Emissions from Flexible Fuel Vehicles with different ethanol blends

AVL MTC 5509

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Abstract

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The emissions were examined using different percentage ethanol blends in gasoline including E5, E10, E70, and E85 fuels. Tests were performed as single tests in the NEDC and the Artemis driving cycles at test cell temperature +22°C. NEDC tests were also performed at -7°C. The E70 tests performed at -7°C were conducted both with and without the use of engine pre-heater.

The cold start of the NEDC was associated with higher emissions of most exhaust components in both the +22°C and in the -7°C tests. At -7°C, however, NOx showed higher emissions in the second half of the urban part of the NEDC cycle. Due to the absence of cold start effect, the Artemis driving cycles generally showed lower emissions as compared to the NEDC.

The -7°C tests show considerably higher emissions of regulated components as compared to the +22°C tests with the exception for NOx showing emissions in the same range as for the +22°C tests.

Test using engine pre-heater at -7°C showed considerably lower emissions of CO, HC, particulate mass, and acetaldehyde (reduced by 10-50%).

In all tests, only a minor portion of the NOx is emitted as NO2 (in the NEDC about 5%). The NOx emissions in the Artemis Urban and the Artemis Extra Urban were lower by as much as 70% for the E70 and the E85 as compared to the E5 and E10 fuels.

High acetaldehyde emissions were observed in the NEDC for the E70 and the E85 fuels. It was indicated that this emission occurred during the cold start of the cycle.

The particle number emissions did not show any clear fuel or cycle dependence. Higher emissions were observed in the -7°C NEDC tests as compared to the tests at +22°C.

Suggestion of keywords
Passenger cars, Flexible Fuel Vehicles, ethanol, emissions, PMP - Particulate Measurement Programme, particle number, aldehydes

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The Swedish Road Administration

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2005-10-18

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High acetaldehyde emissions were observed in the NEDC for the E70 and the E85 fuels. It was indicated that this emission occurred during the cold start of the cycle.

The particle number emissions did not show any clear fuel or cycle dependence. Higher emissions were observed in the -7°C NEDC tests as compared to the tests at +22°C.

Svensk sammanfattning

Tre Euro 4 Ford Focus flexible fuel personbilar har undersöks med avseende på emissioner av reglerade och ickereglerade avgaskomponenter inkluderande aldehyder och emissioner av partikelmassa och partikelantal. Partikelmassa mättes både enligt den reglerade metoden samt i enlighet med PMP-protokollet. Partikelantalsmätningar utfördes i enlighet med PMP-protokollet vilket innefattar avlägsnande av kondenserat material innan mätning.
Emissionerna undersöktes då olika procentuella etanolinblandningar i bensin användes inkluderande E5, E10, E70 och E85 bränslen. Proven genomfördes som enkeltest i NEDC och i Artemiskörcyklerna i provcellstemperaturer vid +22°C. Prov med NEDC genomfördes även vid -7°C. Prov med E70 som genomfördes vid -7°C kördes både med och utan motorvärmare.

Kallstarten vid NEDC associeras med högre emissioner av de flesta avgaskomponenterna både vid prov körda vid +22C och vid -7°C. Vid -7°C visade dock NO_x högre emissioner i den andra halvan av stadskörningsdelen av NEDC. Till följd av kallstarteffekt visade Artemis vanligtvis lägre emissioner jämfört med NEDC.

Prov körda vid -7°C visade avsevärt högre emissioner av reglerade komponenter jämfört med prov körda vid +22°C med undantaget för NO_x vilket visade emissioner i samma storleksordning som för proven körda vid +22°C.

Prov körda med motorvärmare vid -7°C visade avsevärt lägre emissioner av CO, HC, partikelmassa och acetaldehyd (reducerade med 10-50%).

Endast en mindre fraktion av NO_x emitterades som NO_2 (i NEDC ungefär 5%). Emissionerna av NO_x i Artemis Urban och Artemis Extra Urban var lägre med så mycket som 70% för E70 och E85 jämfört med vad som uppmättes för E5 och E10 bränslena.

Höga emissioner av acetaldehyd observerades i NEDC för E70 och E85 bränslena. Det finns indikationer på att dessa emissioner huvudsakligen sker vid cykelns kallstart.

Emissionen av partikelantal visade inte någon tydligt bränsle eller körcykelberoende. Högre emissioner observerades i NEDC vid -7°C jämfört med proven körda vid +22°C.

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1. INTRODUCTION

Alternatives to fossil fuels are of increasingly importance. The combustion of fossil fuels releases carbon to the atmosphere that contributes to the increased green house effect and thus climate change. Fossil fuels are also of limited resources and the access to these available resources is gradually meeting increasing competition. According to Directive 2003/30/EC, EU member states should develop indicative targets with the following reference values (by energy content): by 2005, 2% of fuels sold should be biofuels and by 2010, 5.75% of the fuels should be biofuels.

Among the alternative fuels, ethanol is an interesting fuel since it may be produced in significant volumes from a number of different raw products including forestry and agricultural products. Ethanol is a non-toxic liquid and easily blended with gasoline.

For the above reasons in combination with significant support activities in the Swedish society the proportion of vehicles that operate using alternative fuels in the national fleet will likely increase in the foreseeable future.

In the present Swedish vehicle fuel market two blends of ethanol is available: the common gasoline into which approximately 5% ethanol is blended, and the E85 quality which is a blend of 85% ethanol in 15% gasoline.

In this work, three flexible fuel passenger cars of the same model was examined for exhaust emissions, including aldehyde and particle number emissions, as they were operated with different ethanol concentrations in gasoline under different environmental conditions and driving conditions.

The focus of this report is the presentation and summarizing of the measurement data and it is not within the aims of this report to perform a detailed interpretation. However, a short discussion and brief conclusions are presented.

2 EXPERIMENTAL

2.1 Vehicles

Three combi-coupé Ford Focus 1.6 flexible fuel vehicles with a manual gear box have been examined for exhaust emissions in this work (Table 1). The cars meet the certification standards of Euro 4 (Table 2). The certification is performed using gasoline fuel only and thus the emission limit values are not valid for ethanol blend fuels. The cars may use different blends of ethanol in gasoline and as different fuels are used in this study, fuel adaptation is performed in accordance with instructions of the manufacturer. This procedure includes the fuel change followed by an NEDC driving cycle and thereafter a period of three minutes at 3000 rpm using the third gear. After this procedure, conditioning for a normal NEDC test is performed in accordance to the legislation.

The three vehicles examined are in the following report denoted according to their registration numbers as: SYU, TNT, and SYS.

Table 1: Vehicle specifications, Ford Focus 1.6 FFV.

	SYU	**TNT**	**SYS**
Model year	2003	2003	2002
Odometer (km)	38200	48700	29800
Vehicle weight (kg)	1169	1169	1169
Valves per cylinder	4	4	4
Displacement (cm^3)	1596	1596	1596
Bore/stroke (mm)	84.8 / 88.0	84.8 / 88.0	84.8 / 88.0
Compression ratio	10	10	10
Power (kW@rpm)	75@6000	75@6000	75@6000
Torque (Nm@rpm)	148@4000	148@4000	148@4000
Gears	5	5	5
Environmental class	Euro4	Euro4	Euro4
Emission control	TWC*	TWC*	TWC*

* Three-way catalyst

Table 2. Euro 4 emission limit values for gasoline passenger cars.

Exhaust component, NEDC* +22°C	**Emission limit values (g/km)**
CO	1.0
HC	0.10
NO_x	0.08
Exhaust component, UDC* -7°C	**Emission limit values (g/km)**
CO	15
HC	1.8
Exhaust component	**Evaporative emissions (g)**
HC	2.0

* Indicates the driving cycle used in the regulation (section 2.3, below).

2.2 Fuels

Four different ethanol fuels with different proportions of ethanol in gasoline have been examined in this study including E5 (5%v/v ethanol in gasoline), E10, E70, and E85. The fuels have been mixed at AVL MTC by use of dry ethanol in a single batch commercial normal Swedish summer quality gasoline (E5). The E5 quality is used as supplied since the gasoline is a low concentration ethanol blend containing 5% ethanol. The E85 fuel differs from the commercially available E85 fuel in that the commercial fuel contains 2% MTBE (methyl tertiary butyl ether) and 0.4% isobutanol (Sekab, ETAMAX B specification 2002).

2.3 Driving cycles

A set of different driving cycles were used in the study and includes the NEDC (with a cold engine start), and the Artemis cycles (using warm engine start).

NEDC

The legislative NEDC cycle (Figure 1) is the test cycle for emission certification of light duty vehicles. The first 780 s includes four identical cycles, representing the Urban Driving Cycle (UDC). This part may be further divided into two parts of 390 s each (C_1+2 as UDC1 and C_3+4 as UDC2) in order to compare vehicle emissions from the cold engine and exhaust system with the emissions at operating temperature. The period from 780 s to the cycle end at 1180 s represents the higher speed part of the cycle, the Extra Urban Driving Cycle (EUDC).

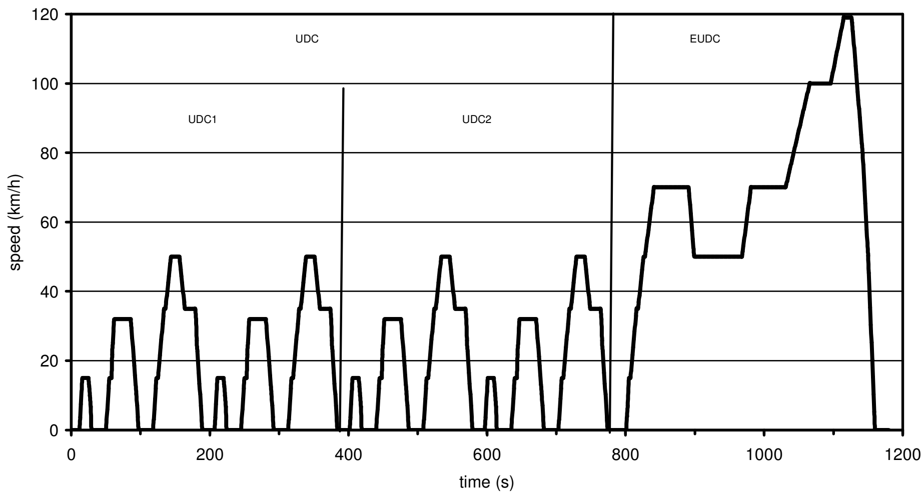

Figure 1. The NEDC driving cycle.

Artemis Cycles

The Artemis driving cycles was originally built by INRETS as Real World Cycles and has been used in the Artemis project. The cycles describe various current driving conditions encountered frequently in Europe as they were built from a database of real-world driving conditions for a set of 80 cars from different European countries. The three cycles used (Figures 2-4) are referred as Artemis Urban (AU), Artemis Extra Urban (AEU), and Artemis Highway (AH).

The cycles are all warm start cycles and include a preconditioning part of different lengths for the different cycles (73 s for AU, 102 s for AEU, and 177 s for AH). For the AH cycle there is also a post-conditioning part of the cycle from 912 s and onwards. During precondition and post-conditioning parts of the cycles, no measurements are performed. All results presented and discussed in the following report only treat the valid part of the cycle. In the figures, below, the start of the valid part of the cycle is marked by a line.

As a result of the warm start of the cycle, and in order to improve repeatability between tests, the procedure to warm up the engine prior to test presented in Table 3 is followed.

Table 3. Vehicle conditioning procedure prior to Artemis.

Minutes elapsed between two tests	**Number of EUDC**
0-15	0
15-30	1
>30	2

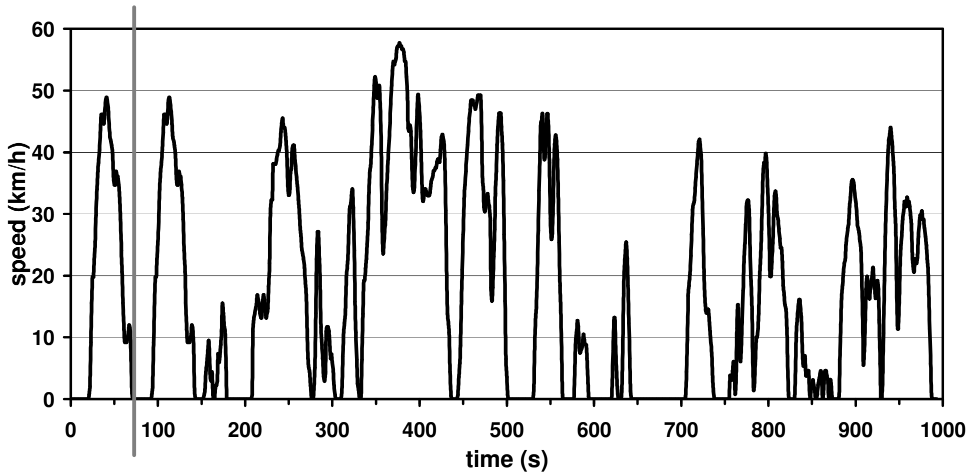

Figure 2. The Artemis Urban driving cycle (73 to 993 s).

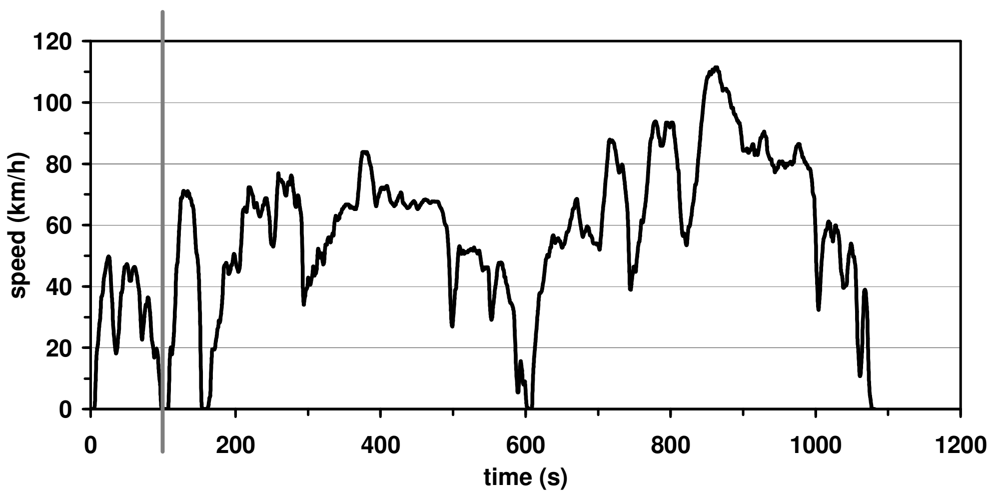

Figure 3. The Artemis Extra Urban driving cycle (102 to 1082 s).

