Report

Emissions from three Euro 5 gas-powered light duty vehicles

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Report no 127064

Ecotraffic

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1. Projektinformation (Swedish)

Beställare	Trafikverket	**Beställningsnummer**	
Beställningsdatum		**Slutdatum enligt beställning**	2013-12-31
Ansvarig hos beställare	Peter Smeds	**Projektnummer**	7064
Ansvarig hos Ecotraffic	Lars Eriksson	**Rapportering**	Rapport på engelska
Avvikelser		**Provningsplats**	TÜV Nord, Essen
Rapport språkgranskad		**Rapport godkänd av**	
Rapportnummer	127064	**Rapporteringsdatum**	2013-12-23
Författare	Lars Eriksson		

2. Abbreviations, acronyms and glossary

CH4	Methane
CO	Carbon monoxide
CO2	Carbon dioxide
FC	Fuel Consumption
HC	Hydro Carbon
NEDC	New European Driving Cycle
NOX	Nitrogen oxides (NO + NO2)
NO	Nitrogen oxide
NO2	Nitrogen dioxide
PM	Particulate Matter
PN	Particle number
THC	Total Hydrocarbons
CNG	Compressed natural gas
SAE database	
TWC catalyst	

3. Sammanfattning

Ecotraffic har på uppdrag av Trafikverket undersökt om metanemissioner från moderna gasdrivna bilar kan bli ett framtida problem. Anledningen till frågeställningen är att gasdrivna bilar förväntas öka med tiden och att det tidigare har funnits indikationer på att det kan vara problem med metanemissioner från denna typ av fordon, både som läckage och som avgasemissioner. Metan är en mycket potent växthusgas och relativt små utsläpp av metan kan minska nyttan med att använda natur- och biogas som fordonsbränsle.

I detta arbete har en begränsad litteraturstudie samt tester på tre moderna gasdrivna personbilar utförts. Testerna har utförts på TÜV Nord's laboratorium i Essen, Tyskland. Det finns inte mycket litteratur om metanutsläpp från moderna gasdrivna personbilar. Dock så indikerar den litteratur som ändå finns tillgänglig att det kan vara ett problem med metanutsläpp från gasdrivna bilar. I USA finns en oro angående metandrivna fordon, särskilt vad gäller lastbilar och bussar. Tillgången på naturgas ökar med tiden i USA - och delvis beror detta på att användning av ”fracking” för att utvinna gas och olja ökar år från år. Detta leder vidare till att naturgasens användning som bussbränsle i många städer ökar med tiden. Det är allmänt känt bland kemister, katalysatorforskare och i litteraturen att metan är en mycket stabil molekyl och att metan är svår att oxidera över en katalysator.

Så med detta som bakgrund genomfördes en begränsad litteraturgenomgång samt tester av tre moderna (Euro 5) gasdrivna personbilar med en körsträcka från 5 400 mil till ca 7 600 mil.

Litteraturstudien

Litteraturstudien indikerade att det kan vara ett problem med metanutsläpp från gasdrivna fordon – särskilt från lastbilar och bussar. Dock så är antalet tester som finns publicerade begränsat.

Testresultat

Då bränslet som användes i dessa tester var naturgas så var det dominerande kolvätet i avgaserna metan.

	Enhet	Gräns	Car 1	Car 2	Car 3
NEDC kallstart (22 C)					
THC	mg/km	100	138,4	61,4	84,1
CH_4	mg/km		92,9	27,0	65,4
NEDC varmstart					
THC	mg/km		38,3	14,9	4,8
CH_4	mg/km		32,3	12,3	4,2

NEDC (med kallstart) är det test som används vid certifiering av fordonen. I dessa tester så klarade en av bilarna inte gränsvärdet för THC. Dock så är (se figuren ovan) 0,093 g CH_4 ett relativt lågt värde och omräknat till CO_2-ekvivalenter så motsvarar det ca 2.2 – 3.2 g per km. Då bilarna testades men varm motor (detta test kördes direkt efter kallstartsprovet) så klarade all bilarna gränsvärdet. Detta indikerar att katalysatorerna fungerar bra för alla bilarna då de nått arbetstemperatur.

Shedtestet (mäter avdunstningsemissioner) resulterade i höga metanemissioner för Car 1 (6.55 g, gränsvärdet är 2.0 g). Detta höga värde indikerade att det fanns en läcka i bränslesystemet. Med hjälp av en ”sniffer” hittades läckan vid anslutningen till en av de tre gastankarna.

Alla bilar klarade med god marginal alla andra reglerade komponenter (CO, NO_X och partiklar)

Slutsatsen baserat på dessa tester är att metanutsläpp från moderna gasdrivna personbilar inte ser ut att vara något stort problem eftersom dessa tester visade på relativt låga emissionsnivåer av metan. Jämfört med äldre mätningar så verkar det som om bilarnas avgasrening fungerar bättre nu och att metanemissionerna minskat signifikant över tid (och med ökande Euro-nummer). Dock så var THC-emissionerna för en bil ca 38 % över gränsvärdet i NEDC-testet och det fanns även en läcka i bränslesystemet.

Rekommendationen är att mäta avgasemissioner på gasdrivna fordon på några utvalda bilbesiktningsstationer. Den analysator som används för kolväten idag kan inte detektera metan. Så av den anledningen så skulle man på de utvalda stationerna komplettera med en analysator som kan detektera metan. Denna typ av screeningtest kommer att hitta bilar med höga metanemissioner och någon av dessa individer skulle kunna omtestas på avgaslaboratorium för att kvantifiera nivåer samt finna orsaken.

Efter testerna

Efter testerna kontrollerades bilen av personal från biltillverkaren (Car 1). De hittade också läckan – och åtgärdade felet. De kommer att fortsätta att undersöka fler bilar av samma model.

