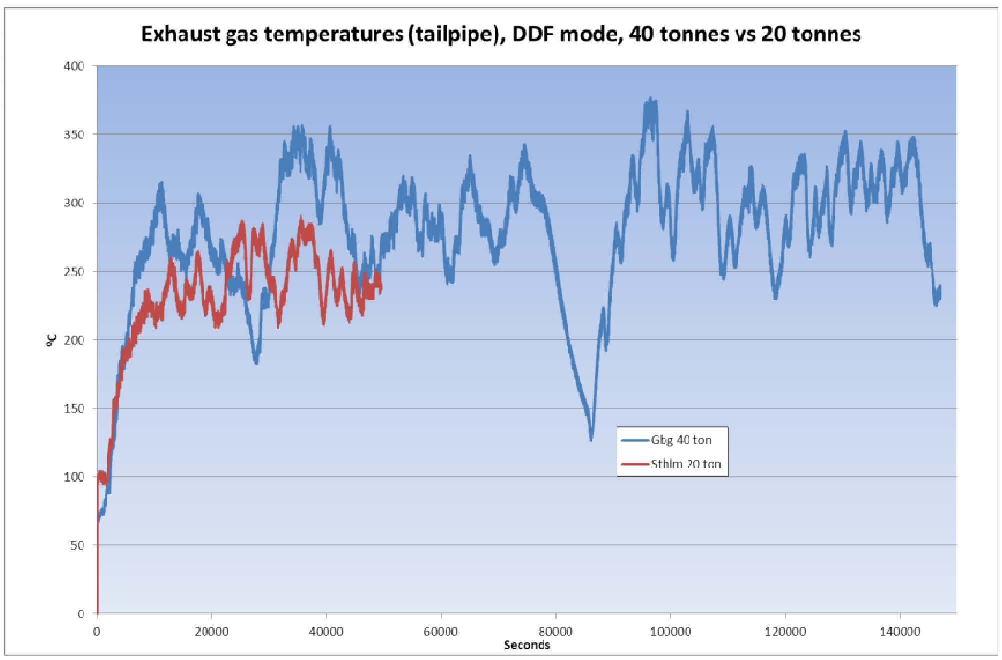


Figure 98. Variation of tailpipe exhaust gas temperatures, 20 tonnes vs 40 tonnes

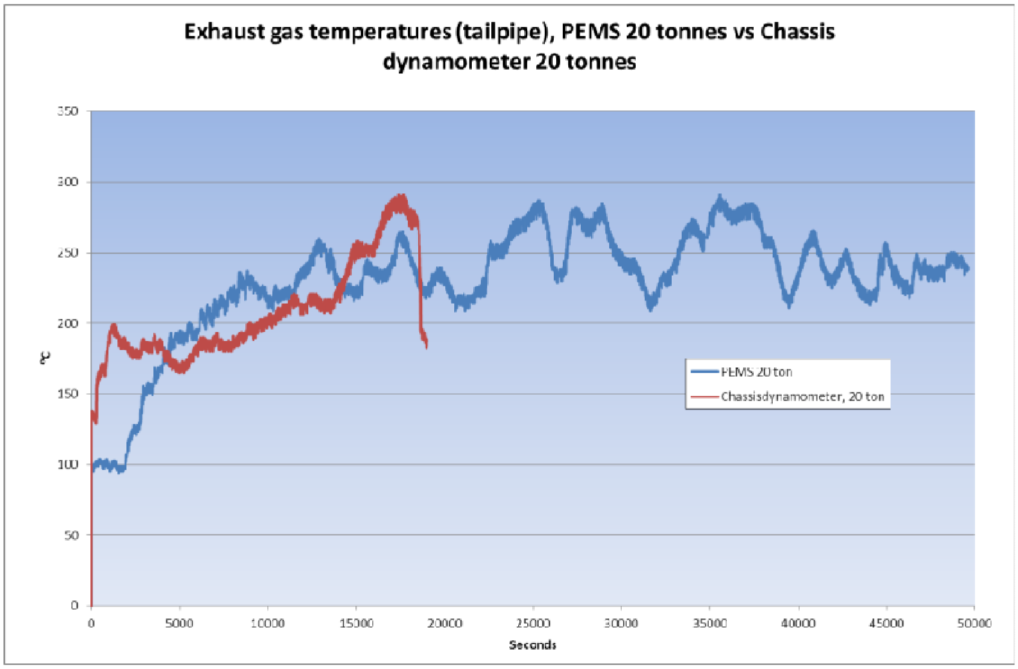


Figure 99. Variation of tailpipe exhaust gas temperatures, on road vs chassis dyno