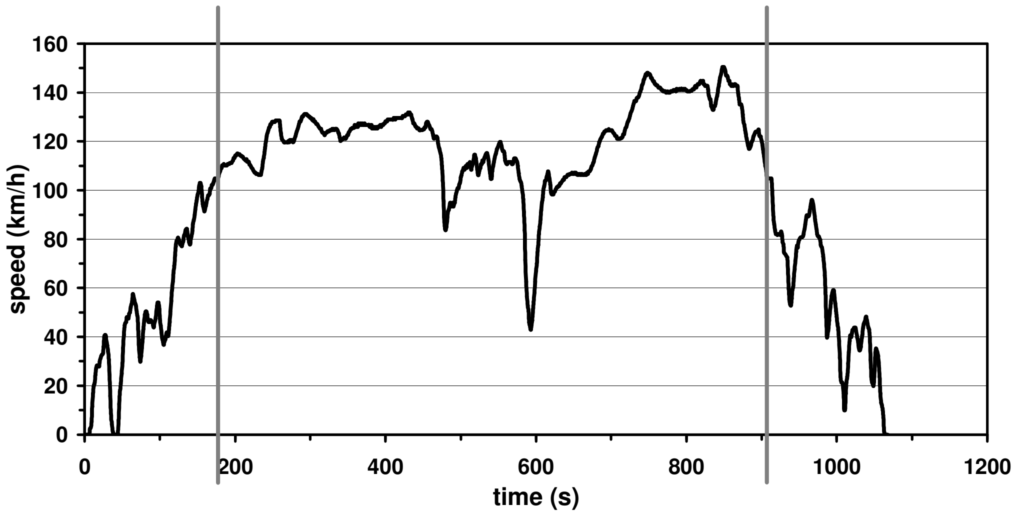

Figure 4. The Artemis Highway (177 to 912 s).

In this work, an additional set of Artemis cycles was performed for all cars and fuels at +22°C. The measurements includes real-time on-line measurements for the regulated compounds (CO, HC, NO_x) and were conducted in parallel with the regulatory sampling in teflon bags with subsequent analysis of the same components. These measurements were conducted in order to evaluate and compare the two measurement techniques. The data for this work is presented in Appendix A.

2.4 Chassis dynamometer

The cars were tested on an electric Clayton DC500 two 500 mm roller chassis dynamometer at test cell temperatures +22°C. The dynamometer settings were applied for each vehicle according to the regulation and the vehicle type approval data.

2.5 CVS-tunnel

A Constant Volume Sampler (CVS) (Horiba, CVS-9300T) was used in the study. The CVS-tunnel has a total length of 3150 mm long with an inner diameter of 250 mm and is connected to the tailpipe via a 5 m long section of 110 mm diameter insulated stainless steel transfer tube. The transfer tube is connected to the tailpipe with a 30 cm section of flexible stainless steel tubing welded to the tailpipe. At a distance of 30 cm from the tailpipe cleaned and HEPA filtered test cell air was introduced to the transfer tube, into the exhaust stream. The CVS-tunnel flow rate is controlled by use of a 9 m^3/min critical venturi.

2.6 Gaseous emissions and PM measurements

Regulated gaseous components were measured according to the test procedures corresponding to the regulation (96/69/EC). A Horiba Mexa 9000 series (9400D) instrument was used for CO, HC, CH_4, NO_x, NO, CO_2 and fuel consumption (FC) analysis (Table 4). The NEDC test bag-sampling was divided into three phases: UDC1, UDC2, and EUDC. Artemis emissions were measured as a single test.

Formaldehyde and acetaldehyde were measured by use of DNPH (2,4-dinitrophenyl hydrazin) cartridges (Waters). A single cartridge was used over each individual cycle and thus the emissions are given as an integrated value over the cycle. After sampling the cartridges were stored in a freezer until analysing. The aldehydes were analysed at an external laboratory by extracting the cartridges using acetonitrile with subsequent measurement of the hydrazones using HPLC (High Performance Liquid Chromatography).

The particulate mass (PM) measurement was performed using two methods in parallel. The first PM method was performed in accordance with the 96/69EC regulation using two 47 mm diameter Teflon coated glassfibre filters (Pallflex T60A20) in series of which the second filter is a back-filter to collect particulate breakthrough from the first. The second PM-method followed the PMP-protocol (GRPE_PMP, 2004) Prior to the filter holder an impactor was used in order to remove coarse particles (cut-off approx. 5 µm). The filter holder meets the standards of the US2007 regulation (Andersson, 2004) and the temperature of the filter holder is controlled at 47±5°C. In this method a single 47 mm diameter Teflon bonded glassfibre filter (Pall TX40) is used. All filters were weighted with a balance (Satorius) with a resolution of 0.1 µg.

Table 4. Measurement principles.

Emission component	Measurement principle
Total hydrocarbons (HC)	HFID (heated flame ionization detector, 190°C)
Methane (CH_4)	HFID (heated flame ionization detector, 190°C)
Carbon monoxide (CO)	NDIR (Non-dispersive infrared analyzer)
Nitrogen oxides (NO_x)	Chemiluminescence
Carbon dioxide (CO_2)	NDIR (Non-dispersive infrared analyzer)
Fuel consumption (FC)	Carbon balance of HC, CO and CO_2
Particulate emissions (PM)	Gravimetric

2.7 PMP particle number measurements

The PMP-system in accordance with the PMP-protocol for particle number measurements is presented in Figure 5. The system is designed to generate number concentration measurements of aerosol particles from which volatile material is removed from the particulate phase by heating and dilution of the aerosol. In brief, the system may be described as: a sampling probe inside the CVS-tunnel, a unit to remove coarse particles (e.g. a cyclone), a dilution unit to provide dilution factors (DF) in the range 1-1000, the evaporation tube (ET) to heat the aerosol, a second dilution stage to provide DF 1-30, and an instrument to measure the particle number concentration (GRPE_PMP, 2004).

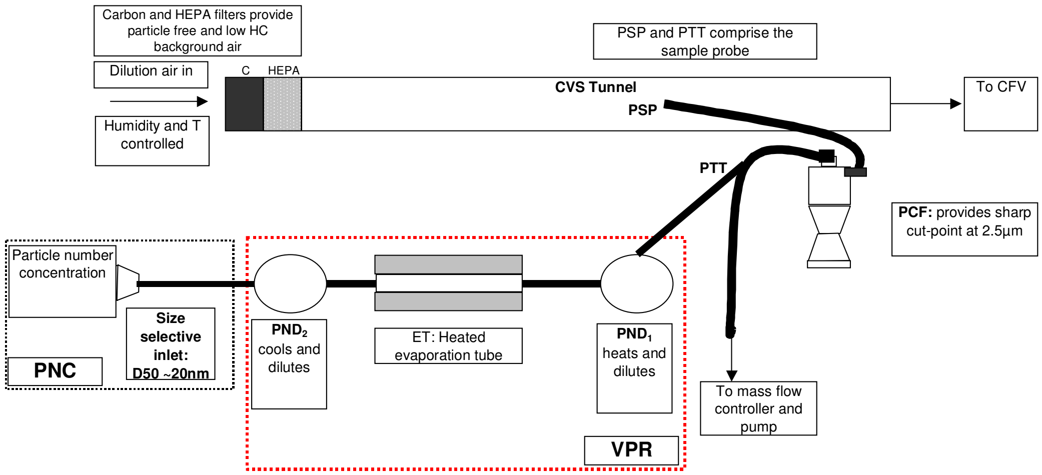

Figure 5. Schematic of the recommended PMP-system (GRPE_PMP, 2004).

In this work, the PMP-system used a stainless-steel inlet sample probe with the tip in a counter-flow position in the CVS-tunnel. The dimensions of the probe were 12 mm i.d. with a total length of 30 cm, of which 20 cm was positioned inside the CVS-tunnel. A Dekati SAC-65 cyclone was connected to the sample probe. The cyclone particle cut-off diameter meets the requirement of the PMP-protocol and is approximately 3.5 µm.

An insulated and electrically heated (150°C) ejector dilutor (Dekati, DI-1000) operated with preheated dilution air was mounted after the cyclone. This diluter was followed by the ET consisting of an electrically heated (350°C) 80 cm long stainless steel tubing of i.d. 6.1 mm with a calculated residence time of 0.4 s. After the ET, a second ejector diluter, operated at room temperature, was mounted (the dilution ratios of the two ejector diluters was determined by NO_x measurements). The particle number measurements were performed by use of a TSI3010 CPC with the lower particle cut-off diameter adjusted to 23 nm. The measurement range was 0-10000 particles/cm^3 and the time resolution was 1 Hz.

For the NEDC tests performed at -7°C, the heated ejector dilutor was replaced by a rotating disc dilutor (MD19, Matter engineering) in order to allow higher dilution ratios and flexibility for different particle number emission levels. The two different dilution systems, the rotating disc and the heated ejector dilutor, have previously been examined within the PMP-project (de Serves and Karlsson, 2004). However, this comparison also included different ETs and CPCs and is thus not a true comparison of the dilution units but an instrumental system comparison. The comparison showed 25% higher particle concentrations for the ejector diluter system at particle emissions in the same range as in the present work.

The ET used was in accordance with the design criteria in the PMP-protocol but the performance of the ET has up to date not been investigated. Kasper (2004) reported performance data of an ET for the removal of tetracontane ($C_{40}H_{82}$) particles of mean diameter 95 nm. The ET had a 0.27 s residence time (length of 240 mm, i.d. 6 mm) when operated at 300°C and a volatile particle removal efficiency higher than 99%. Thus, taking into account the longer residence time and the higher operating temperature used in the present work it is assumed that the ET used in this study complies with the performance criteria in the PMP-protocol in respect to volatile particle removal efficiency.

2.8 Evaporative emissions in the VT-SHED

Evaporative HC-emissions were examined for three cars and two fuels in a VT-SHED according to the regulated procedure. The three cars were the TNT, the SYS, and a third car of the same model, carX. The measurement consists of two parts: the hot soak measures the evaporative emissions during one hour after a NEDC+UDC cycle, and the diurnal measures evaporative emissions during 24 hours.

3 RESULTS AND DISCUSSION

3.1 Evaporative emissions in the VT-SHED

Evaporative HC emissions were examined for the E5 and the E10 fuels and the sum of the hot soak and the diurnal soak is presented in Figure 6. All three cars exceed the emission limit value of 2 g HC for both fuels.

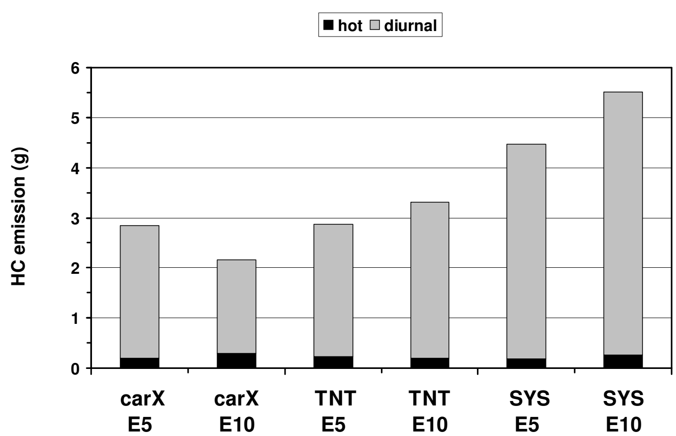

Figure 6. Evaporative HC emissions in the VT-SHED.

3.2 Gaseous emissions and fuel consumption

In the following section, emissions of gaseous compounds and parameters are presented as obtained from both NEDC and Artemis cycle measurements performed at test cell temperatures of +22°C.

3.2.1.1 CO emissions in the NEDC

In the following Figures 7-9, the CO emissions are presented as the weighted contribution of the sub-cycles to the NEDC cycle emissions.

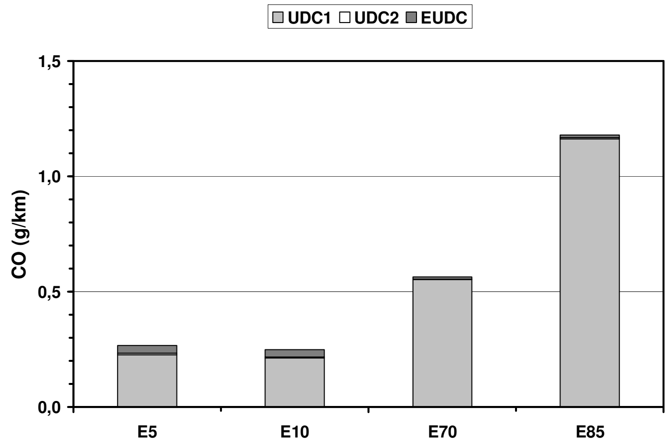

Figure 7. NEDC CO emissions for the SYU.

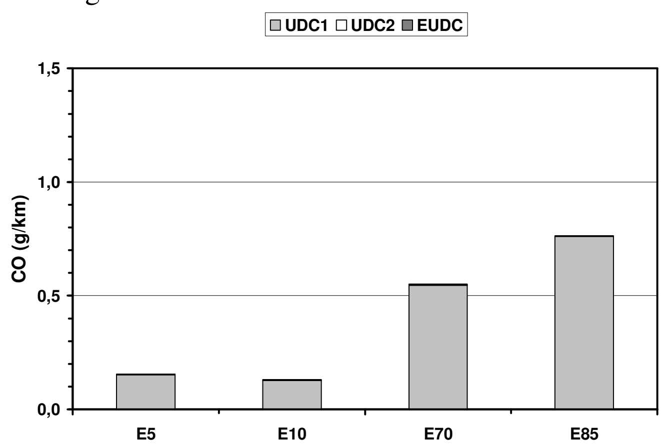

Figure 8. NEDC CO emissions for the TNT.

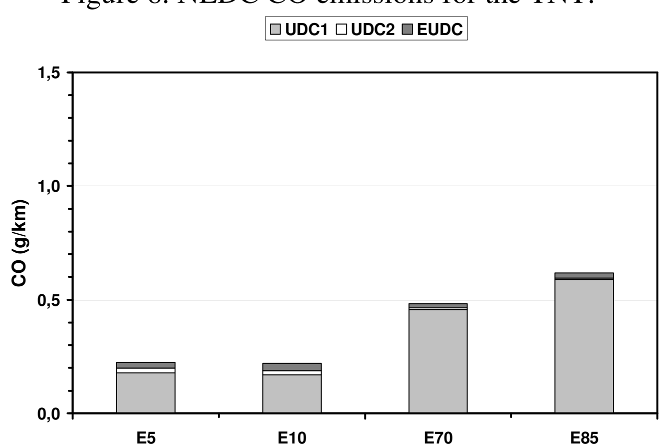

Figure 9. NEDC CO emissions for the SYS.

The three vehicles show the same emission pattern with the most significant portion of the CO emission occurring in the UDC1. This indicates a cold start effect with a poor CO removal efficiency before the catalyst reaches proper operational temperature. In the UDC2, the driving pattern is identical to that of the UDC1 but the catalyst is warm. This effect tends to be increasingly important for the E70 and E85 fuels as compared to the E5 and E10 fuels.
The emission limit value of 1.0 g/km is only exceeded by one of the vehicles operated with E85.