4. Summary

Ecotraffic has been commissioned by the Swedish Transport Administration to study if methane emissions from cars may be a problem. The reason for the question is that the amount of gas-powered (read methane-powered) vehicles will increase with time and it has previously been indications that gas cars may be associated with emission of methane, both as leakage and as emissions through the exhaust pipe. Methane is a very potent greenhouse gas and for that reason relatively small methane emissions may decrease the climate benefits of using CNG (compressed natural gas) and biogas as vehicle fuel. In this work a limited review of the literature and tests of three modern gas-powered cars have been carried out. Tests have been done on TÜV Nord's exhaust laboratory in Essen, Germany. There is not much literature on the topic of methane emissions from modern gas-powered vehicles. However, the literature study indicates that there may be problems with the methane emissions from this type of vehicle. In the U.S.A there are concerns about methane emissions, especially from heavy duty vehicles and buses. The use of natural gas is increasing due to extracting natural gas by fracking. For example, the use of gas-powered buses in many cities is increasing.

It is generally known among chemists, catalyst researchers and through the literature that methane is a very stable molecule and that methane is difficult to oxidize over a catalyst. So on this basis a limited literature review and emission measurements on three modern used cars with an odometer reading from about 54 000 to 76 000 km was carried out (Euro 5):

Literature study

The literature study indicates that it may be problem with methane emissions from gas-powered vehicles, especially on heavy duty vehicles and buses. However the amount of test results published is limited.

Test results

Since the fuel use in all tests was CNG the THC emissions mainly consist of one specific hydrocarbon, methane.

	Unit	Limit	Car 1	Car 2	Car 3
NEDC cold start					
THC	mg/km	100	138,4	61,4	84,1
CH_4	mg/km		92,9	27,0	65,4
NEDC warm start					
THC	mg/km		38,3	14,9	4,8
CH_4	mg/km		32,3	12,3	4,2

Figure 1 THC and CH4 emissions from NEDC tests

The NEDC (cold start) is the test cycle used for certification of the vehicles. In these test the Car 1 failed the test with respect to THC limit. However (see figure 1 above) 0,093 g CH_4 per km is a relatively low value and corresponds to only about 2.2 – 3.2 g CO_2 equivalents per km.

In the NEDC (warm start) all vehicles tested passed the tests. This indicates that the catalytic converters after being heated up work fine for all cars.

Shed (for evaporative emissions) test gave high methane emissions for the Car 1 car, 6.55 g when the limit is 2.0 g. This indicates that it may be some leakages in the gas fuel system. By using a sniffer a leak was found and this leak may fully explain the high shed emissions. The shed values were under limit for the other two cars in this study.

For all the tested cars all of the other regulated components (CO, NO_X and particles) were under Euro 5 limits.

The conclusion based on these tests is that the methane emission doesn´t seem to be a big problem (for modern passenger cars) since the emissions in these tests indicates relatively low methane emissions. Compared with older studies with cars with similar driving distance it seems that the methane emission has decreased significant over time (and by higher Euro numbers).

However, for one of the cars the THC value was about 38 % over Euro 5 limit during NEDC and there was also a leakage of methane.

The recommendation is to measure methane exhaust emissions on gas-powered vehicles on a limited amount of cars at some car inspection stations. The analyzer used till now is not able to detect methane so it is necessary to find a suitable analyzer for these tests. If there are any problems with high methane emissions this type of screening will find it out and if cars with high methane emission are found additional tests at an emission laboratory may be carried out for these cars to quantify and find out the reason for the high emissions.

After test

After the tests – the personal from the car manufacture (Car 1) investigated the vehicle and. They found also found the leak – and repaired the fault. They will also continue to investigate more cars of the same model.

5. Work description and methodology

Background

Reduced resources of mineral oil and growing world energy consumption will increase the demand for alternative energies. CNG is one of the alternatives. The main motivation for the use of gas are oil substitution source diversification and independency of fuel supply as well as the reduction of greenhouse gases especially CO2 [7]. However, methane is a strong greenhouse gas. Previously it has been talked about 20-25 times more potent than CO_2 but new findings say that 30-35 times is more correct [9]. Reduction of methane emission over (total oxidation) catalysts available today is problematic, especially at low temperatures. Methane is the most stable of all hydrocarbons. It is difficult to activate methane, i.e. breaking the first coal-hydrogen bonding. Methane emission is therefore one of the most difficult emission component to transform into harmless substances [4].

Scoop of works

If methane leaks into the atmosphere this will contribute to an increased carbon footprint. Methane is a so called short-lived climate gas (SLCP). During the last 10-15 years there has been a limited amount of cars that can be powered by gas on the market. With future development with a possible shortage of oil and new methods for extracting natural gas and with increased focus on the production of biogas, the share of gas cars will increase. If gas cars leak methane from fuel system or as unburned methane via the exhaust pipe the climate benefits of gas vehicles will disappear. A worst case scenario would be that we after 10-20 years will have a large amount of gas vehicles globally and then pay attention to methane leakage from this large fleet. The Swedish Transport Administration would therefore conduct a check of the state of knowledge in this field. It is important to now, as soon as possible create a picture of the situation. The findings can then be used for the discussion of regulatory changes for this type of vehicle, if necessary.

The goal of this project is to create an image of the state and make measurements that verify if there is a problem with leakage of methane and attempt to quantify this.

Literature study

In this work, a limited literature review has been carried out. Mainly, the data sought in the SAE database. Expert interviews were also conducted. Since this study was limited it is not comprehensive. The aim was to do a survey to see if there is support in the literature that methane leakage can be a problem for gas-powered vehicles.

Emission measurements

Test site

All tests have been carried out at TÜV NORD in Essen. All tests were performed during December 2013.