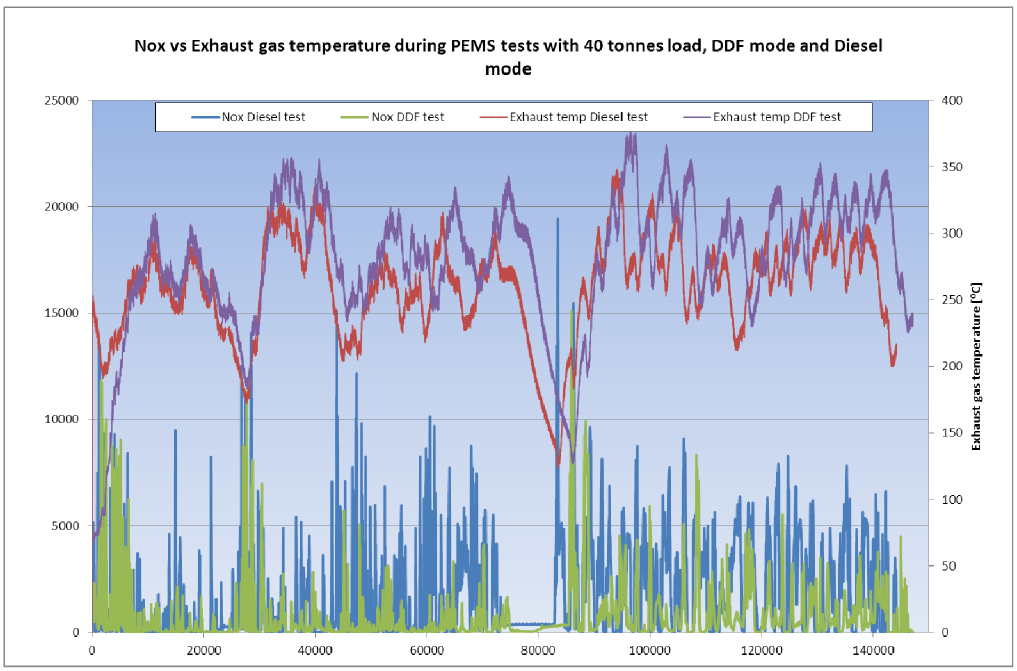


Figure 100. NOx vs. exhaust temperature.

Comments

For a vehicle operated with methane, it can be assumed that almost all HC consists of methane. With regard to brake specific emissions, in DDF mode, THC is well above the methane limit value for Euro V i.e 1,1 g/kWh in all cycles.

Also emissions of NOx are in some cycles slightly high, but Figure 98 indicates that when the calculations for the on road tests are performed according to ECE Regulation no 49 as for conformity of in-service engines or vehicles, the NOx emission values can be considered as compliant, at least when the vehicle is operated in DDF mode. The reason for the high emissions of NOx is most likely a result of that the exhaust temperature is lower and the SCR catalyst is not functioning as well as when the exhaust temperature is higher. The exhaust gas temperatures illustrated in figures 14-16 shows higher temperatures in DDF mode tests compared to Diesel mode tests. They also show higher temperatures when the vehicle is operated with a higher payload.

Vehicle L and M

Vehicle L and M where two 75 tonnes heavy duty timber trucks of Euro IV emission standard and equipped with SCR systems. The fuel used for the tests was commercially available Environmental class 1 diesel (Mk1).

Presentation of vehicles:

Table 21. Vehicle L data.

Year model	2009
Mileage, km	580 000
Euro standard	IV
Power, kW (approx.)	500
Aftertreatment	SCR
Test weight, kg	22 000 – 75 000

Table 22. Vehicle M data.

Year model	2008
Mileage, km	400 000
Euro standard	IV
Power, kW (approx.)	500
Aftertreatment	SCR
Test weight, kg	22 000 – 75 000

Test program

The vehicles were tested on road in a test route that represented a normal working day of the particular vehicles, with and without load,

Below is the test routes presented divided into driving with and without load, 22000kg and 75000 kg respectively, Figure 101 – 104.

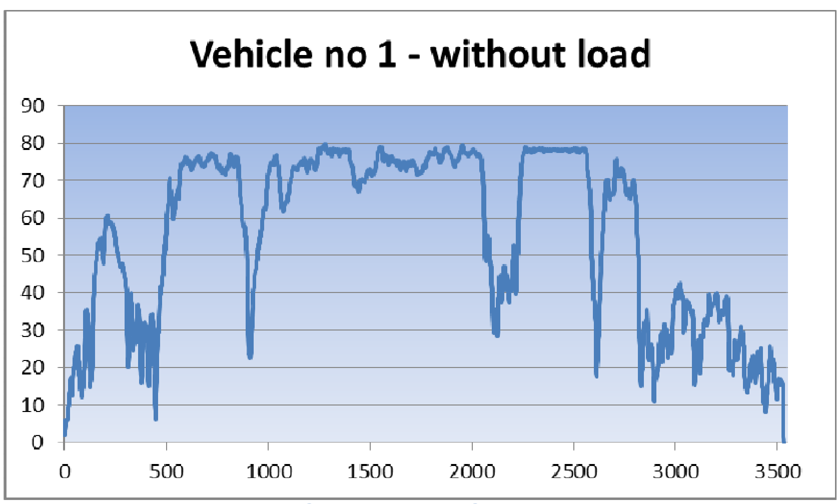


Figure 101. Driving pattern. Speed vs time (Sec).