3.2.1.2 CO emissions in the Artemis cycles

The CO emissions for the Artemis cycles are presented in the Figures 10-12.

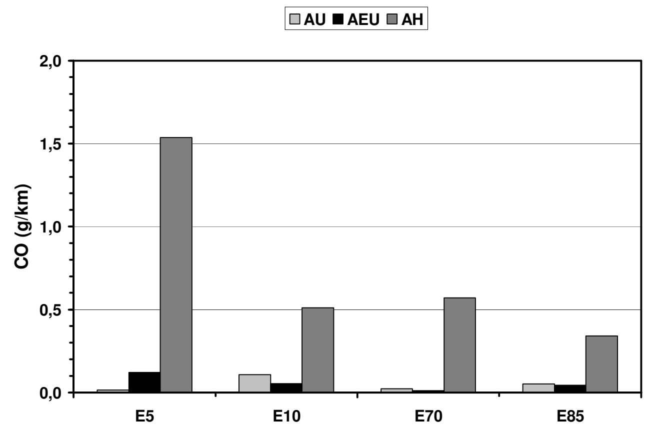

Figure 10. CO emissions in the Artemis cycle for the SYU.

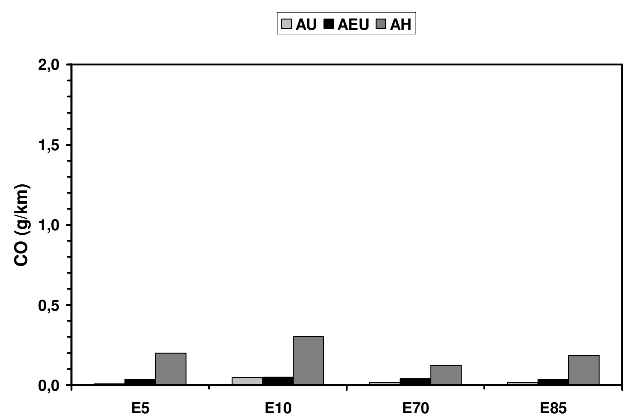

Figure 11. CO emissions in the Artemis cycle for the TNT.

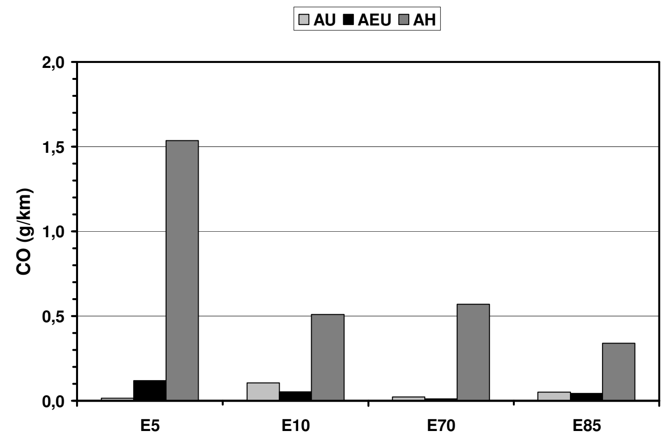

Figure 12. CO emissions in the Artemis cycle for the SYS.

As compared to the NEDC cycle, the hot engine start of the Artemis cycles shows very low CO emissions for the AU and the AEU cycles. The AH cycle shows drastically higher CO emissions indicating a rich fuel/air mixing ratios in the high speeds of this cycle with less effective CO conversion in the catalyst. There is also a fuel effect showing lower CO emissions for the high concentration ethanol fuels. However, this observation is not stringent as there is an individual pattern among the vehicles with TNT emissions much lower as compared to those from the other cars.

3.2.2.1 HC emissions in the NEDC

In Figures 13-15, the HC emissions are presented as the weighted contribution of the sub-cycles to the NEDC cycle emissions.

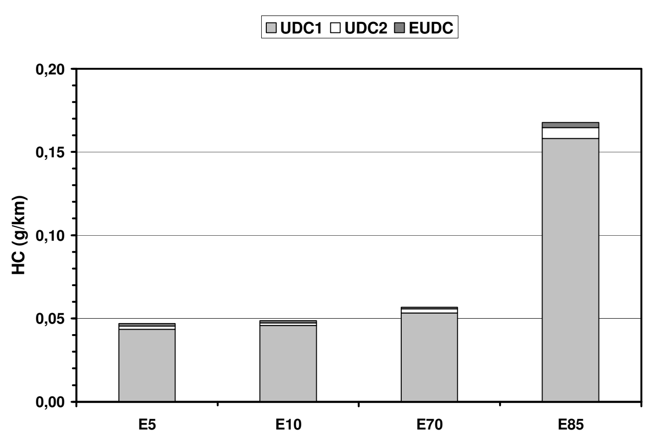

Figure 13. NEDC HC emissions for the SYU.

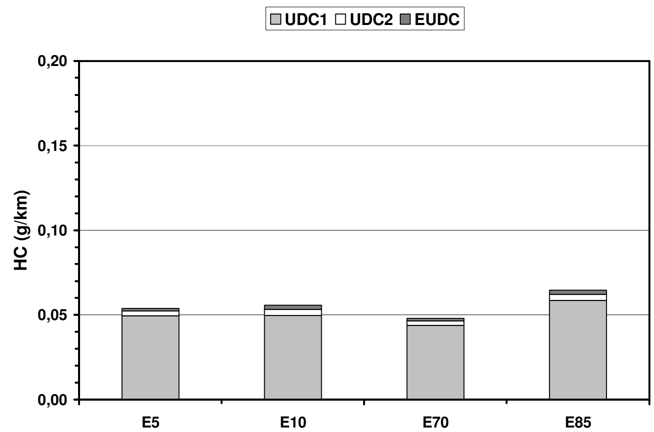

Figure 14. NEDC HC emissions for the TNT.

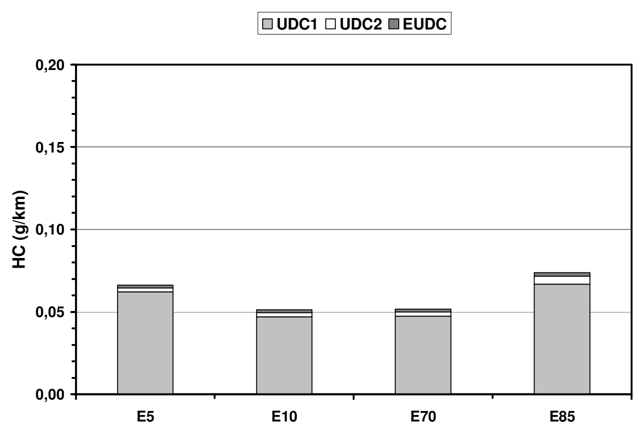

Figure 15. NEDC HC emissions for the SYS.

The HC emissions resemble those of the CO with the main emissions occurring in the UDC1 part of the driving cycle and again, this may be explained by the cold catalyst. In contrast to CO, there is no clear fuel effect to the HC emissions.
The emission limit value for HC is 0.10 g/km and is only exceeded by the SYU operated with E85 (as in the case of CO, Figure 7).

3.2.2.2 HC emissions in the Artemis cycles

The HC emissions for the Artemis cycles are presented in the Figures 16-18.

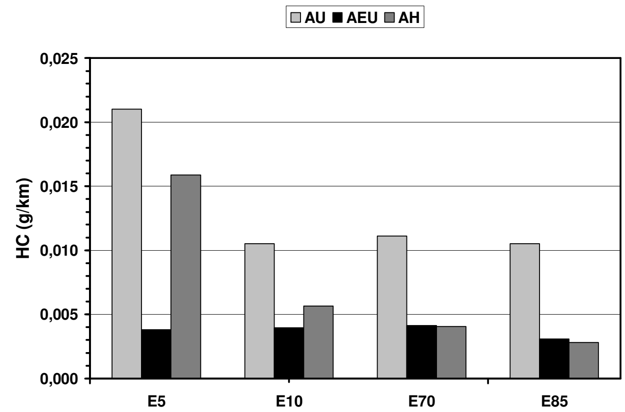

Figure 16. HC emissions for the SYU in the Artemis cycle.

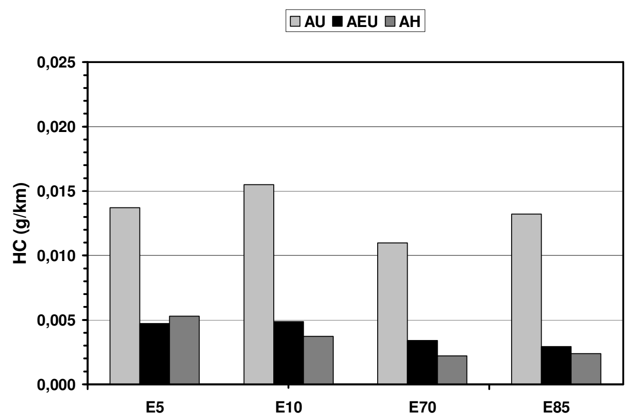

Figure 17. HC emissions for the TNT in the Artemis cycle.

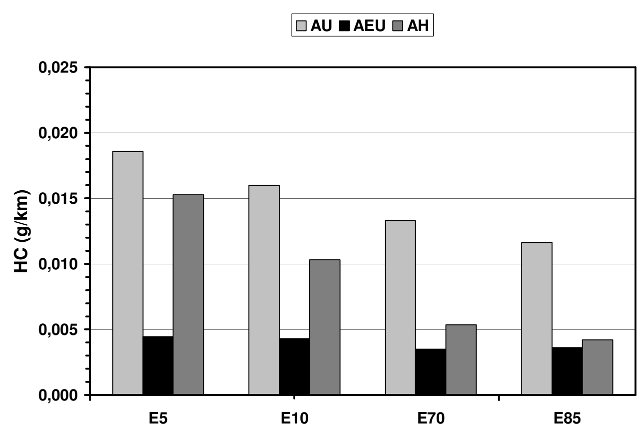

Figure 18. HC emissions for the SYS in the Artemis cycle.

The highest HC emissions are observed in the AU-cycle as an effect of low speeds and high fraction of idle associated with a lower temperature of the exhaust after treatment system. The higher emissions in the AH cycle is very likely explained by rich fuel/air mixing ratios followed by less effective catalyst operation.

3.2.3.1 NO_x emissions in the NEDC

In Figures 19-21, the NO_x and NO measurements are presented for the different NEDC subcycles. The NEDC NO_x and NO emissions are given in numbers for each fuel.

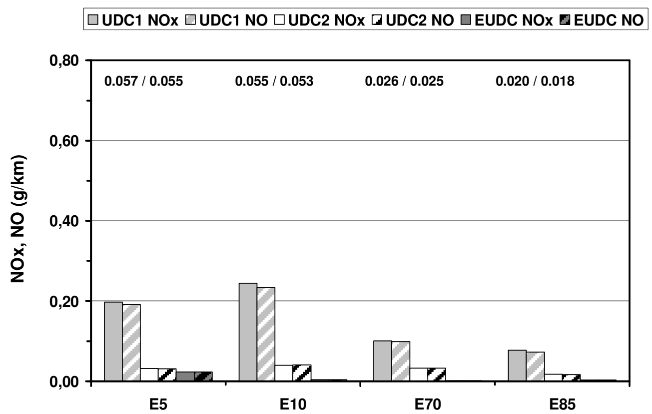

Figure 19. NO_x and NO emissions for the SYU in the NEDC (NO_x and NO cycle emissions are presented).

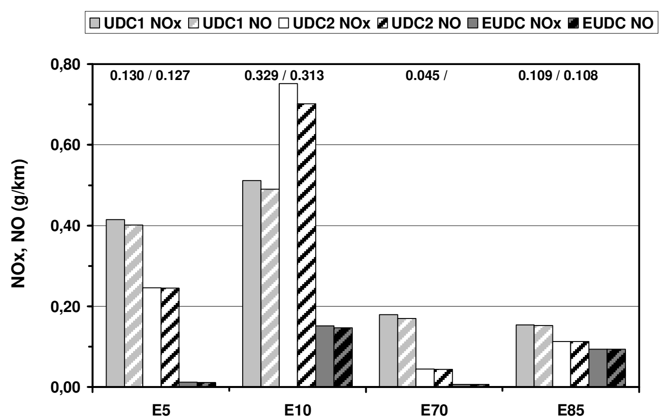

Figure 20. NO_x and NO emissions for the TNT in the NEDC (NO_x and NO cycle emissions are presented).

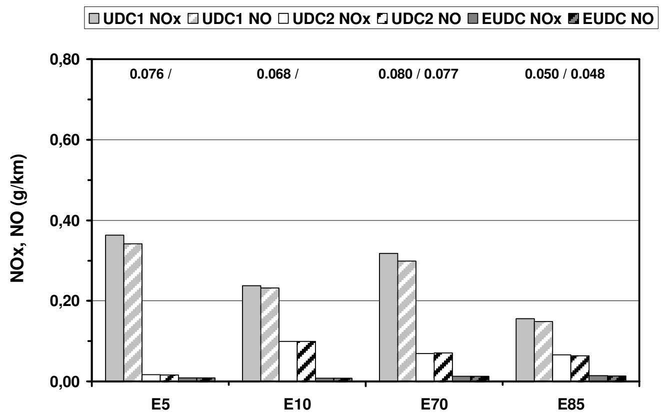

Figure 21. NO_x and NO emissions for the SYS in the NEDC (NO_x and NO cycle emissions are presented).

In all but one cases, the NO_x emissions are highest in the UDC1 and lowest in the EUDC. A likely explanation to this behaviour is that during the start of UDC1, the catalyst is cold. It is apparent that the UDC2 is considerably lower in NO_x emissions which further indicate the cold start effect. The highest NO_x emissions are observed for the E5 and E10 fuels. In all tests, only a minor portion of the NO_x is emitted as NO_2 with an overall NEDC average for all cars and fuels of 5%.
The NO_x emission limit value is 0.08 g/km and is exceeded by one of the cars (the TNT).

3.2.3.2 NO_x emissions in the Artemis cycles

In Figures 22-24, the NO_x and NO measurements are presented for the different Artemis cycles and fuels.

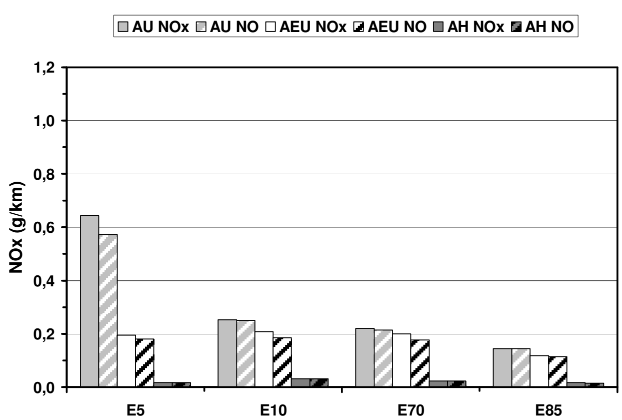

Figure 22. NO_x and NO emissions for the SYU in the Artemis cycles.