	Test Cell 3
Climatisation	-20°C - +35°C WEISS
Chassis Dynamometer	MAHA ECDM 48L 4x4
Control Unit	MAHA
CVS-Unit	MAHA-CVS
Analytical System for gaseous emissions (CO, CO_2, THC, NMHC, NO, NO_x)	MAHA-AMA D1
Particle Collector	MAHA-PTS
Particle Balance for particle mass	SARTORIUS SE2-F
Particle Counter	MAHA

Figure 2. Test cell 3, TÜV NORD, Essen

Fuel Evaporative Emission Measuring System (SHED)

Enclosure		
Name of manufacturer	York International GmbH	
Type	VT-SHED	
Construction of the Variable Volume enclosure:	TWIN – BAG system	
Capacity of the SHED:	60, 60 m³	
Material of the inlet surface:	Stainless steel	
Collecting pipe install position:	side wall	
Temperature control system		
Setting range	High	Low
Outlet temperature	41° C	18°C
Minimum graduation	0,1° C	
Accuracy	0,1° C	
HC analyzer		
Name of manufacturer:	Ratfisch	
Type:	RS 55 – T	
CH4 analyzer		
Name of manufacturer:	AMLUK	
Type:	FIDAMAT	
Canister loading system		
Name of manufacturer	PEUS – Systems GmbH	
Type	PEGASys PECAN	
Canister weight measuring device		
Name of manufacturer:	Sartorius	
Type:	Sartorius BP 4100S	

Figure 3 Shed test cell, TÜV NORD, Essen

For all tests reference fuel according to the applicable Directive is used, that is Haltermann Products, Dow Olefinverbund GmbH, Hamburg.

Vehicles

Three bi-fuel passenger cars were used in this study.

	Car 1	Car 2	Car 3
Odometer	75 974 km	59 904 km	54 018 km
Exhaust class	Euro 5	Euro 5	Euro 5
Year model	2010	2011	2011

Figure 4 Vehicles used in this tests

Dynamometer settings

Identical values as in the type approval tests were used

		Car 1	Car 2	Car 3
F0	N	125,3	124,0	182,0
F1	[N/(km/h)]	0,994	0,800	0,620
F2	$[N/(km/h)^2]$	0,0316	0,0281	0,0300
Inertia	kg	1700	1700	2040

Figure 5. Dynamometer settings

Test cycle

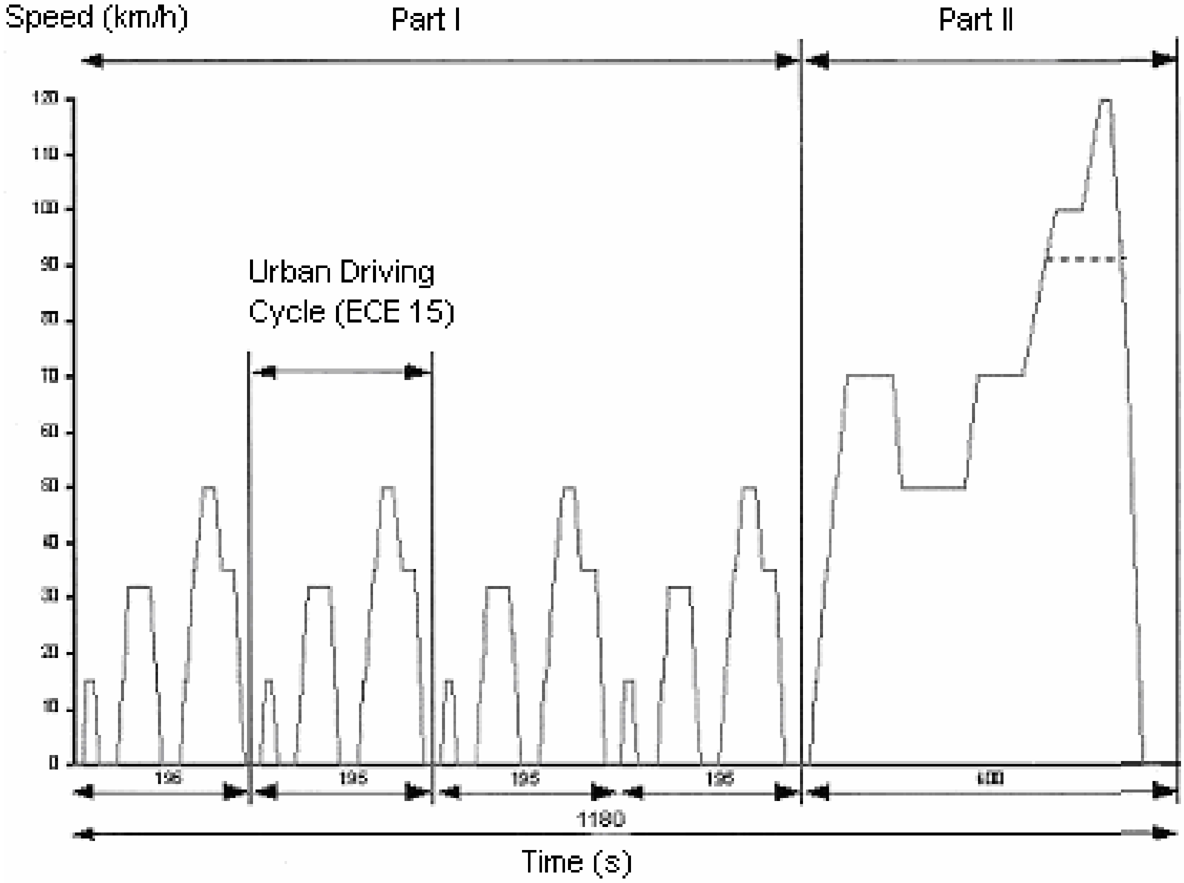


Figure 6 NEDC test cycle

6. Results

Literature study

12 literature studies were conducted. Summaries are given in the following text.

1. **Metanemissioner från gasdrivna fordon – en studie över katalysatorns hållbarhet, Ecotrafficrapport 107050, 2010 (report in Swedish)**

Ecotraffic has on behalf of the Swedish Energy Agency investigated emission of methane from gaseous (bio-gas and CNG) driven vehicles. The study was focusing on function of the catalytic converters on in use vehicles. Tests were carried out as on board measurements and as test during idling. These kinds of test do not give exact answers (in absolute levels) about the exhaust levels but give a rough answer about the function of the catalyst. It is therefore important to notice that these tests are screening tests and the results are indicative results that may be followed up with laboratory tests.

