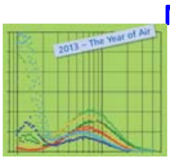

NANOPARTICLE SIZE DISTRIBUTION, SOOT AND AMMONIA EMISSIONS FROM A NGVS FLEET

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In Italy natural gas vehicles (NGVs) constitute more than 50% of the European NGVs fleet and recently a significant increase of conventional fuels costs and environmental awareness led to further favorable conditions towards the use of natural gas as automotive fuel. Some scenario analysis predict a significant growth in the European NGVs market (also related to the bio-methane production development) and many vehicles manufacturers have recently produced new natural gas models, in order to meet the European and the other NGVs most successful markets (e.g., Iran, Pakistan, Argentina, Brazil, India, China) demand [1]. In literature only few data are available on particles, PM soot fraction and ammonia (atmospheric secondary aerosol precursor) exhaust emissions by recent technology engine vehicles and these are mainly related to the comparison between NGVs and conventional fuelled vehicles [2]. In the reported project the gasoline/NG fuelling associated emissions were compared.

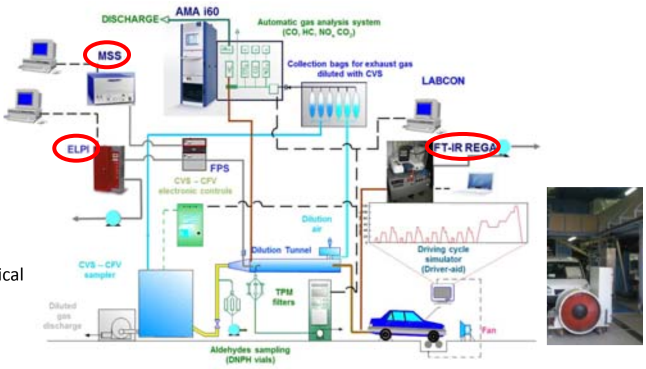
Test vehicles and natural gases characteristics

Vehicle Model		Fiat Marea Bipower	Fiat Doblò Bipower	Fiat Panda Natural Power	VW Touran EcoFuel	Fiat Doblò Natural Power	Fiat Multipla Natural Power	Fiat Grande Punto Natural Power
ID code		A	B	C	D	E	F	G
Emission Homologation Category		**EURO 2**	**EURO 3**	**EURO 4**	**EURO 4**	**EURO 4**	**EURO 4**	**EURO 5**
Tests performance period		Feb-05	Oct-07	Jul-10	Aug-10	Apr-11	Apr-12	Oct-11
Accumulated mileage (km)		97000	30500	10600	15350	15400	54058	18900
Displacement (cc)		1581	1596	1242	1984	1596	1596	1368
Max power (kW@rpm) Gasoline		76 @ 5750	76 @ 5750	44 @ 5000	-	76 @ 5750	76 @ 5750	57 @ 6000
Max power (kW@rpm) Natural Gas		68 @ 5750	68 @ 5750	38 @ 5000	80 @ 5400	68 @ 5750	68 @ 5750	51 @ 6000
Characteristics of natural gas inside the gaseous fuel tank at the time of testing								
GCV	KJ/Sm^3	38620	38460	38738	38305	38218	38691	38527
LCV	KJ/Sm^3	34821	34683	34961	34517	34490	34908	34739
LCV	kJ/kg	48188	47187	45680	48999	44894	46399	47641
Wobbe Index		-	49660	49018	50522	48268	49379	49944
density [kg/Sm^3]	kg/Sm^3	0.723	0.735	0.765	0.704	0.768	0.752	0.729
methane	% vol	94.2	92.77	89.08	96.83	88.42	90.6	93.64
ethane	% vol	2.980	3.390	5.240	1.520	4.520	4.490	3.130
> C2 HCs	% vol	1.000	1.104	1.515	0.682	1.690	1.386	1.034
CO_2	% vol	0.260	0.836	1.713	0.159	1.424	1.153	0.777
N_2	% vol	1.530	1.867	2.413	0.799	3.912	2.342	1.402
He	% vol	0.030	0.025	0.039	0.011	0.036	0.036	0.023
H_2	% vol	-	0.000	0.000	0.000	0.000	0.000	-
O_2	% vol	-	0.000	0.000	0.000	0.000	0.000	-
CO	% vol	-	-	0.000	0.000	0.000	0.000	-

MATERIALS AND METHODS

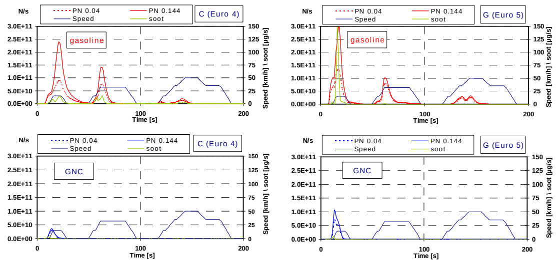
- 7 bi-fuel vehicles (from Euro 2 to Euro 5) all with MPI and TWC systems
- Test gasoline samples were all EN 228 specification compliant [3]
- NEDC + CADC Urban chassys dyno driving sequence
- 95% t-Student test for statistical significance of gasoline/NG emission variations (4 tests each vehicle/fuel)