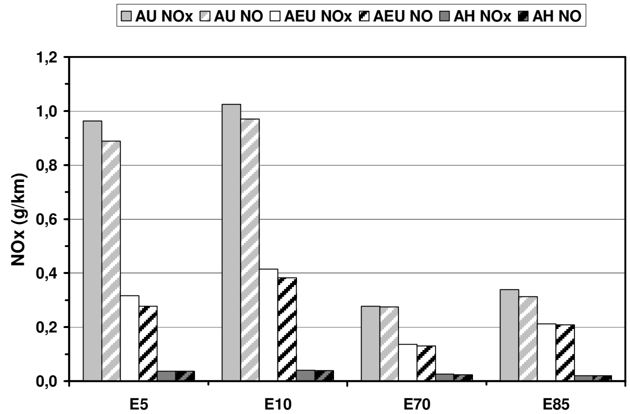

Figure 23. NO_x and NO emissions for the TNT in the Artemis cycles.

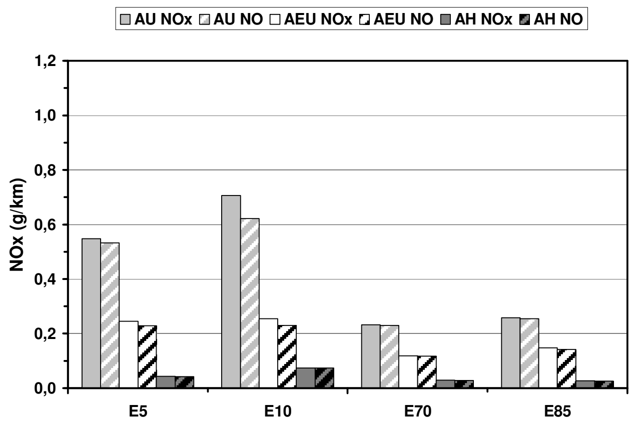

Figure 24. NO_x and NO emissions for the SYS in the Artemis cycles.

For the E70 and the E85 fuels the NO_x emissions are reduced by as much as 70% as compared to the E5 and the E10 fuels in the AU and the AEU.

The AU is for all fuels associated with considerably higher NO_x emissions as compared to the AEU and AH. The AH shows NO_x emissions between 3-12% of the emissions for the AU. Even if all the Artemis cycles includes warm start, a possible explanation to the higher NO_x emissions in the AU may be that the low speeds of this cycle do not allow the catalyst to reach proper operational temperature. Alternatively, it may be an effect of the strategy how to operate within the lambda-window (air-fuel ratio) during different driving conditions which controls the conversion rates of the NO_x.

3.2.4.1 CO_2 emissions in the NEDC

In Figures 25-27, the CO_2 emissions are presented as the weighted contribution of the sub-cycles to the NEDC cycle emissions.

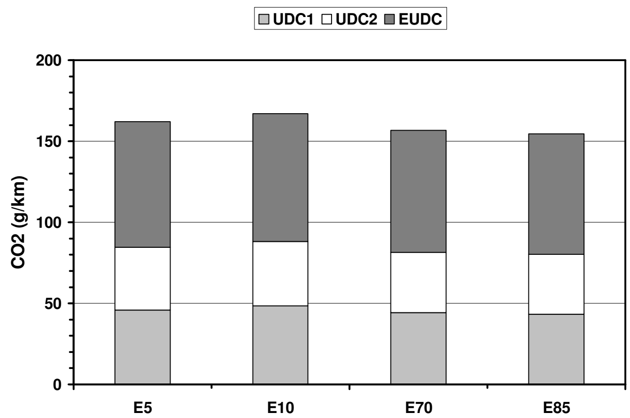

Figure 25. CO_2 emissions for the SYU in the NEDC.

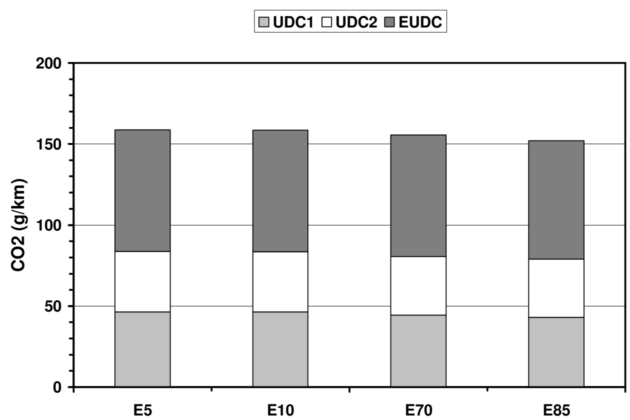

Figure 26. CO_2 emissions for the TNT in the NEDC.

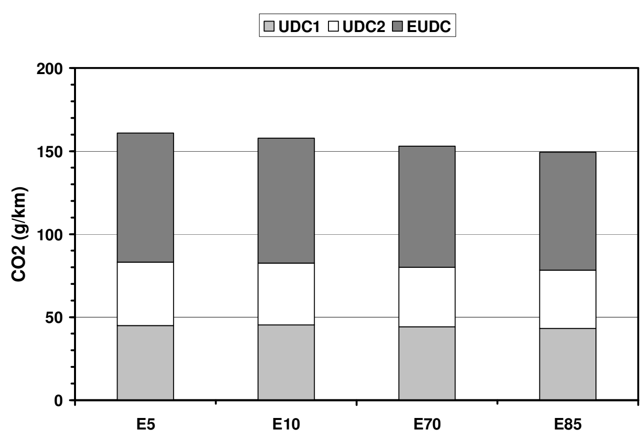

Figure 27. CO_2 emissions for the SYS in the NEDC.

3.2.4.2 CO_2 emissions in the Artemis cycles

The CO_2 emissions for the Artemis cycles are presented in the Figures 28-30.

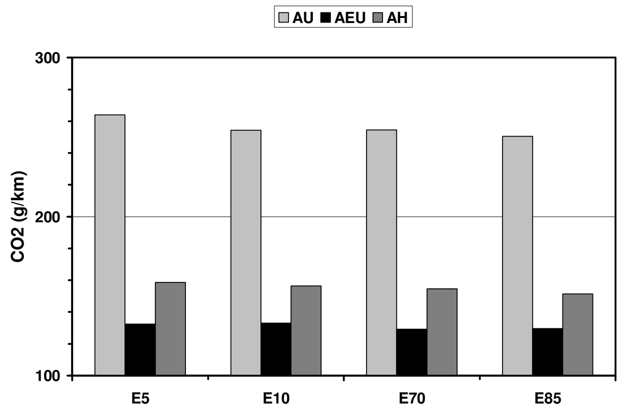

Figure 28. CO_2 emissions for the SYU in the Artemis cycle.

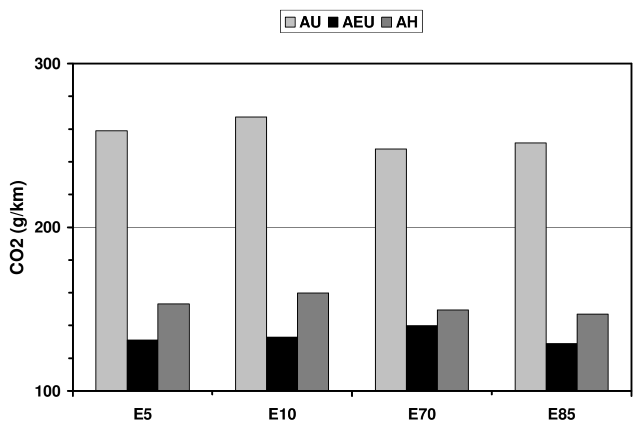

Figure 29. CO_2 emissions for the TNT in the Artemis cycle.

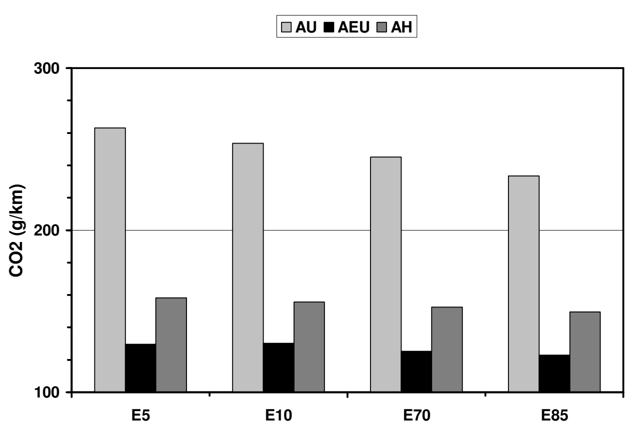

Figure 30. CO_2 emissions for the SYS in the Artemis cycle.

3.2.5.1 CH_4 emissions in the NEDC

In Figures 31-33, the CH_4 emissions are presented as the weighted contribution of the sub-cycles to the NEDC cycle emissions.

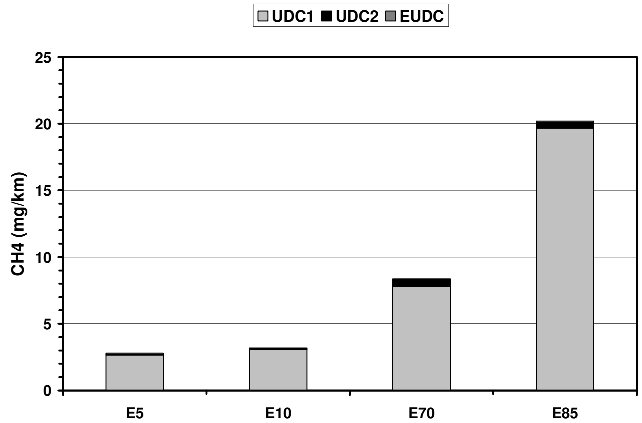

Figure 31. CH_4 emissions for the SYU in the NEDC.

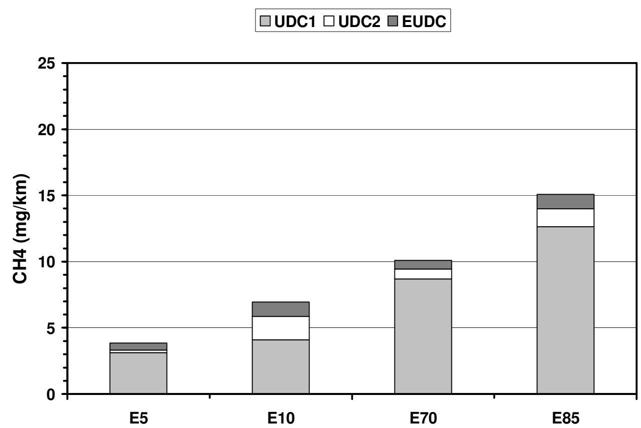

Figure 32. CH_4 emissions for the TNT in the NEDC.

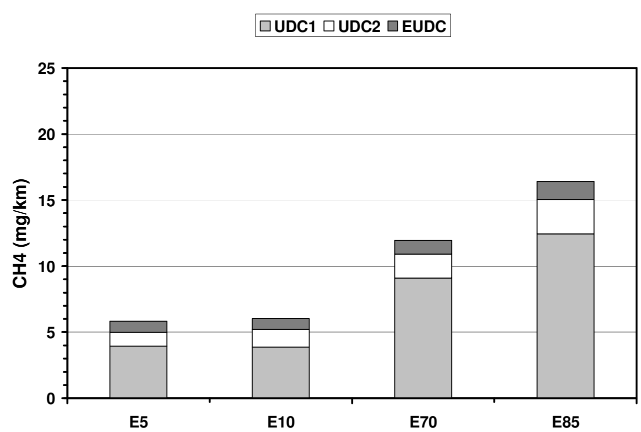

Figure 33. CH_4 emissions for the SYS in the NEDC.

3.2.5.2 CH_4 emissions in the Artemis cycles

The CH_4 emissions for the Artemis cycles are presented in the Figures 34-36.

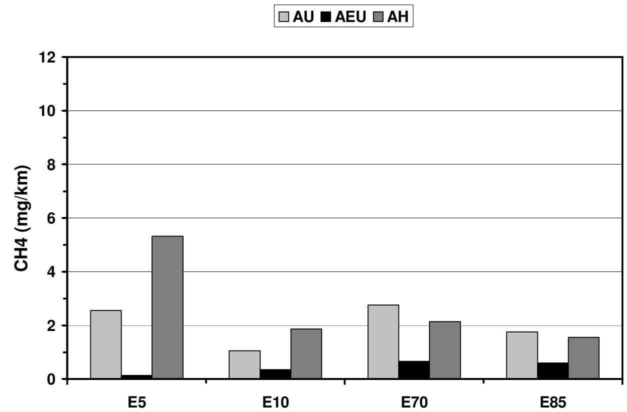

Figure 34. CH_4 emissions for the SYU in the Artemis cycle.

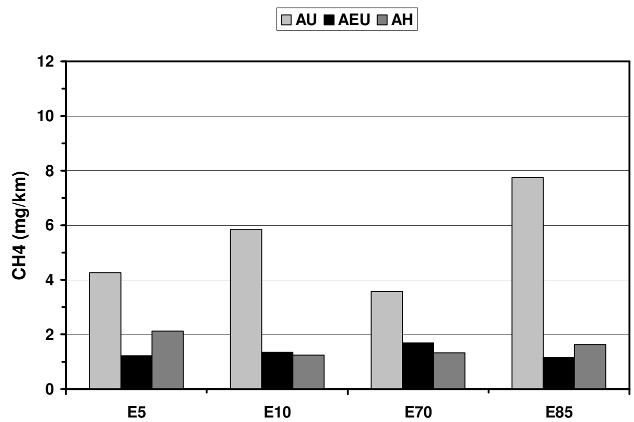

Figure 35. CH_4 emissions for the TNT in the Artemis cycle.

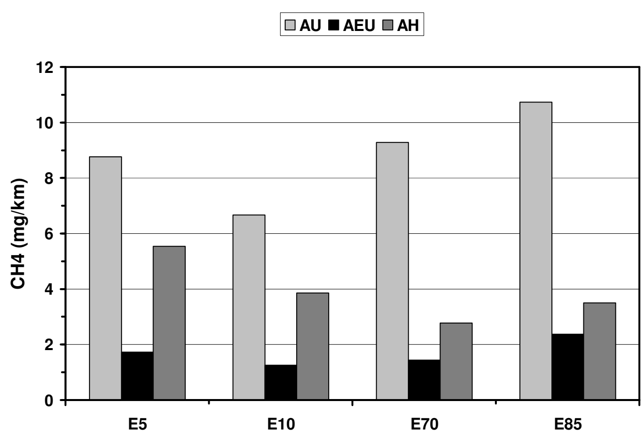

Figure 36. CH_4 emissions for the SYS in the Artemis cycle.