Mostly all catalyst showed high level of function for new vehicles but it seems that the catalytic activity for oxidation of methane declines relatively fast over time. This phenomenon is also described in literature and well known by catalyst researchers.

Earlier studies carried out by Ecotraffic (during 2004 – 2007) have demonstrated that catalysts on gaseous driven vehicles show a shorter durability compared with catalysts used for other fuels (e.g. gasoline or diesel). Low catalytic activity often results in emission of unburned methane. Methane is from a health perspective an innocuous molecule – but it is a potent greenhouse gas (about 25 times CO_2).

Comparing the older tests (32 vehicles) with the new tests (61 vehicles) it seems that there is a positive trend over time – in form of longer durability. However, it is difficult to compare the tests since the new test contain relatively a higher number of new vehicles.

Roughly about half of the vehicles tested in both studies showed a poor catalytic activity even before they reached an odometer reading of 100 000 km. In both the old and the new test all catalysts had an unsatisfying catalytic activity before reaching an odometer reading of 150 000 km. During idling only 6 of total 93 vehicles showed a satisfying catalytic activity. Mostly all of the catalytic converters shut down after driving/load, during idling.

2. **A. Taigawa med flera, Energy 30 (2005), 461**

Methane is a stable chemical compound and difficult to oxidize over a catalyst in comparison with hydrocarbons from gasoline exhaust. Methane is also one of the most difficult chemical compounds to oxidize over a catalyst. In a work by A. Taigawa shows selectivity to catalytically oxidize methane is lower than for all other alkanes. These theses also supports by Professor Skoglundh at KCK in Gothenburg [4].

3. **Catalytic activity and aging phenomena of three-way catalyst in a compressed natural gas/gasoline powered passenger car, Alexander Winkler et.al, EMPA Swiss Federal Laboratories, Applied Catalysis B: Environmental 84 (2008), 162 – 169.**

A study performed at EMPA Swiss Federal Laboratories investigated the catalytic activity over three-way catalysts on cars running on both petrol and gas (bi-fuel car)

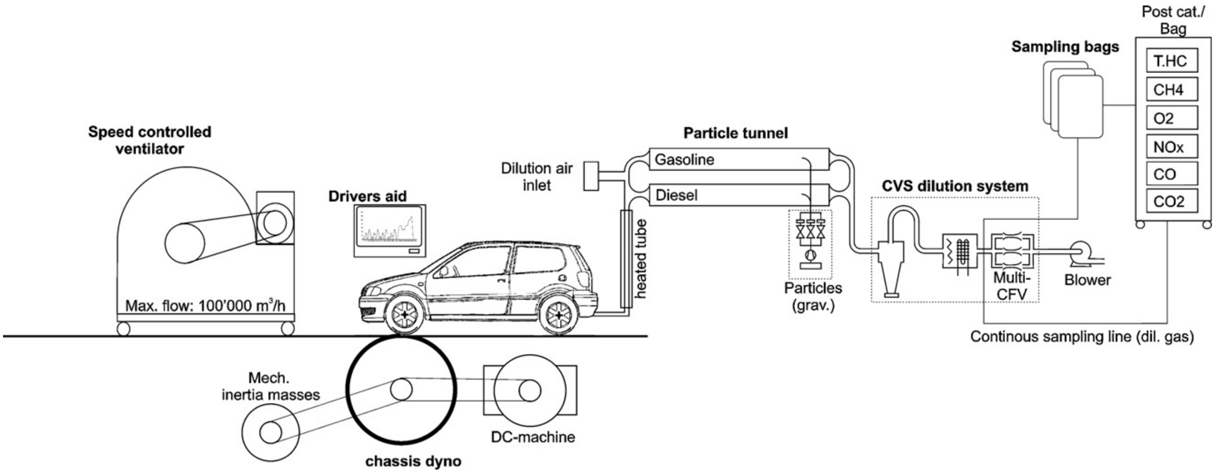


Figure 7 Experimental setup at EMPA Swiss Federal Laboratories

The car has been tested on their exhaust laboratory and the tests have been performed according to the European driving cycle (NEDC) and according to the Common Artemis Driving Cycle (CADC). The vehicle tested was one of the best-selling bi-fuels models in Europe (brand / model not specified in the article). The car was aged by regular daily use in real traffic. In the aging procedure the car operated at about 90% on regular Swiss CNG and 10% gasoline. The car was aged 35 000 km (800 hours of use) prior to test.