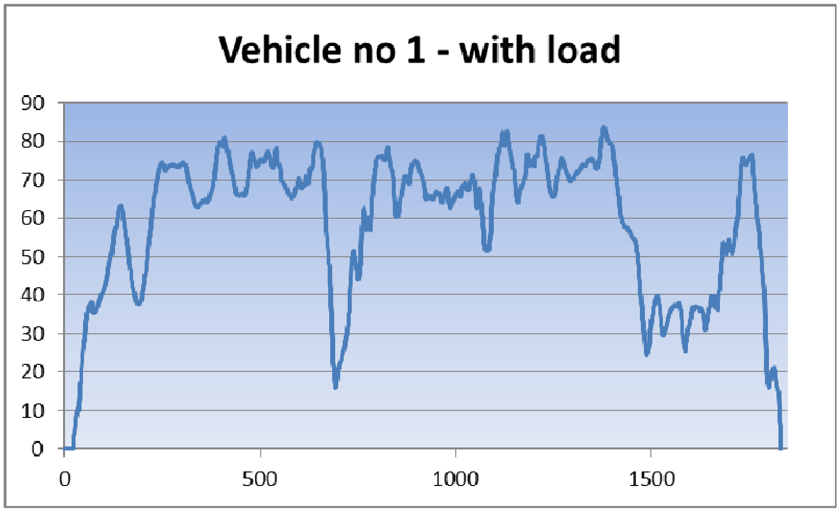


Figure 102. Driving pattern. Speed vs time (Sec).

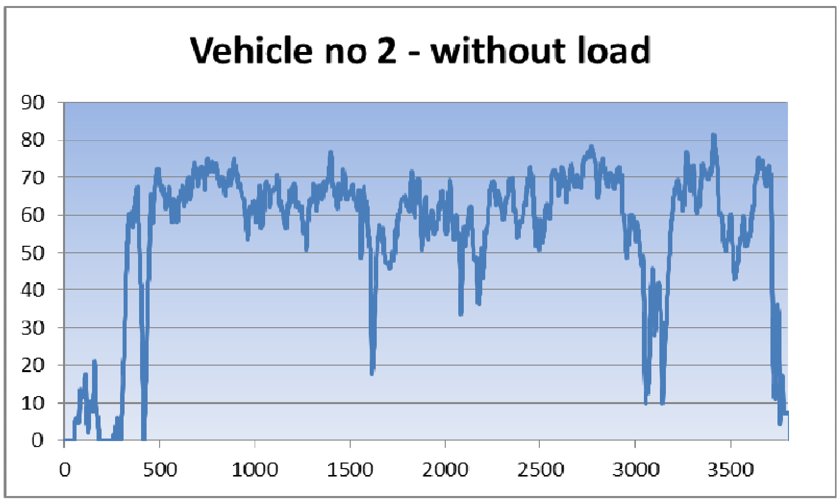


Figure 103. Driving pattern. Speed vs time (Sec).

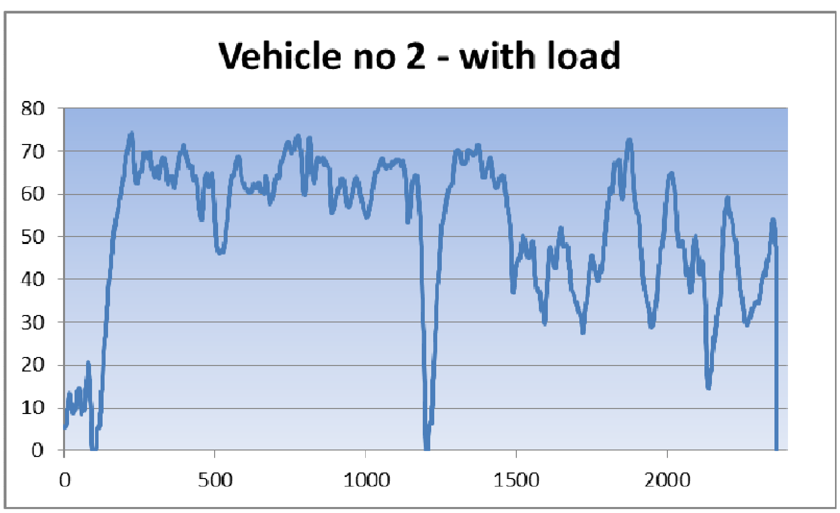


Figure 104. Driving pattern. Speed vs time (Sec).