3.2.6.1 Aldehyde emissions in the NEDC

The NEDC formaldehyde and acetaldehyde emissions are presented in Figure 37 for the different vehicles and fuels.

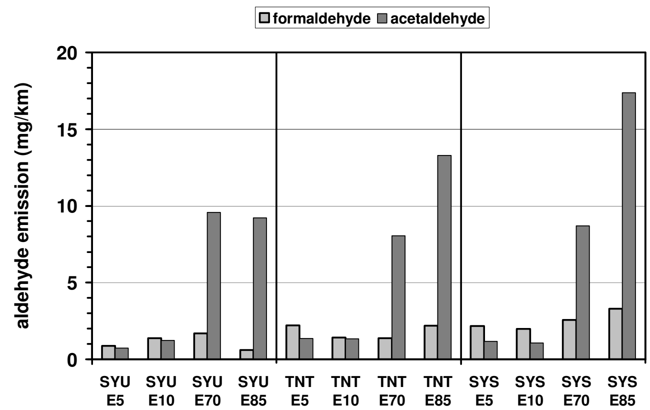

Figure 37. NEDC aldehyde emissions for all vehicles and fuels.

The formaldehyde emissions are slightly higher as compared to those of acetaldehyde for the E5 and the E10 fuels without any clear fuel dependence. The emissions of acetaldehyde show a clear fuel dependence with largely increased emissions for the high ethanol fuels, E70 and E85. This observation indicates the chemical route to form acetaldehyde with ethanol as a precursor. The relatively lower emissions of formaldehyde and the absence of fuel effect indicate that formaldehyde is not formed by ethanol as a precursor.

3.2.6.2 Aldehyde emissions in the Artemis cycle

The formaldehyde and acetaldehyde emissions in the Artemis cycles are presented in Figures 38-40 for the different vehicles and fuels.

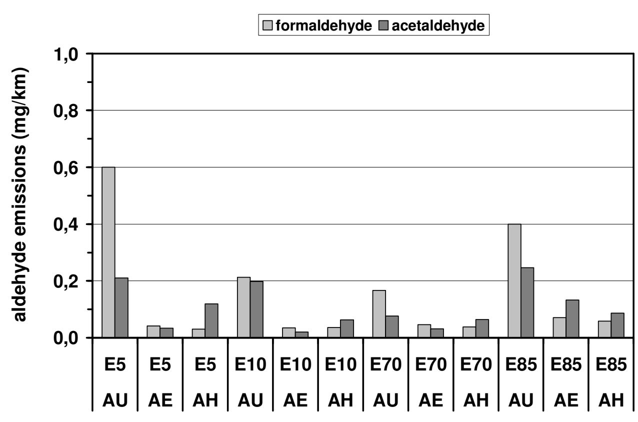

Figure 38. Aldehyde emissions for the SYU in the Artemis cycle.

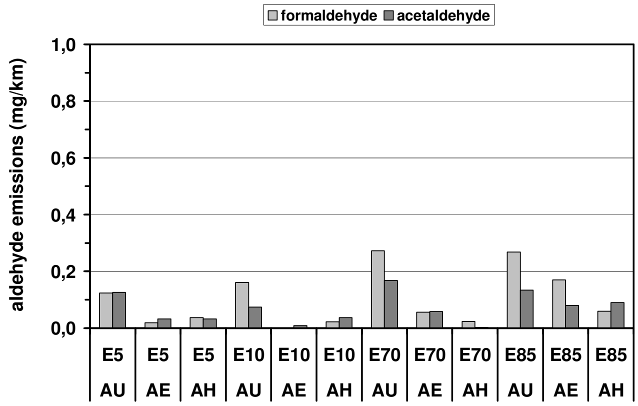

Figure 39. Aldehyde emissions for the TNT in the Artemis cycle.

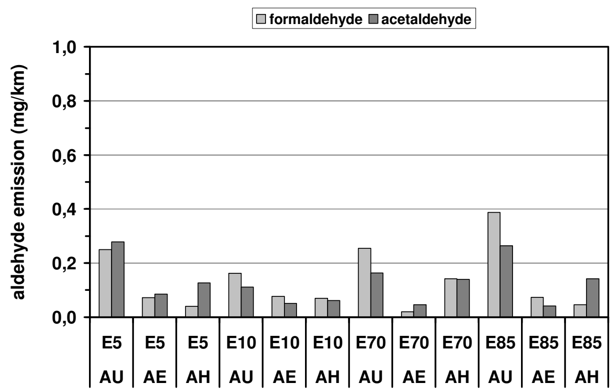

Figure 40. Aldehyde emissions for the SYS in the Artemis cycle.

As compared to the NEDC emissions, the aldehyde emissions in the Artemis cycles are considerably lower. The high acetaldehyde emissions observed for the E70 and E85 fuels in the NEDC cycle are not observed in the Artemis cycles. However, it appears that there is cycle dependence with the highest emissions observed in the AU. The difference in acetaldehyde emissions between the NEDC and the Artemis cycles is attributed to the cold start in the NEDC cycle. It was previously observed that the major part of the HC emissions in the NEDC (Figures 13-15) occurred in the UDC1 as an effect of the cold catalyst. Thus, acetaldehyde is formed from the ethanol fuel but to a large extent removed by the warm catalyst in the Artemis cycles and therefore the high acetaldehyde emissions in the NEDC are not observed.

3.2.7.1 Energy and fuel consumption in the NEDC

The NEDC energy and fuel consumption is presented in Figures 41-43.

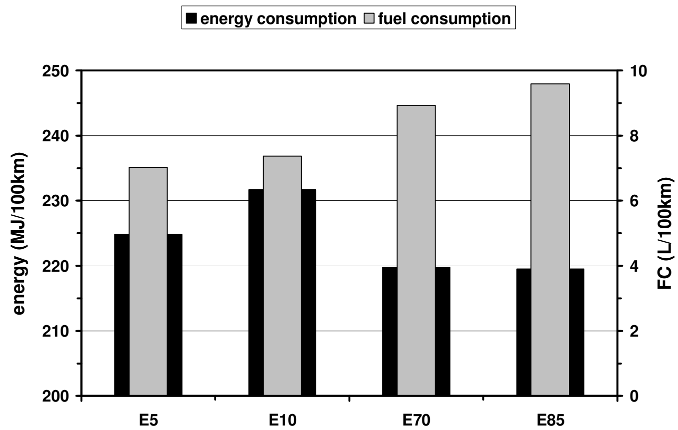

Figure 41. Energy and fuel consumption in the NEDC for the SYU.

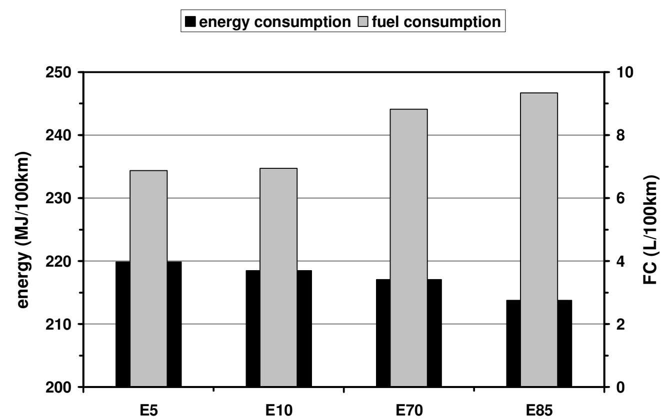

Figure 42. Energy and fuel consumption in the NEDC for the TNT.

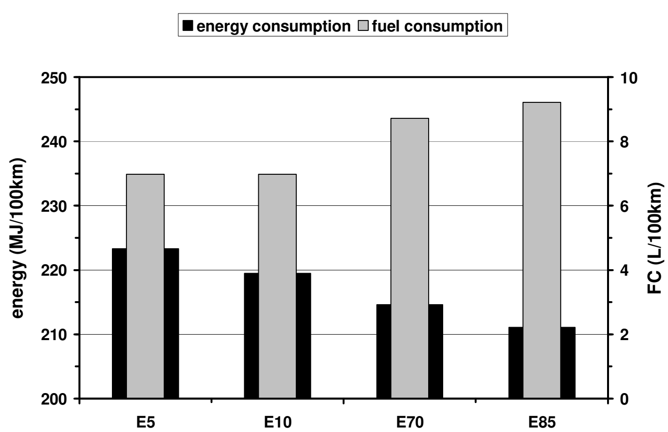

Figure 43. Energy and fuel consumption in the NEDC for the SYS.

The Fuel consumption increases with the higher ethanol concentration fuels as an effect of the lower energy content of the fuel. However, the energy consumption decreases as the ethanol has a higher octane value and is more energy efficient as compared to gasoline.

3.2.7.2 Energy and fuel consumption in the Artemis cycles

Energy and fuel consumption in the Artemis cycles is presented in Figures 44-46.

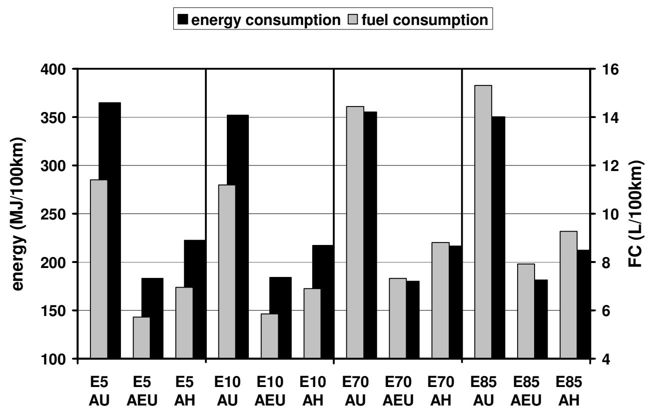

Figure 44. Energy and fuel consumption in the Artemis cycle for the SYU.

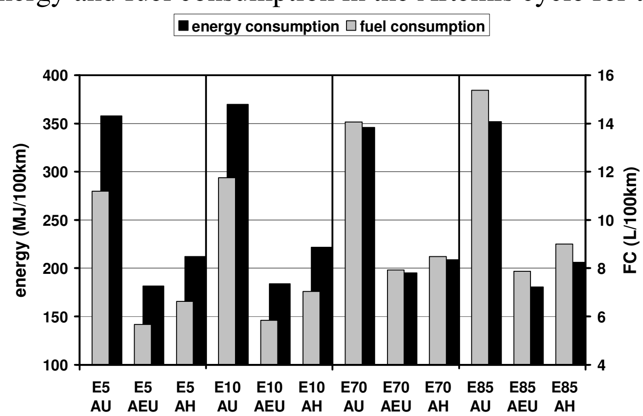

Figure 45. Energy and fuel consumption in the Artemis cycle for the TNT.

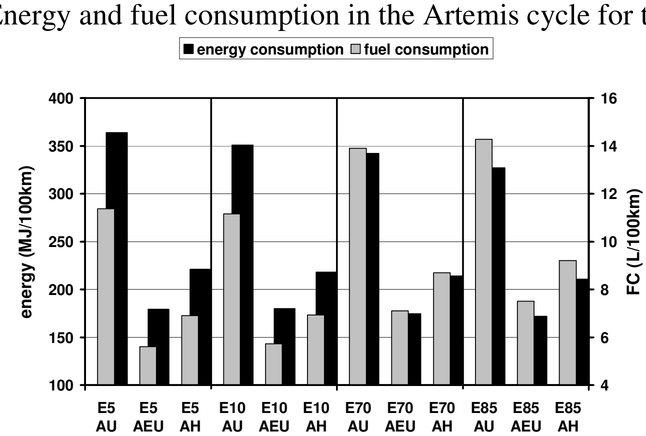

Figure 46. Energy and fuel consumption in the Artemis cycle for the SYS.

In the Artemis cycles, the fuel consumption increases and the energy consumption decreases with gradually higher content of ethanol as earlier discussed for the NEDC cycle.

3.3 Particulate mass and particle number emissions

Particulate mass (PM) and particle number emissions are presented below.

3.3.1 PM emissions in the NEDC

In Figures 47-49, the PM emissions are presented for the two PM methods used. The regulated method is presented as the weighted contribution of the sub-cycles to the NEDC cycle emissions. The PMP-method is presented as the NEDC emission.

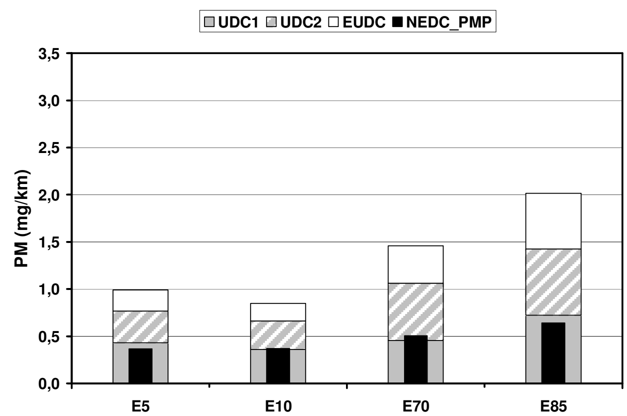

Figure 47. PM emissions for the SYU in the NEDC.

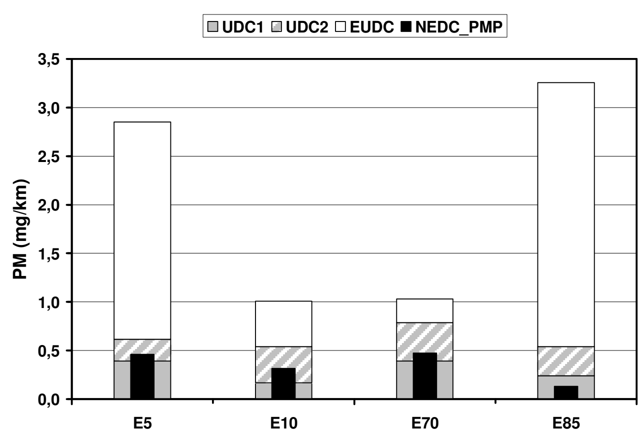

Figure 48. PM emissions for the TNT in the NEDC.

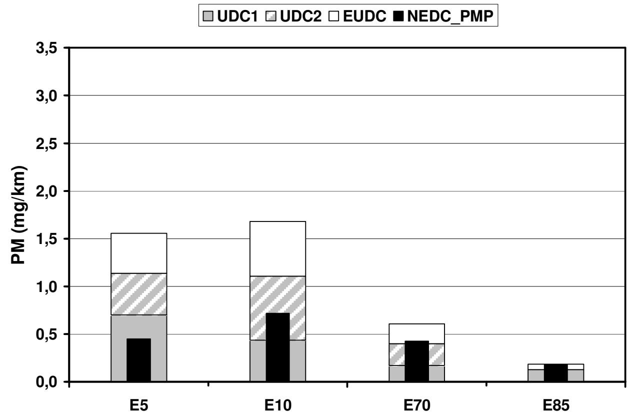

Figure 49. PM emissions for the SYS in the NEDC.