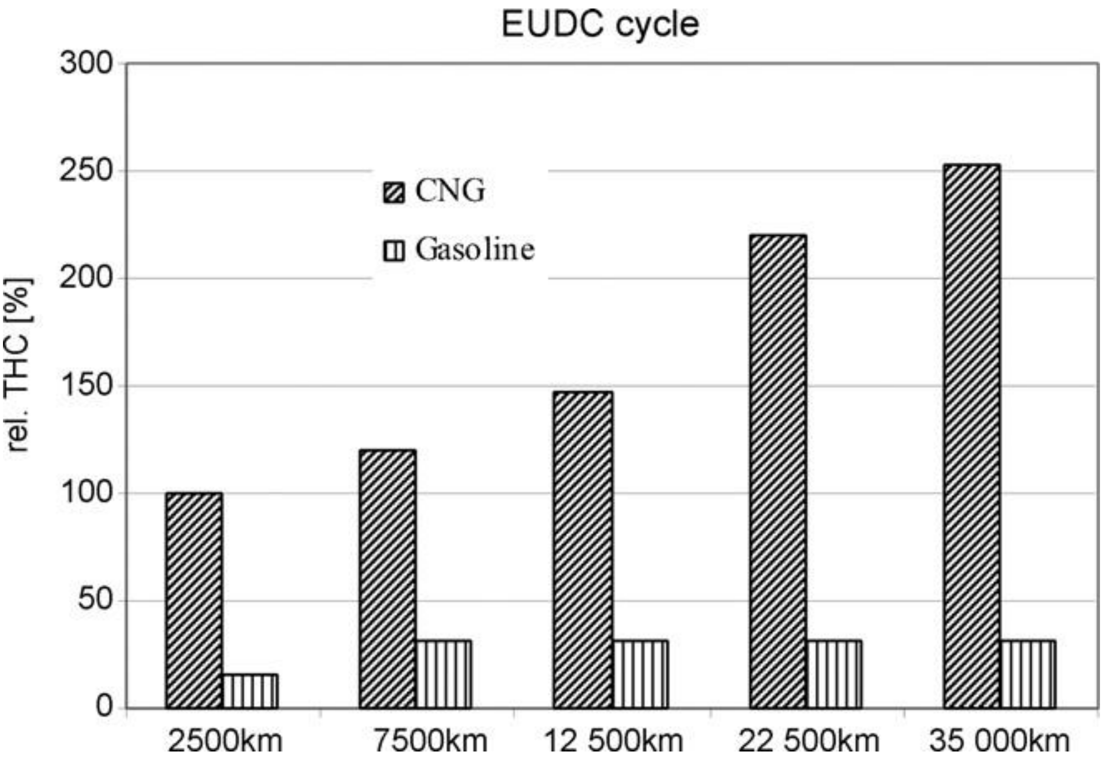
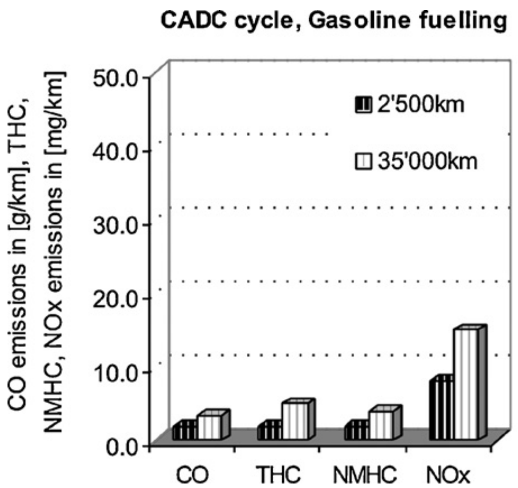


Figure 8 Relative emissions of hydrocarbons from the gas and gasoline operation under the 35 000 km aging procedure and tests according to the NEDC driving cycle, EMPA, Swiss Federal Laboratories

Results from the study showed a large increase in hydrocarbon emissions after a relatively short ageing distance when the vehicle is running on gas. The same tests conducted on gasoline showed no significant increase in hydrocarbon emissions. This shows that the activity to oxidize methane decreases with time while the activity of the oxidizing emissions from gasoline exhaust is not significantly affected. Hydrocarbons in gasoline exhaust contained practically no methane while hydrocarbons from gas basically just consisted of methane.



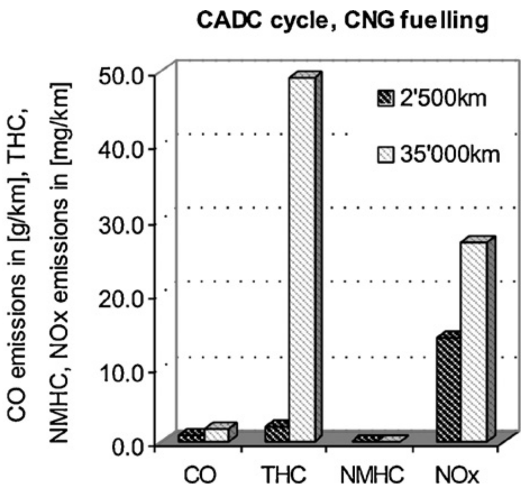


Figure 9 Emissions from CADC driving cycle for both petrol (left) and gas (right) after 2 500 km and 35 000 km, EMPA, Swiss Federal Laboratories

A series of tests were conducted to find out why the activity to oxidize methane decreases with time. Some of the answers were

- A layer of metallic palladium was formed on the catalyst surface (on the un-aged catalyst it was only pure palladium oxide)
- Contamination of P, Ca, and Mg (from engine oil) was found both on the "pre-catalyst," and "under-floor catalyst" (in both the pre-catalyst located close to the engine and on the TWC catalyst located below the vehicle floor)
- The pre-catalyst lost 95% of its active surface during aging while "under-floor catalyst "only" lost 50% of its active surface

The authors conclude that the explanation for reduced activity for methane oxidation depends on the metallic palladium layer formed on an aged catalyst (called Mars and van Krevelen mechanism). Furthermore, it is considered that contaminants from lubricating oil affect the oxidation of methane more than oxidation of heavier alkanes.

4. Interview with professor Magnus Skoglundh Competence Center (KCK) for Catalysis, Chalmers University of Technology (CTH), October 2013

The use of methane as fuel is likely to increase. Reduction of methane over those catalysts (total oxidation) available today is problematic, especially at low temperatures.

Methane is the most stable of all hydrocarbons. It is difficult to activate methane, i.e. breaking the first coal-hydrogen bonding. Methane emission is therefore one of the most difficult emission component to transform into harmless substances

A solution could be to develop catalysts with higher activity for methane activation, especially in the exhaust gases with oxygen excess (e.g. diesel exhaust gases) and higher resistance to catalyst poisons, e.g. sulfur components.

5. Interview with Andreas Lind, Swedish Car Inspection (AB Svensk Bilprovning), August 2013.

AB Svensk Bilprovning uses a sniffer to see if there are gas leaks in tanks, tubes, fuel injection system etc. For measuring the exhaust emissions during gas operation an analyzer calibrated only for gasoline exhaust is used. This means that cars can have high methane emissions without being detected in the control inspection.

6. An emission and Performance Comparison of the Natural Gas Cummins Westport Inc. C-Gas Plus versus Diesel in Heavy-Duty Trucks, SAE Technical Paper series 2002-01-2737.

The gas plus tractor demonstrated significant reduction in CO (87-93 % lower), NO_X (24-45 % lower) and particle matter (> 90 % lower. The CNG tractor had also an advantage in CO_2 emissions (6.5-7 %) lower.