Test results

Obtained test results are presented in Figure 105 - 106. From the data some general conclusions can be made. The emissions of HC are low and close to detection limit and may thus not be significant. The results of distance specific emission are in the same range compared to a 60 tonnes timber truck that was tested within the Swedish In-Service testing programme 2009.
With regard to brake specific emissions (g/kWh) the emissions are below the Euro IV certification limit values. However, it must be emphasised that Pems measurement differs from the certification test procedure and can thus not be used as a pass or fail criteria. The soot emissions from vehicle M were significantly higher compared to vehicle L.

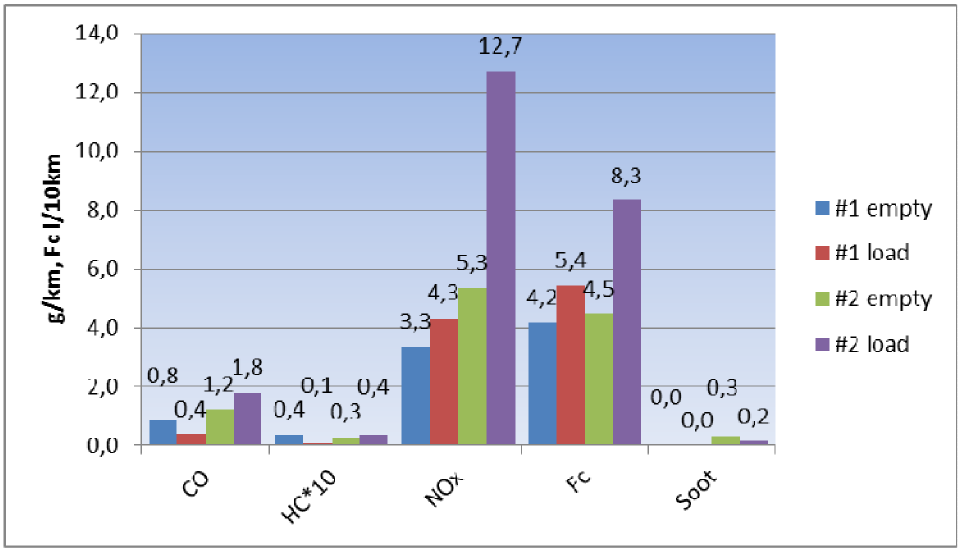


Figure 105. Distance specific mass emission.

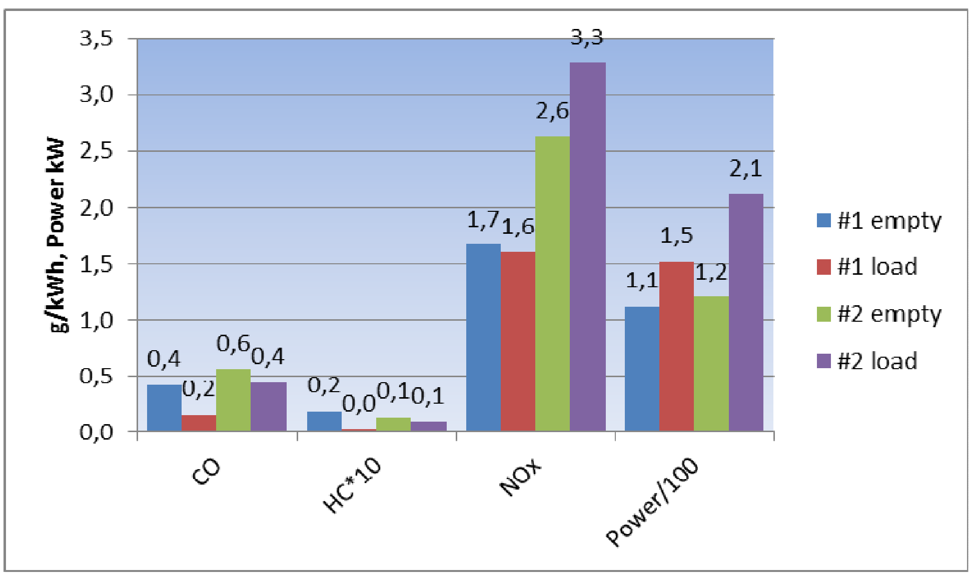


Figure 106. Brake specific mass emission.

Comments

The exhaust temperature was measured after the catalyst, thus not representing the pre catalyst temperature. However, the average measured temperature during both road tests was above 320°C. In order to have full reduction of the SCR system a temperature above 300°C is necessary. The system start working at approximately 220°C and no urea is injected under 200°C. The results of soot from vehicle L were close to detection limit.