A large difference between the two PM methods is observed. In most tests the PMP-method only measures half or even less of what is measured by the regulated method. This observation is in line with the observations made in other studies (for example AECC, 2005). As the NEDC cycle provides relatively cold emissions to be sampled at the filters, a significant portion of the PM-weight is due to condensed material. The PMP-method is, however, operating at a higher and narrower temperature range (47±5°C) and accordingly less condensed material is collected. Furthermore, the PMP-method only uses a single filter which also reduces the contribution of condensates to PM.
There are no obvious trends observed between the different fuels in regard to PM emissions.

3.3.2 PM emissions in the Artemis cycles

In Figures 50-52, the PM emissions for the regulated method and for the PMP method are presented for the different Artemis cycles and fuels.

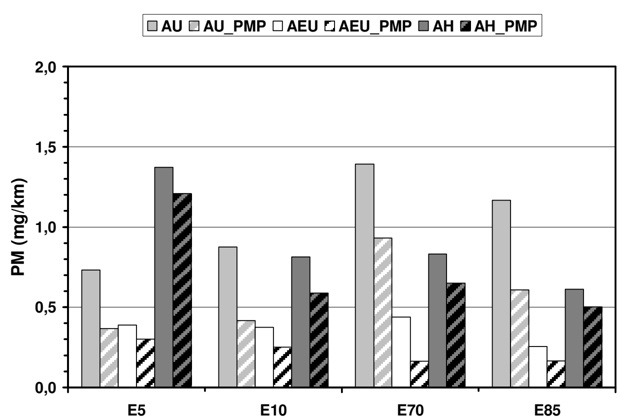

Figure 50. PM emissions for the SYU in the Artemis cycle.

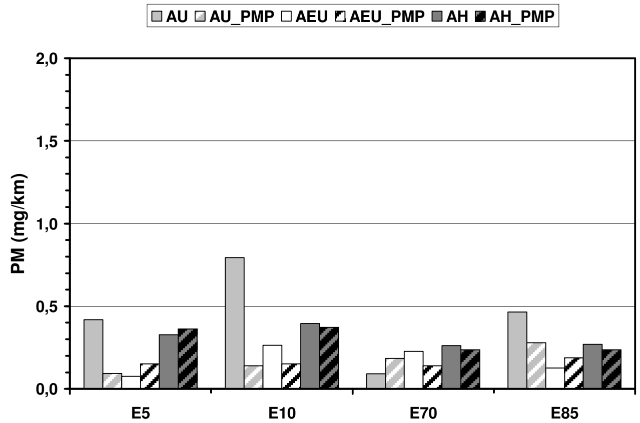

Figure 51. PM emissions for the TNT in the Artemis cycle.

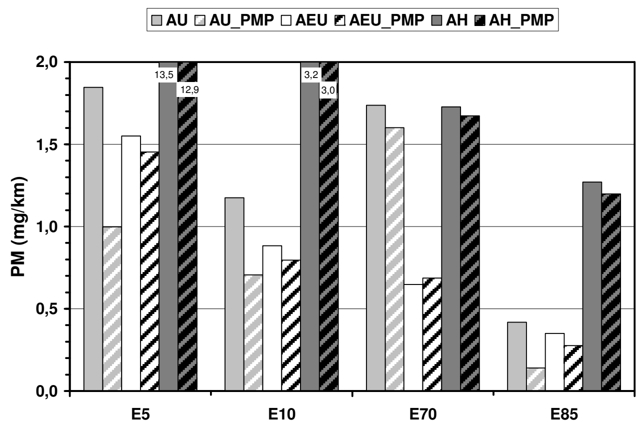

Figure 52. PM emissions for the SYS in the Artemis cycle.

Again, as in the case of the NEDC cycles, the PMP-method measures lower emissions as compared to the regulated method. The difference is, however, considerably smaller as for the NEDC. There is clear cycle dependence with the smallest difference observed in the AEU cycle and the largest in the AU cycle.

There are obviously large differences in PM emissions between the three vehicles with the highest emissions observed for the SYS. The SYS is also the only car that shows a clear fuel related trend in the PM emissions with gradually lower PM emissions in the AH cycle for the fuels with higher ethanol concentrations.

3.4.1 Particle number measurements in the NEDC

The particle number measurements as measured according to the PMP-protocol are presented below (NEDC Figures 52-53, Artemis Figures 54-56) as the total particle emission for the different driving cycles.

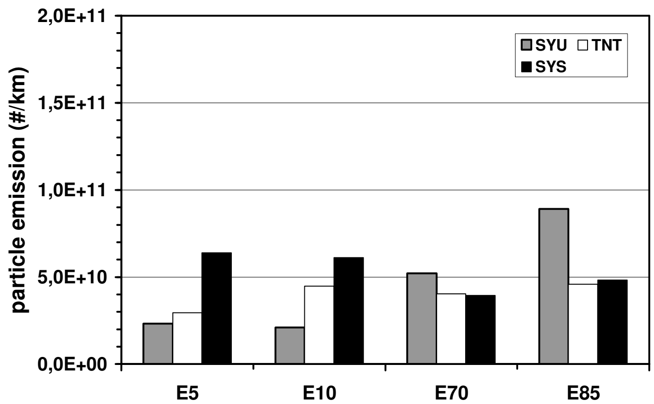

Figure 52. NEDC total particle number emissions for all cars and fuels.

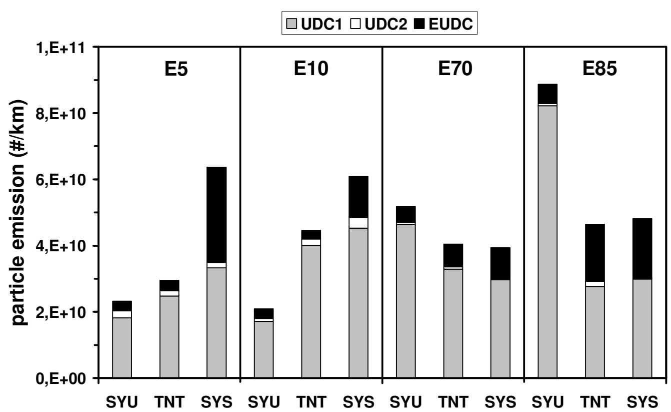

Figure 53. NEDC total particle number emissions for all cars and fuels. The relative proportion of the subcyles to the total NEDC emission is given.

3.4.2 Particle number measurements in the Artemis cycle

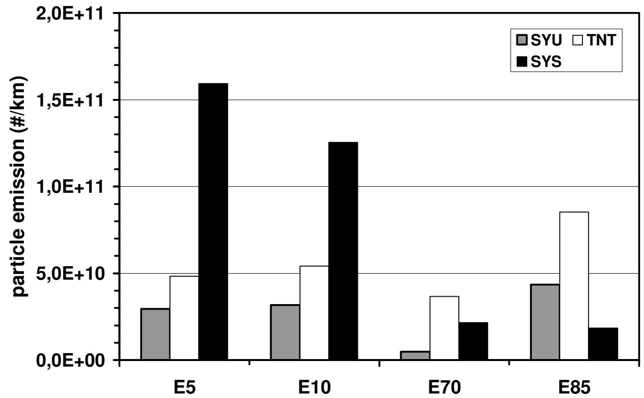

Figure 54. AU total particle number emissions for all cars and fuels.

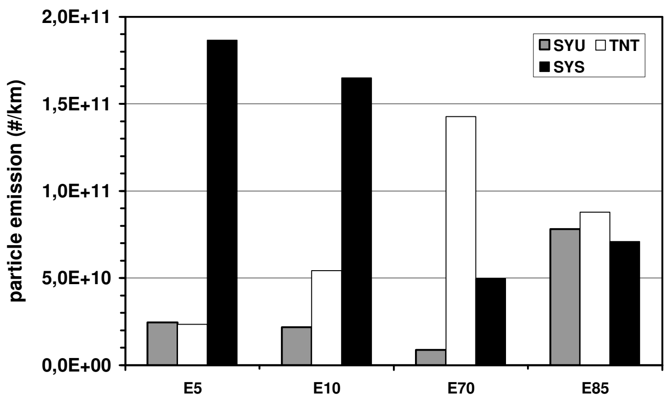

Figure 55. AEU total particle number emissions for all cars and fuels.

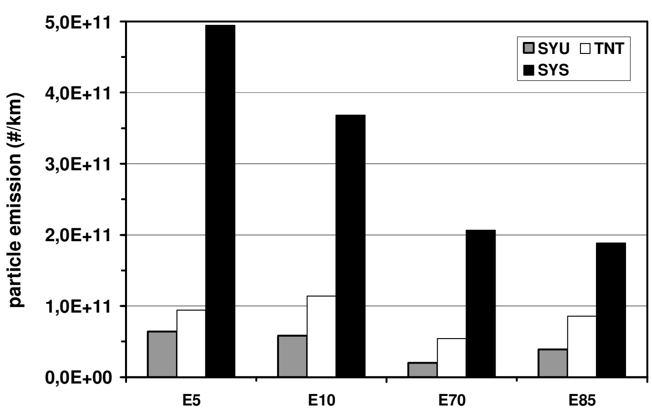

Figure 56. AH total particle number emissions for all cars and fuels.

The PMP number emissions in the NEDC are in the range 10^{10} to 10^{11} particles/km. These emissions are in the lower range of what is reported by Ntziachristos et al. (2004) for gasoline cars meeting the Euro 3 regulation and lower than the $5x10^{11}$ particles/km reported for a Euro 4 gasoline vehicle previously examined with the PMP-method at AVL MTC (AECC, 2005). In the NEDC cycle, there is no obvious fuel effect in the particle number emissions.

The AU and AEU cycles show emissions in the same range as in the NEDC. One of the three cars (the SYS) shows generally higher particle emissions as compared to the other cars and is also the only car that shows clear fuel dependence with decreasing particle number emissions with the higher concentration ethanol fuels.

A comparison of the particle number measurements with the PM shows that the emissions of the SYS in the Artemis cycle compares very well. However, the regression line of the particle number measurements for all tests compared to PM and PM-PMP shows an r^2 value of 0.540 and 0.649 respectively.

3.5 Emissions at -7°C, NEDC

In the following section, results are presented as obtained from NEDC measurements performed at test cell temperatures of -7°C. The E70 fuel was examined both with and without the use of engine pre-heater while the E85 fuel was examined with engine pre-heater. During the tests at which the engine pre-heater was used it was turned on 75 min prior to cycle start and indicated in the following figures as "E70m" and "E85m".

3.5.1 Gaseous emissions and fuel consumption at -7°C

CO emissions at -7°C, NEDC

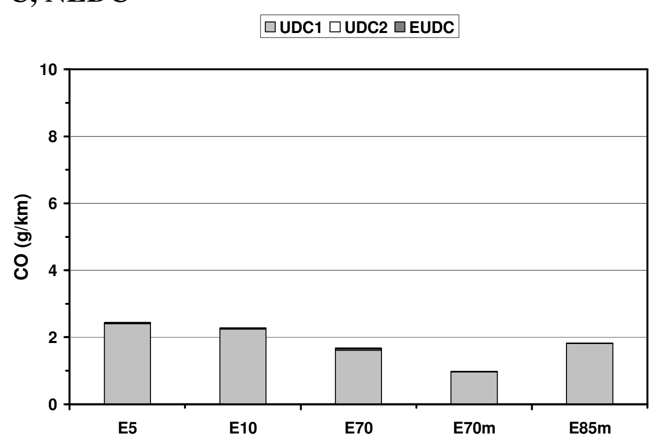

Figure 57. NEDC CO emissions at -7°C for the SYU.

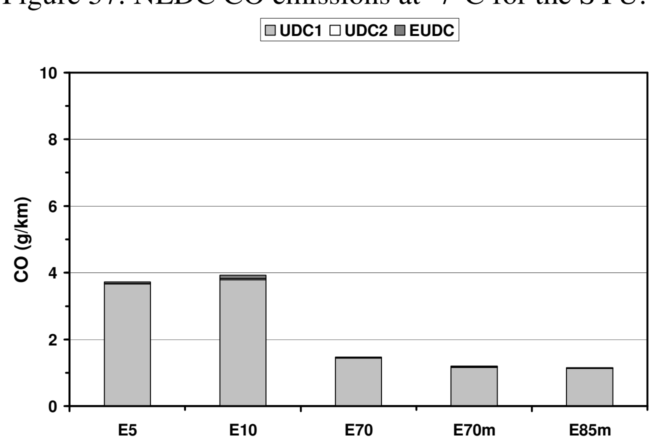

Figure 58. NEDC CO emissions at -7°C for the TNT.

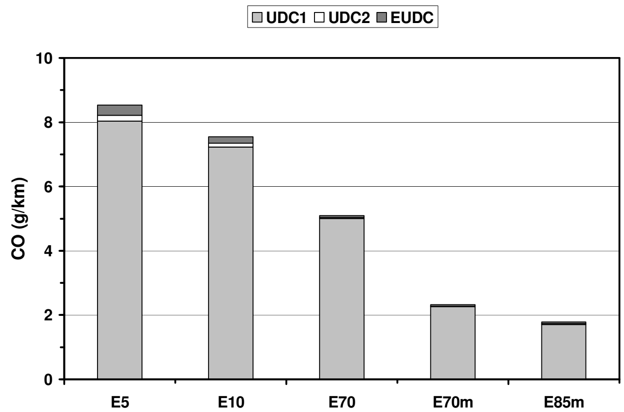

Figure 59. NEDC CO emissions at -7°C for the SYS.

The CO emissions at -7°C is considerably higher as compared to those obtained at +22°C. For the E5 and the E10 fuels, the emissions are more than 10 times higher and for the SYS (showing the highest emissions), the CO emissions at +22°C were about 0.25 g/km. The CO emissions at -7°C decreases for the higher concentration ethanol fuels which is opposite to what was observed at +22°C. In all tests using E70 in combination with engine pre-heater, the CO emissions are reduced by 10-50%.

HC emissions at -7°C, NEDC

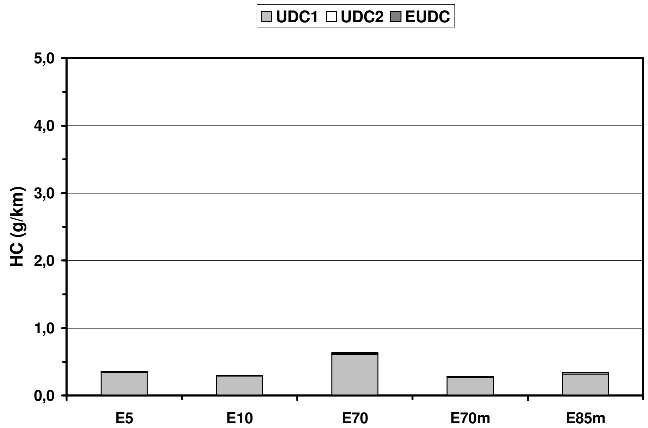

Figure 60. NEDC HC emissions at -7°C for the SYU.