Both the diesel- and the CNG tractors where equipped with oxidation catalysts

The THC emissions detected were far higher for the CNG tractor than for the diesel tractor (23-31 times higher). The THC in the CNG case mostly consists of CH_4. For the diesel exhaust the CH_4 content was close to zero.

"The authors also mention that catalytic methane reduction is more difficult than NMHC reduction and requires specific catalyst formulation"

7. Performance improvement and emission reduction of NGV bi-fuel engines for passenger cars, SAE Technical Paper series, 2004-01-3468.

Reduced resources of mineral oil and growing world energy consumption will increase the demand for alternative energies, CNG is one of the alternatives. The main motivation for the use of gas are oil substitution source diversification and independency of fuel supply as well as the reduction of greenhouse gases especially CO_2.

In this study an Audi A6 1.8 was used for the tests. Special attention was given to stability of emissions over the life of the vehicle. The production catalyst was used to demonstrate the compliance with emission level Euro 4 after ageing. Ageing was done with the FEV ageing procedure at 1050 C. The aged catalyst was measured in gasoline and CNG operation.

- The increase in THC emission comparing new and aged catalyst was stronger in CNG operation (+ 130 %) than in gasoline operation (+ > 100 %).

8. (Sveriges Radio, 2013-10-31, based on an article in Science)

Methane is a strong greenhouse gas. Previously it has been talked about 20-25 times more potent than CO_2 but new findings say that 30-35 times more potent is more correct

9. Methane emissions in the Swedish CNG/CBG chain – A current situation analysis, SCG Rapport 2013:282

One of the factors is identified as crucial for climate benefits, that is, emission of methane. It can occur at several stages of the chain (see figure 10 below) and with estimated emissions included (In parentheses = if use of best available technic)

	Heavy duty vehicles	Light duty cars
	gram CH_4/kWh gas	gram CH_4/kWh gas
Biogas production	2.7 (0.1)	2.7 (0.1)
Operation of vehicles	0.41 (0.2)	0.14 (0.2)
Distribution	0.034 (0.18)	0.0340 (0.13)
Refueling	0.0001 (0.0001)	0.0008 (0.001)
TOTAL	**3.1 (0.45)**	**2.8 (0.41)**
Emission in % of used gas	4.2 (0.61)	3.8 (0.55)

Figure 10 Methane emissions at different stages (best use technology in parentheses)

The total leakage of biogas can amount to 10-20 % before giving negative climate benefits compared to fossil based systems. The trend of methane emissions is decreasing because of the high focus on emissions from biogas production and minimization of leaks. The report also pointed out a few areas where further action is needed (here only one of these areas is included)

Control of catalyst performance of older buses and trucks should be conducted regularly. In the absence of rules for this at the regulated vehicle inspection, the larger public transport authorities should impose this as requirement on their contractors. Alternatively, contractors voluntarily take a greater responsibility. At the very least this should be checked by making sample testing on a random basis.

In Table 19 in the report it says that emissions of methane (read HC) are not checked at the vehicle inspection for trucks and buses. It is also said that it is controlled for passenger cars. Ecotraffic would like to make a clarification, a comment.

Comment

For passenger cars HC emissions are measured at “car inspection” but with a method that cannot detect methane. Exhaust emissions of methane can be high without getting any measurement value for methane (Ref 5). Ecotraffic has on many occasions over the past more than 10 years, pointed this out in different contexts

10. Unregulated emissions with TWC, Gasoline and CNG, SAE International, 2010-01-1286

This article reports the results for various nitrogen oxides, ammonia and differentiated hydrocarbons emitted at part load from a small 4-S SI-engine. It was operated with gasoline and CNG and with two different three-way (TWC) catalytic converters.

CNG produces less HC and less aromatic. But the HC conversion rate is insufficient. This is due to lower exhaust gas temperatures at part load with CNG and due to higher stability of light HC:s. Methane, the principal HC component of CNG, is a very stable molecule.

11. Slate Magazine (The big problem with vehicles that run on natural gas: methane, published August 15, 2013)

A large tenet of Obamas energy plan is to promote the use of shale natural gas that has recently become accessible due to advances in drilling technology, fracking. A recent report by U.S. Energy Information Administration shows that carbon dioxide emissions in the USA are steadily decreasing in large part to the substitution of coal with natural gas. More recently, the economist has also embraced the potential of natural gas to replace demand for oil.

However, shale exploitation is not without critics. And the critics can be summarized in two main arguments:

- Extraction and pipeline transport process of shale results in leaking methane
- Methane emissions from in-use natural gas

Over the past decade, there has been an increase in the adoption of natural gas vehicles in bus and truck fleets and there is momentum in the trucking industry to adopt natural gas vehicles, as the increase in shale gas supply has made the fuel cheap and economically attractive.

Methane is a pollutant that is emitted by natural gas vehicles. Vehicle emissions are highest when operating conditions are unsteady or dynamic, such as when a cool engine is first turned on or when an engine has to speed up.

The total global warming impact for natural gas vehicles could be greater than current diesel buses. The methane impact from smaller vehicles is unclear as most studies have been conducted on heavy duty trucks and buses.

One clear solution is to develop a catalyst that is able to reduce methane. But this is easier said than done because existing catalysts are not effective at reducing methane, a very stable compound that is resistant to chemical reaction.

12. Regulated and non-regulated emissions and fuel economy from conventional diesel, hybrid electric diesel and natural gas transit buses, Journal of the Transportation Research Forum, Vol 47, No 3 (Public Transit Special Issue 2008). pp. 105-125

Distance-specific (measured on chassis cycles) fuel economy and emissions from transit buses representing diesel, retrofitted diesel, hybrid-electric diesel, and lean-burn natural gas technologies are presented in this paper.

Methane emissions dominate the THC emission (> 90 %) from CNG buses.