Exhaust sampling and emissions analysis system



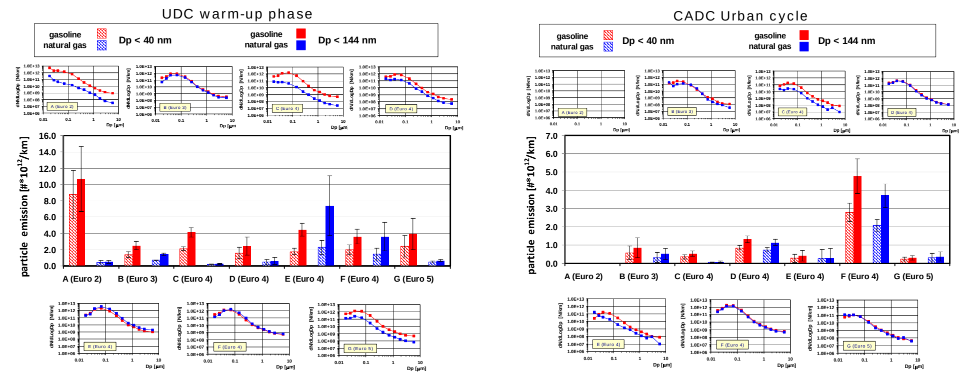
RESULTS: NANOPARTICLES (NP), ULTRAFINE PARTICLES (UFP), SOOT EMISSIONS

NP (Dp < 40 nm), UFP (Dp < 144 nm) and soot emissions in UDC warm-up phase - vehicles C (Euro 4) and G (Euro 5)



- In the first seconds after engine starting, particle emissions were always related to gasoline feeding
- Significant prevalence of NP, UFP and soot with gasoline
- NG fed vehicles emitted particles with Dp mainly < 40 nm
- Lower particle emissions in 40 ÷ 144 nm Dp range with NG
- A noticeable soot peak after the Euro 5 vehicle cold start, when fuelled with gasoline

NP and UFP NGVs fleet emissions and dimensional distribution: NG vs. gasoline

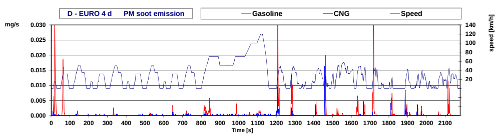


- PN emissions decreased for four vehicles NG fuelled in the Dp full range, measurable by ELPI
- PN emission peak at Dp ~ 70 nm for almost all vehicles
- Most of the UFP had Dp < 40 nm with both gasoline and NG feeding
- NP and UFP emission level was visibly lower when five vehicles were fuelled with NG

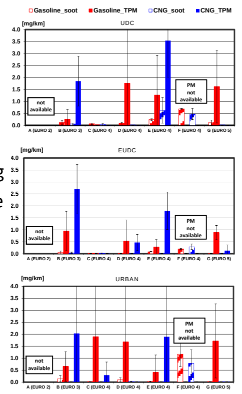
- Lower PN emission with NG for vehicles C and E, no significant difference for all the others
- PN emission peak ranged in 70 ÷ 140 nm Dp for almost all vehicles
- Slight decrease of NP/UFP emissions with NG feeding
- Most of the UFP had Dp < 40 nm with both gasoline and NG feeding

RESULTS: SOOT

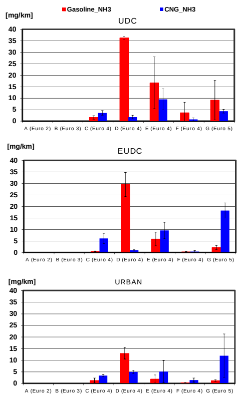
- Significant variability of total particulate matter (TPM) and soot emissions (low levels)
- TPM (mostly semi-volatile substances [4]) decreased with NG except for vehicles B and E → not optimized NG set-up
- Soot emission reduction generally detected with NG feeding
- Very high soot emission in the warm-up phase with gasoline
- Focus on vehicle D: highest soot emissions in warm-up phase and in Urban cycle, gasoline fed



Modal soot fraction emission - vehicle D (Euro 4)



TPM vs soot average emissions for the fleet vehicles



Ammonia average emission for the fleet vehicles

RESULTS: AMMONIA

Very few informations found in literature [5; 6] suggesting NH_3 generates in catalytic devices during speed transients (acceleration) engine operating conditions, that require a temporary enrichment of the air/fuel mixture. Other possible causes are related to the effects of aging of the lambda probe (air/fuel controller) and of the catalyst itself.

- In all driving conditions NH_3 emission level was quite variable between the tested vehicles
- NH_3 emission in UDC was significantly lower with NG for all vehicles except C: reduction range 40% ÷ 95%.
- NH_3 emission in EUDC and CADC Urban cycles increased with NG feeding, except vehicle D
- Due to the strong variability of measures (no statistical significance), more tests were found to be necessary

CONCLUSION

With a suitable engine set-up in urban driving conditions the natural gas feeding, compared to the gasoline one, was shown to have lower emissions in terms of nano- and ultrafine particles, soot and ammonia.

The research was developed through institutional funding (Italian oil and gas industries) of Innovhub-SSI, SSC Division. A special thank goes to ARPA Lombardia, AMSA (contacted through AMAT), and to ENI Gas & Power for providing three vehicles of the fleet. ENI Gas & Power kindly provided also the natural gas analysis reports.

1) The GVR – Gas Vehicles Report (May 2013) - http://www.ngvjournal.com
2) D. Schreiber et al. – "*Particle Characterization of Modern CNG, Gasoline and Diesel Passenger Cars*" – SAE 2007-24-0123
3) European Standard EN 228 – Automotive fuels - Unleaded petrol (version in force at the time of testing)
4) "*Characterization of Exhaust Particulate Emissions from Road Vehicles - PARTICULATES*" - EU Research Programme – Final Report (2005)
5) T. Huai et al.– "*Investigation of NH_3 Emissions from New Technology Vehicles as a Function of Vehicle Operating Conditions*" Environ. Sci. Technol., 37, (2003)
6) F. Avella – "*Characterization of gasoline and diesel passenger cars unconventional pollutants emissions*" – PARFIL Project – PLG1 Final Report (2008)