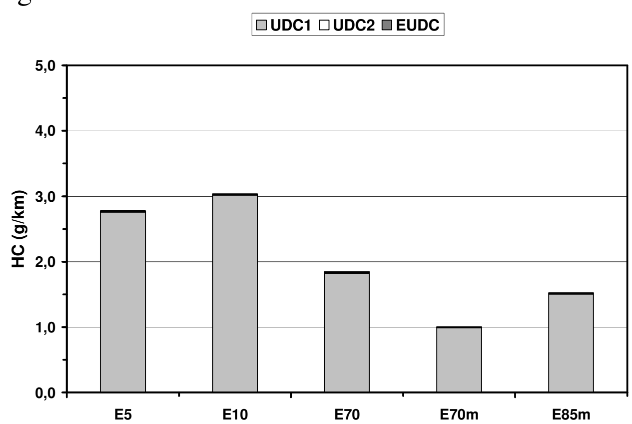

Figure 61. NEDC HC emissions at -7°C for the TNT.

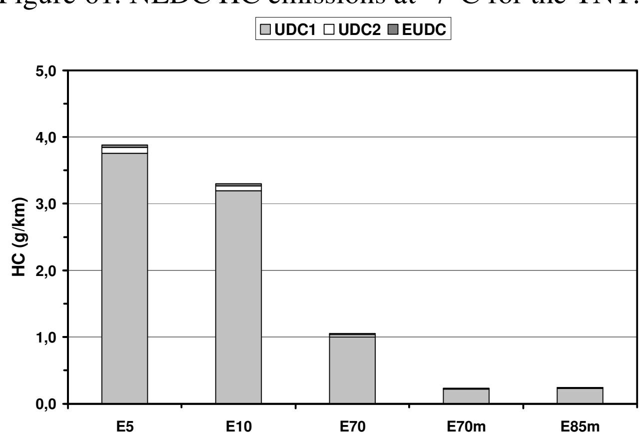

Figure 62. NEDC HC emissions at -7°C for the SYS.

As for the CO, the HC emissions at -7°C are higher as compared to the emissions at +22°C (10-50 times higher). The effect of engine pre-heater is clearly observed for the E70 fuel showing a HC emission reduction of about 50%.

NO_x emissions at -7°C, NEDC

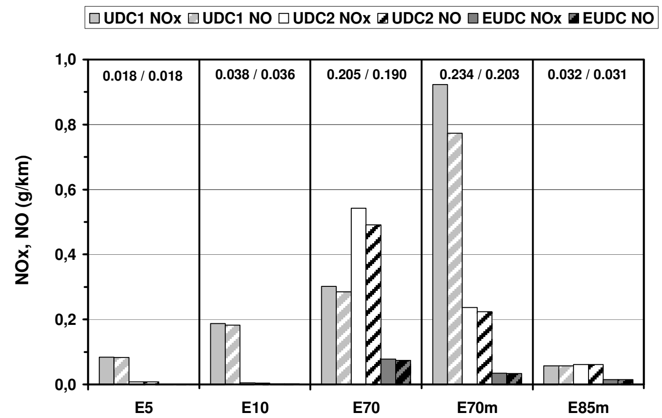

Figure 63. NEDC NO_x and NO emissions at -7°C for the SYU.

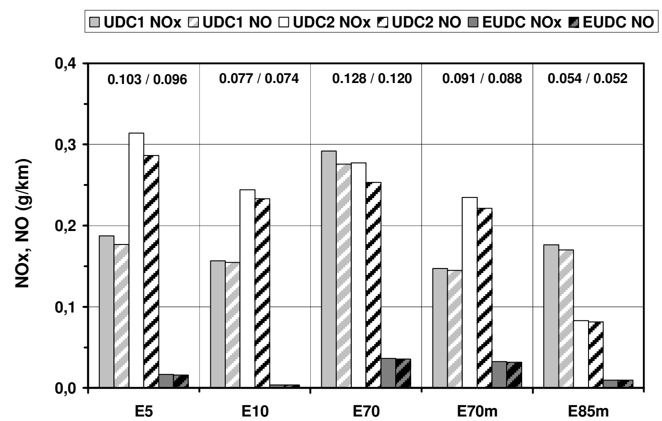

Figure 64. NEDC NO_x and NO emissions at -7°C for the TNT.

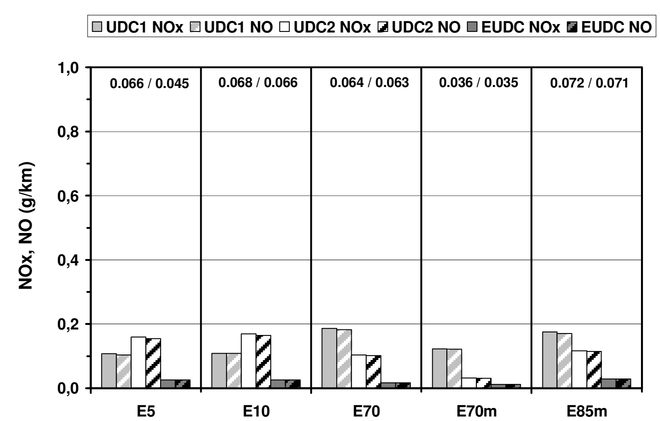

Figure 65. NEDC NO_x and NO emissions at -7°C for the SYS.

The NO_x emissions are in the same range as the emissions at +22°C.

CO_2 emissions at -7°C, NEDC

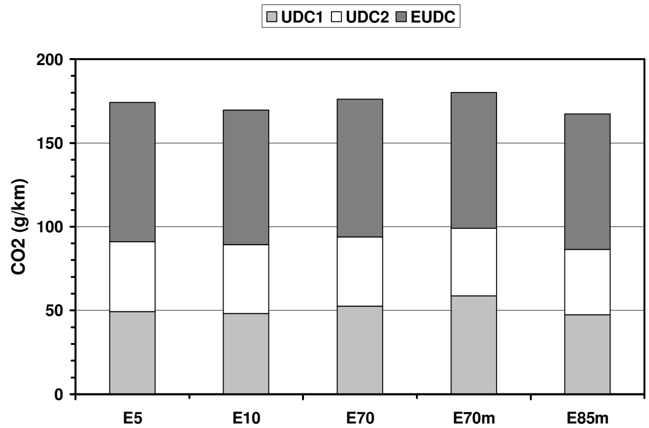

Figure 66. NEDC CO_2 emissions at -7°C for the SYU.

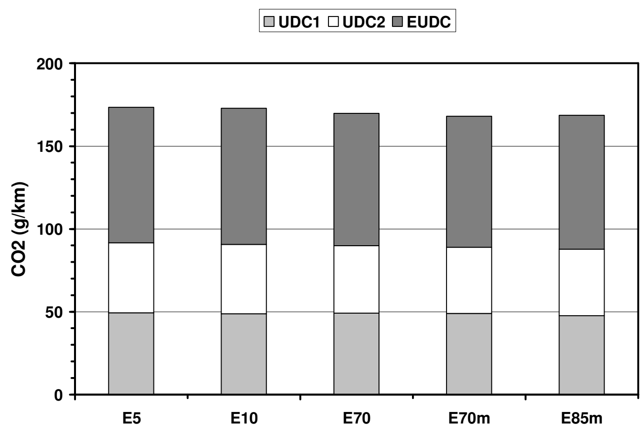

Figure 67. NEDC CO_2 emissions at -7°C for the TNT.

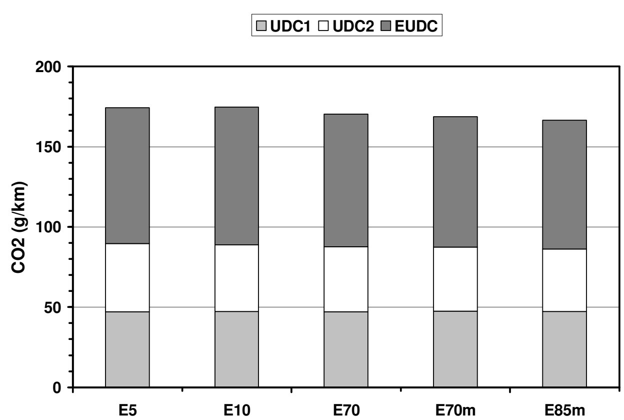

Figure 68. NEDC CO_2 emissions at -7°C for the SYS.

The CO_2 emissions are higher as compared to the emissions at +22°C which is also reflected in the energy consumption (Figures 73-75, below).

CH_4 emissions at -7°C, NEDC

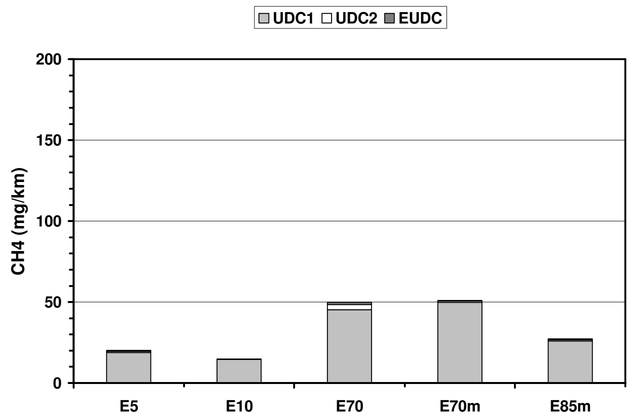

Figure 69. NEDC CH_4 emissions at -7°C for the SYU.

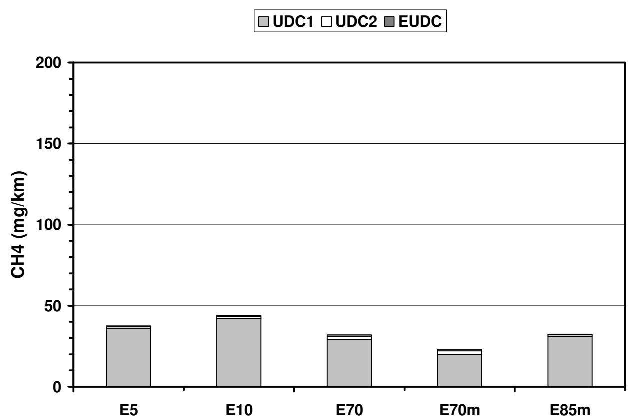

Figure 70. NEDC CH_4 emissions at -7°C for the TNT.

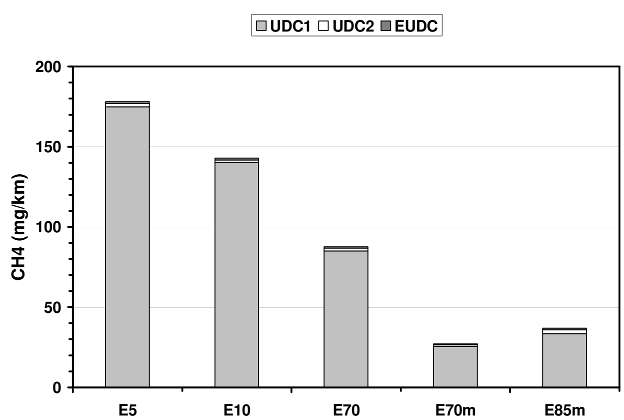

Figure 71. NEDC CH_4 emissions at -7°C for the SYS.

The CH_4 emissions are 2-10 times higher at -7°C as compared to +22°C.

Aldehyde emissions at -7°C, NEDC

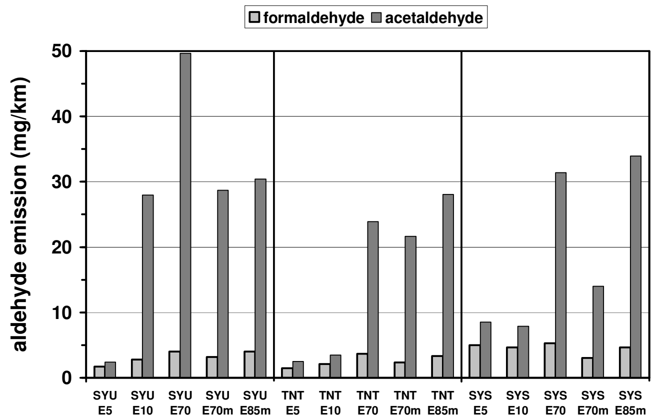

Figure 72. NEDC formaldehyde and acetaldehyde emissions at -7°C for all vehicles and fuels.

The aldehyde emissions are higher at -7°C as compared to +22°C. As for +22°C, acetaldehyde is increased for E70 and E85 while the formaldehyde emission is about the same for all fuels.

The effect of engine pre-heater shows lower emissions of acetaldehyde for the E70 fuel.

Energy and fuel consumption in the NEDC at -7°C

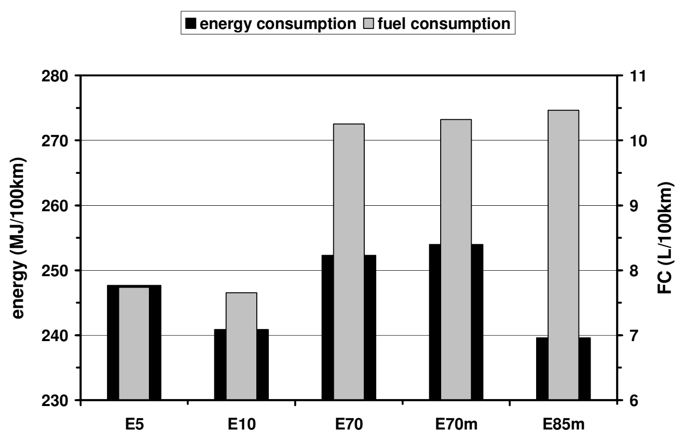

Figure 73. Energy and fuel consumption in the NEDC at -7°C for the SYU.

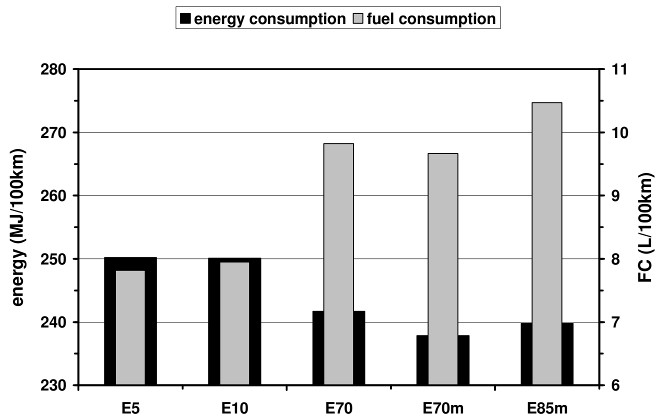

Figure 74. Energy and fuel consumption in the NEDC at -7°C for the TNT.