Methane emissions from the John Deere buses varied from 4.6 g/km on the Arterial cycle to 32 g/km on the New York Bus cycle

Methane emissions from the Cummins buses varied from 8 g/km on the Arterial cycle to 50 g/km [*] on the New York Bus cycle

Comment

[*] *50 g methane per km correspond to around 1 000 – 1 700 g* CO_2

Emission measurements

Overview

In the table below the NEDC and Shed tests are summarized. The Car 1 CNG car failed the tests with respect to HC emissions (+ 38 %) and the shed test (+ 227 %). NEDC test was repeated two times with similar results.

	Unit	Limit	Car 1	Car 2	Car 3
THC	mg/km	100	138,4	61,4	84,1
CH_4			92,9	27,0	65,4
NOX	mg/km	60	35,8	16,8	41,3
CO	mg/km	1 000	156,8	316,6	87,1
PM	mg/km	4.5	0,10	0,45	0,22
PN			2,67E+11	7,13E+11	3,00E+10
SHED (THC)	g	2.00	6,55	1,02	0,97
SHED (CH_4)	g		5,20	0,23	0,00

Figure 11 Results from NEDC and Shed tests

In the table below the NEDC started with warm engine (e.g. test repeated after the initial NEDC) and the THC and CH_4 values decreases significantly for all cars. This may due to higher activity on a warmer catalyst.

	Unit	Limit	Car 1	Car 2	Car 3
THC	mg/km	(100)	38,3	14,9	4,8
CH_4			32,3	12,3	4,2
NOX	mg/km	(60)	20,6	7,7	4,8
CO	mg/km	(1 000)	22,2	48,6	94,5
PM	mg/km	(4.5)	0,12	0,35	0,39
PN			2,69E+10	1,22E+10	1,61E+10

Figure 12 Results from NEDC started with warm engine

Methane gas leak tests

Shed test gave high methane emissions for Car 1, 6.55 g and the limit is 2.0 g. This indicates that it may be some leakage in the gas distribution system. By using a sniffer a leak was found and this leak may fully explain the high shed emissions, see figure 13 below. The shed values were under limit for the outer two cars in this study.

The leakage was found on one of the tanks where the connection (screw belt) goes in. The shed test was not repeated after repairing the leakage but it is very likely that the leakage found fully explain the high methane emission during the shed test.

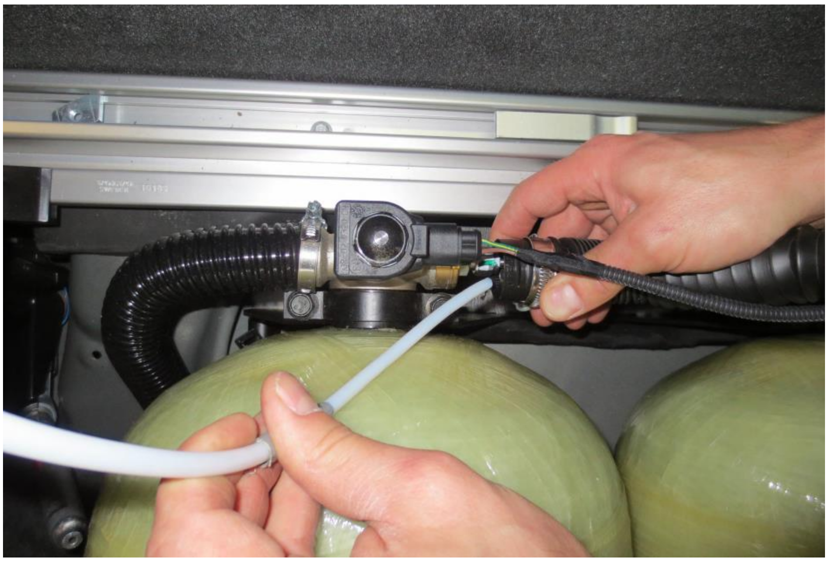


Figure 13 Leak test on Car 1 – show the place where the leakage was found

Methane (CH_4) and hydrocarbon (HC) exhaust emission

Since the fuel use were in all tests CNG the THC emissions mainly consist of one specific hydrocarbon - methane.

	Unit	Limit	Car 1	Car 2	Car 3
NEDC cold start					
THC	mg/km	100	138,4	61,4	84,1
CH_4	mg/km		92,9	27,0	65,4
NEDC warm start					
THC	mg/km		38,3	14,9	4,8
CH_4	mg/km		32,3	12,3	4,2

Figure 13 THC and CH_4 emissions during NEDC tests

The NEDC (cold start) is the test cycle used for certification of the vehicles. So in these test Car 1 failed the test with respect to THC limit. However, 0,093 g CH_4 per km is a relatively low value and correspond to about 2.2 – 3.2 g CO_2 equivalents per km.

In the NEDC (warm start) all vehicles tested passed the tests. This indicates that the catalytic converter works fine for all cars. As shown in the figure below most of the hydrocarbons are emitted in the first part of the test cycle. After a time the catalytic converter is warm enough to give high oxidation rate of methane.

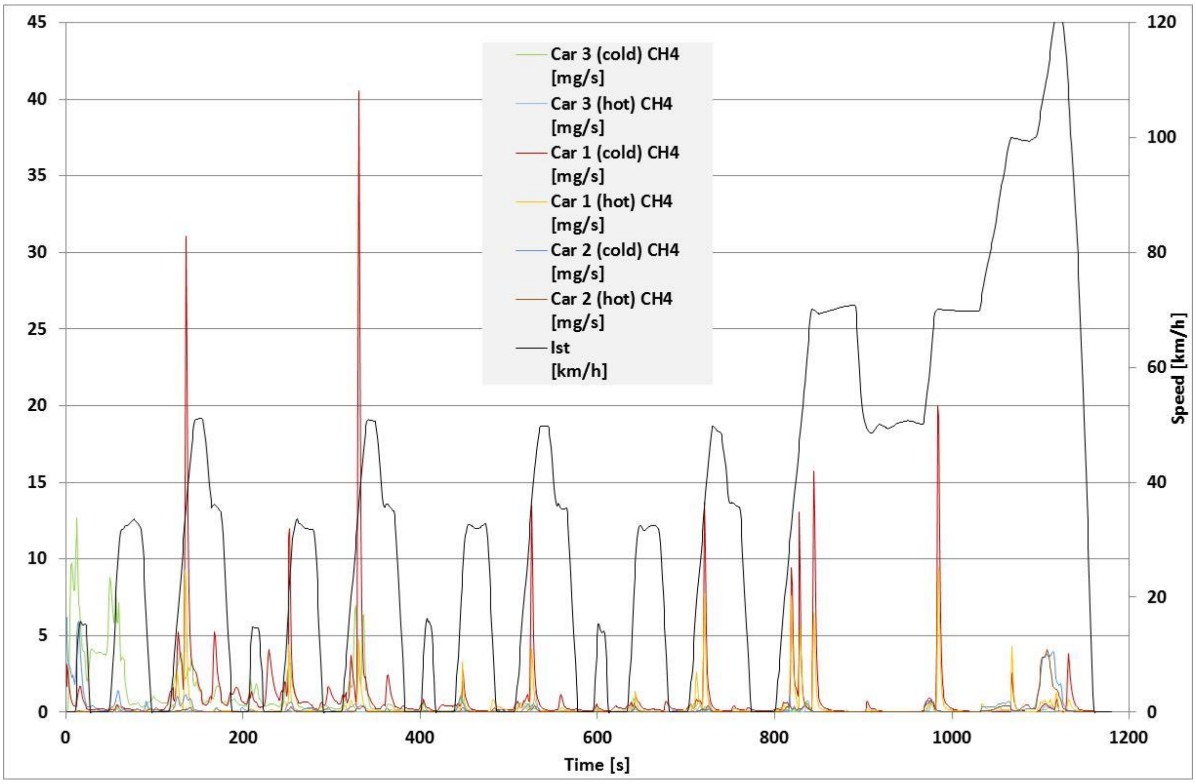


Figure 14 On-line measurements of methane during NEDC tests

Carbon monoxide (CO) exhaust emission

In all tests the emissions of CO were much lower than limit, se table below

	Unit	Limit	Car 1	Car 2	Car 3
NEDC (cold start)					
CO	mg/km	1 000	156,8	316,6	87,1
NEDC (warm start)					
CO	mg/km		22,2	48,6	94,5

Nitric oxides (NO_X) exhaust emission

Also all NO_X emissions were lower that the Euro 5 limit.

	Unit	Limit	Car 1	Car 2	Car 3
NEDC (cold start)					
NO_X	mg/km	60	35,8	16,8	41,3
NEDC (warm start)					
NO_X	mg/km		20,6	7,7	4,8

Particle exhaust (PM and PN) emission

The emissions of particles based on mass were much lower than Euro 5 limit for all cars in this stud. The particles were close to detection limit. For number based particles there is no limit values for SI engines. For CI engines (diesel) the limit for Euro 5 B and Euro 6 is $6*10^{11}$ particles per km. For SI engines (only Direct Injected engines) a number based limit will be introduced with Euro 6. The value is during the first 3 year of Euro 6 (Sep 2014 – Sep 2017) $6*10^{12}$ particles per km an thereafter $6*10^{11}$.

	Unit	Limit	Car 1	Car 2	Car 3
NEDC (cold start)					
PM	mg/km	4.5	0,10	0,45	0,22
PN	#/km		2,67E+11	7,13E+11	3,00E+10
NEDC (warm start)					
PM	mg/km		0,12	0,35	0,39
PN	#/km		2,69E+10	1,22E+10	1,61E+10

CO_2 exhaust emission

The Car 1 and Car 2 showed similar CO_2 emissions whereas the Car 3 showed significant lower value in the NEDC test. But since the power, vehicle weight and engine size not is the same it is not possible to compare.

	Unit	Limit	Car 1	Car 2	Car 3
NEDC (cold start)					
CO_2	g/km		170,1	179,5	133,8
NEDC (warm start)					
CO_2	g/km		151,1	153,6	121,7

7. Conclusion – Discussion – Recommendation

The literature study indicates that it may be problem with methane emissions from gas-powered vehicles, especially on heavy duty vehicles and buses. However the amount of test results published is limited. It is also well known in the literature and among researchers that methane is a stable molecule and that it is difficult to oxidize it over a catalyst.

The tests carried out in this study on three Euro 5 passenger cars do not indicate high methane emissions, but for one of the cars, the THC value was about 38 % over the Euro 5 limit during NEDC and there was also a leakage of methane from the fuel distribution system.

The test method the vehicle inspection companies use for leakage test is relatively slow

- In Germany Wöhler GS 220 Gasspürer
- In Sweden GPD 3000 – FAB Detect (Bilprovningen)

TÜV Nord first used one of this analyzer’s but did not find the leak. But by using a faster analyzer they found the leak.

- MAHA-AMA D1 (FID-analyser)

Important to note is that the leak was inside the car so if the car not is used for a while the content of methane inside the vehicle may reach a critical level.

The conclusion based on these tests is that the methane emission doesn´t seem to be a big problem (for modern passenger cars) since the emissions in these tests indicates relatively low methane emissions. Compared with older studies with cars with similar driving distance it seems that the methane emission has decreased significant over time (and by higher Euro numbers).

However, for one of the cars the THC value was about 38 % over Euro 5 limit during NEDC and there was also a leakage of methane from the fuel distribution system.

The recommendation is to measure methane emissions on gas-powered vehicles on a limited amount of cars at some car inspection stations. The analyzer used till now is not able to detect methane so it is necessary to find a suitable analyzer for these tests. If there are any problems with high methane emissions this type of screening will find it out and if cars with high methane emission are found additional tests at an emission laboratory may be carried out for these cars to quantify and find out the reason for the high emissions.

After test

After the tests – the car manufacture (Car 1) investigated the vehicle and they also found the leak – and thereafter repaired the fault. The manufacture will continue to investigate more cars of the same model.

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