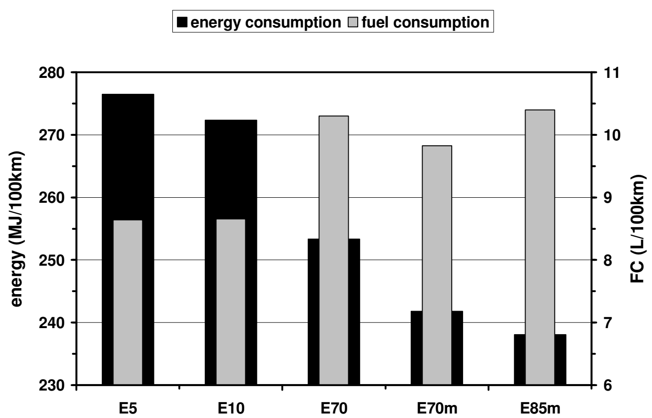

Figure 75. Energy and fuel consumption in the NEDC at -7°C for the SYS.

3.5.2 PM emissions at -7°C, NEDC

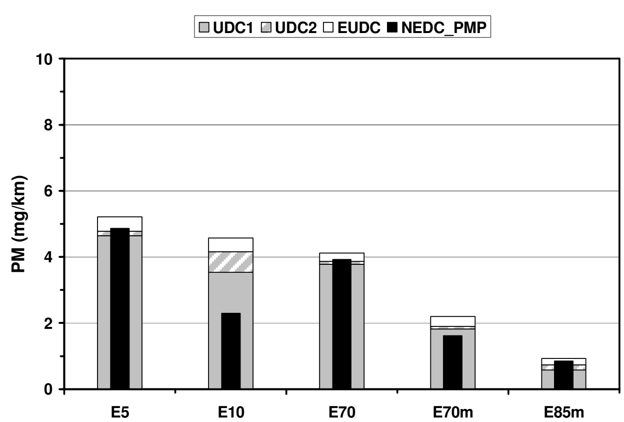

Figure 76. PM emissions for the SYU in the NEDC at -7°C.

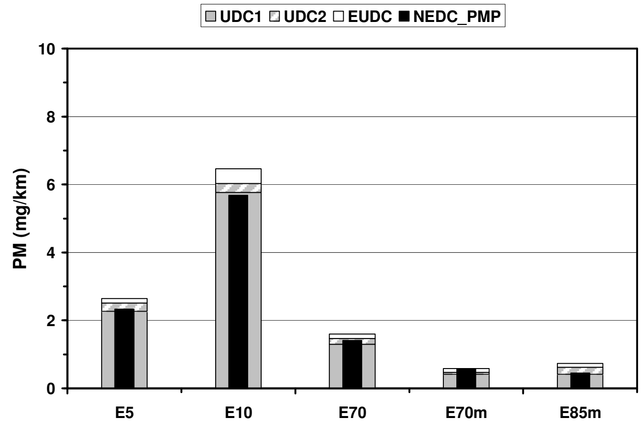

Figure 77. PM emissions for the TNT in the NEDC at -7°C.

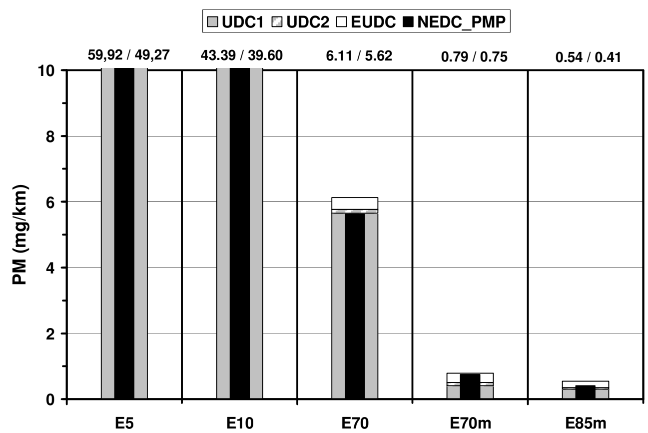

Figure 78. PM emissions for the SYS in the NEDC at -7°C.

The PM-emissions are higher at -7°C as compared to the emissions at +22°C. The SYS shows very high emissions for the E5 and the E10 fuels with emissions up to 60 mg/km which is comparable to the emissions from diesel cars. The PM emissions are reduced by about 50% for the E70 tests using engine pre-heater.

The two PM methods show considerably better agreement as compared to what was observed at +22°C. This may be an effect of different proportions of soot/condensed material trapped by the two methods as compared to the +22°C which can, however, not be concluded unless a chemical analysis is performed.

3.5.3 Particle number emissions at -7°C, NEDC

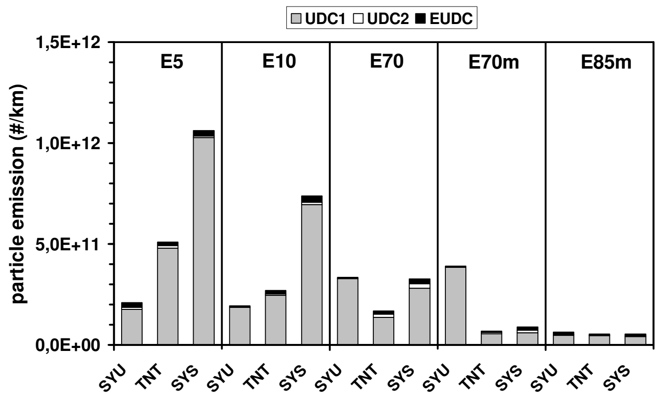

Figure 79. Particle number emissions for all cars and fuels in the NEDC at -7°C.

As for the PM, the particle number emission is higher at -7°C as compared to +22°C (Figure 53). The lowest emissions are observed for the E85 fuel and the highest for the E5. The effect of engine pre-heater is not obvious as observed for the E70 fuel.

The UDC1 part of the cycle shows higher relative emissions as compared to the UDC2 and the EUDC for the tests performed at -7°C as compared to the tests performed at +22°C indicating the importance of the cold start emissions at low temperatures.

The regression line r^2 value of the particle number measurements as compared to PM and PM-PMP are 0.808 and 0.804 respectively.

4. SUMMARY AND CONCLUSIONS

Three Euro 4 Ford Focus flexible fuel passenger cars have been examined for regulated and nonregulated emissions including aldehydes, and particulate mass and particle number emission (measured in accordance with the PMP-protocol).

The emissions were examined using E5, E10, E70, and E85 fuels (percentage ethanol blends in gasoline) in the NEDC and the Artemis driving cycles at test cell temperature +22°C. NEDC tests were also performed at -7°C. All tests were performed as single tests. The E70 tests performed at -7°C were conducted both with and without the use of engine pre-heater. In addition, the regulated method for the CO, CO_2, and NO_x measurements are also compared to the integrated value of real-time measurements (Appendix A).

- **Cold start effect**

In the NEDC, a cold start effect is observed. The UDC1 part of the cycle shows the highest emissions for CO, HC, NO_x, HC, and aldehydes with only minor contributions to the cycle emissions from the UDC2 and the EUDC. This indicates poor removal efficiency of these exhaust components before the catalyst reaches proper operational temperature.

The cold start effect is, however, not seen for NO_x in the test conducted at -7°C as the UDC2 often shows higher emissions as compared to the UDC1.

- **NEDC at -7°C**

The NEDC tests conducted at -7°C generally shows higher emissions as compared to those at +22°C. The CO and HC emissions were more than 10 times higher. The PM emissions were considerably higher with emissions of up to 60 mg/km for one of the cars when using the E5 and the E10 fuels.

The NO_x showed emissions in the same range as those of +22°C.

- **Driving cycle**

The Artemis cycles are started with hot engine and exhaust after treatment system and consequently there is no cold start effect with considerably lower cycle emissions for a number of exhaust components.

The Artemis CO emissions are very low in the AU and the AEU cycles while the highest HC emissions are observed in the AU-cycle. The AH cycle shows higher CO and HC emissions indicating rich fuel/air mixing ratios in the high speeds of this cycle with less effective catalyst efficiency.

In contrast to CO and HC, NO_x shows the lowest emissions in the AH with emissions of 3-12% as compared to the emissions for the AU. Large differences were observed in the NO_x emissions between the different cars.

- **Engine pre-heater**

Test were performed with and without engine pre-heater for the NEDC E70 fuel tests at -7°C showing considerably lower emissions of CO, HC, PM and acetaldehyde (reduced by 10-50%).

- **Fuel effect**

The CO NEDC cold start effect tends to be increasingly important for the E70 and E85 fuels showing higher emissions as compared to the E5 and E10 fuels. At -7°C, however, the CO emissions were lower for the higher concentration ethanol fuels opposite to what was observed at +22°C.

There was no clear fuel effect observed in the HC emissions but in the Artemis cycles there is a tendency for lower emissions for the E70 and E85 fuels.

The NO_x emissions in the Artemis AU and the AEU were lower by as much as 70% for the E70 and the E85 as compared to the E5 and E10 fuels.

The PM did not show any obvious trends between the different fuels in the NEDC at +22°C. At -7°C the emissions were considerably higher with emissions of up to 60 mg/km for one of the cars using the E5 and the E10 fuels.

- **NO_2**

In all tests, only a minor portion of the NO_x is emitted as NO_2. The overall NEDC average of this portion for all cars and fuels is 5%.

- **Aldehydes**

The NEDC formaldehyde and acetaldehyde emissions are about the same for the E5 and the E10 fuels whereas the acetaldehyde shows clear fuel dependence with largely increased emissions for the high ethanol fuels, E70 and E85. This observation indicates the chemical route to form acetaldehyde with ethanol as a precursor.

Higher aldehyde emissions were observed for the -7°C NEDC tests, showing the same general pattern with high acetaldehyde emissions for the E70 and the E85.

- **Comparison of PM-methods**

Significant differences between the two PM methods used in parallel were observed. In many NEDC tests the PMP-method (a single TX40-filter operated at 47±5°C) only measures half or even less of what is measured by the regulated PM method. This difference is attributed to different collection efficiencies of soot and condensed material between the two methods. In the tests performed at -7°C, the two PM methods show considerably smaller differences.

- **Particle number emissions**

The particle number emissions were measured according to the PMP-method in the 10^{10} to 10^{11} particles/km range for the NEDC. There was no obvious fuel effect in the particle number emissions. At -7°C, the particle number emission was higher as compared to +22°C showing a relatively higher cold start emission. The highest emissions were observed for the E5 fuel and the lowest for the E85. The effect of engine pre-heater is not obvious as observed for the E70 fuel.

The AU and AEU cycles show emissions in the same range as in the NEDC. One of the three cars showed higher particle emissions as compared to the other cars and is also the only car showing clear fuel dependence with lower particle number emissions for the higher concentration ethanol fuels.

- **Correlation of PM and particle number emissions**

A comparison for all particle number measurements at +22°C with PM shows a regression line with the r^2 value to PM and PM-PMP of 0.540 and 0.649 respectively.
The same comparison for the -7°C tests showed the r^2 values of 0.808 and 0.804 respectively.

5. REFERENCES

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Ntziachristos L., Mamakos A., Samaras Z., Mathis U., Mohr M., Thompson N., Strandling R., Forti L., and de Serves C., Overview of the European “Particulates” project on the characterization of exhaust particulate emissions from road vehicles: results for light-duty vehicles, SAE 2004-01-1985, 2004.

APPENDIX A

Appendix A. Emissions of CO, HC, and NO_x from CVS bag measurements as compared to on-line measurements in the Artemis cycles.

Car	Fuel	Artemis cykel	Bag			On-line		
			CO g/km	HC g/km	NO_x g/km	CO g/km	HC g/km	NO_x g/km
SYU	E5	urban	7.55	0.15	0.04	7.72	0.13	0.04
SYU	E5	road	1.67	0.01	0.09	1.65	0.01	0.10
SYU	E5	highway	11.64	0.09	0.02	12.62	0.07	0.02
SYU	E10	urban	11.77	0.19	0.06	12.51	0.15	0.06
SYU	E10	road	2.20	0.02	0.15	2.22	0.01	0.16
SYU	E10	highway	16.19	0.11	0.04	17.67	0.10	0.05
SYU	E70	urban	0.04	0.01	0.59	0.04	0.01	0.63
SYU	E70	road	0.01	0.00	0.15	0.01	0.00	0.16
SYU	E70	highway	0.28	0.00	0.03	0.30	0.00	0.03
SYU	E85	urban	0.01	0.02	0.49	0.01	0.01	n.a.
SYU	E85	road	0.01	0.00	0.20	0.00	0.00	n.a.
SYU	E85	highway	0.06	0.00	0.08	0.05	0.00	n.a.
TNT	E5	urban	0.06	0.00	0.46	0.06	0.00	0.61
TNT	E5	road	0.15	0.00	0.17	0.15	0.00	0.18
TNT	E5	highway	0.49	0.00	0.03	0.51	0.00	0.04
TNT	E10	urban	0.07	0.00	0.78	0.07	0.00	0.84
TNT	E10	road	0.12	0.00	0.22	0.12	0.00	0.25
TNT	E10	highway	0.14	0.00	0.02	0.15	0.00	0.03
TNT	E70	urban	0.04	0.00	0.23	0.03	0.00	0.25
TNT	E70	road	0.02	0.00	0.15	0.02	0.00	0.17
TNT	E70	highway	0.08	0.00	0.01	0.08	0.00	0.02
TNT	E85	urban	0.04	0.01	0.37	0.03	0.01	0.40
TNT	E85	road	0.01	0.00	0.19	0.01	0.00	0.20
TNT	E85	highway	0.00	0.00	0.25	0.00	0.00	0.25
SYS	E5	urban	0.96	0.01	0.17	0.96	0.01	0.22
SYS	E5	road	0.31	0.00	0.07	0.31	0.00	0.08
SYS	E5	highway	0.76	0.01	0.02	0.77	0.00	0.02
SYS	E10	urban	2.11	0.02	0.13	1.82	0.02	0.13
SYS	E10	road	0.55	0.00	0.07	0.53	0.00	0.07
SYS	E10	highway	1.47	0.01	0.01	1.57	0.01	0.02
SYS	E70	urban	0.81	0.02	0.13	0.81	0.02	0.13
SYS	E70	road	0.04	0.00	0.06	0.04	0.00	0.07
SYS	E70	highway	0.36	0.01	0.01	0.38	0.01	0.02
SYS	E85	urban	0.20	0.01	0.12	0.20	0.01	0.12
SYS	E85	road	0.05	0.00	0.08	0.05	0.00	0.08
SYS	E85	highway	0.25	0.00	0.01	0.25	0.00	0.02