

Real-world Emission Monitoring of Natural Gas Vehicles with Higher Mileage

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ABSTRACT

This study evaluates the potential of CNG propulsion systems for long-term operation. For this purpose, light and medium duty vehicles as well as passenger cars with very different service performance were investigated under real-world conditions. The research also includes tests of a vehicle with natural gas and bio-methane to assess the effects of the energy supply on the performance. The demonstration and evaluation of CNG operational fleets with higher mileage provide a sustainable monitoring of clean propulsion systems based on innovative real-world in-car measurements. A benchmarking to the same passenger car with diesel powertrain was done as well. For a consistent comparison of the different test vehicles, the results for each drive test are presented as emission rates versus the mean vehicle speed.

INTRODUCTION

The automotive research has already influenced the field of alternative propulsion systems with important developments [1] and works constantly to launch environmental friendly drive trains. From the side of users, increases the demand for clean vehicles, particularly because of the overstepping of air quality limits at traffic sampling points and the hardly possible fulfillment of the Kyoto criteria. This can be equally applied to fleet operators, urban transport as well as to private customers. The development of the market for alternative and low-emission propulsion systems is strongly coupled with the supply of clean energy sources such as biofuel and CNG [2]. These gaseous fuels also require new storage technologies. Furthermore, long-term performance of the new drive trains under real-world conditions is still hardly known. The Key Project "Clean Energy Pathways 2020" has linked the efforts of

the automotive research, energy suppliers, users and stakeholders with the industry to deal with the transition to sustained vehicle technology on the basis of gaseous fuels. This study shows the emission monitoring results measured within the key project on six different CNG test vehicles.

The real-world emission measurements presented in this study were carried out with our ultra compact on-board measurement device. These measurements are based on a modal analysis of the emission concentrations in the tailpipe of the vehicle. The exhaust gas mass flow is calculated from the air mass flow and the gas components with a real time reaction model. The distance related mass emissions determined by the measurement system were CO₂, CO, HC and NO_x. These results were linked with the corresponding GPS tracking in order to compare the emission values along the driving sections. For the emission monitoring representative routes were covered, including sections with significantly different driving conditions. Also tests at different constant speeds on freeways were carried out.

METHODOLOGY OF THE REAL-WORLD EMISSION MONITORING

This research measures the real-world emissions and fuel economy of different CNG vehicles with a high mileage over a series of driving schedules including urban, suburban and freeway tests. From the distance related mass emissions and the corresponding GPS tracking at each drive test several evaluation factors were established (Figure 1). The analyses of the exhaust emissions when idling, at start up and cut off periods as well as the emission rates versus the mean vehicle speed enabled to evaluate the long-term performance of the CNG drive trains. In addition to these

factors, a diesel powertrain was also measured for the evaluation.

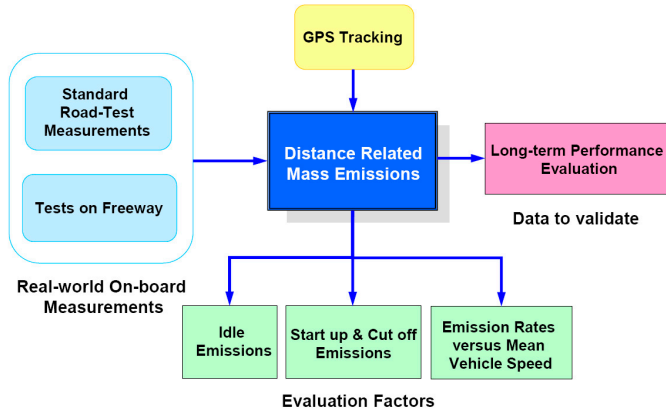


Figure 1: Methodology of the emission monitoring

ON-BOARD MEASUREMENT SYSTEM – For the emission monitoring under real-world conditions the test vehicles were equipped with a newly developed experimental on-board measurement (OBM) device. The ultra compact OBM with a total weight of less than 15 kg measures the emitted exhaust gas mass emissions of the vehicle in real-time without affecting the powertrain and vehicle characteristics. The gas concentration measurement works on the basis of a constant partial flow, which is taken from the exhaust gas in the tailpipe. Emission components measured by the OBM system were CO₂, CO, HC, NO_x, and O₂. The CO₂, CO and total HC concentrations were measured with non-dispersive infra-red absorption. Comparable investigations between infra-red and FID HC measurements showed satisfying results and provided a particular compensation function. NO_x and O₂ concentrations were detected using electrochemical sensors. Combined with the intake air mass flow and the vehicle speed, mass emissions of the exhaust gas for every detected component were calculated. The results can be observed in real time on the control subnotebook in the vehicle. For subsequent analysis, every second a complete data string was saved. To determine the mass emissions, the application of a chemical reaction model [3] is required to calculate the time related exhaust gas mass flow (Figure 2). Detailed cross-checks with CVS systems at certification chassis dynamometer were performed to ensure the accuracy of the OBM device [7].

The OBM provides the following data:

- Air-fuel ratio.
- Exhaust gas mass flow.
- Exhaust gas mass emissions of the measured components in [g/s] and [g/km].
- Fuel consumption in [g/s], [l/100 km] or [kg/100 km] by means of carbon balance method according to EU Commission directive 1999/100/EC [4].

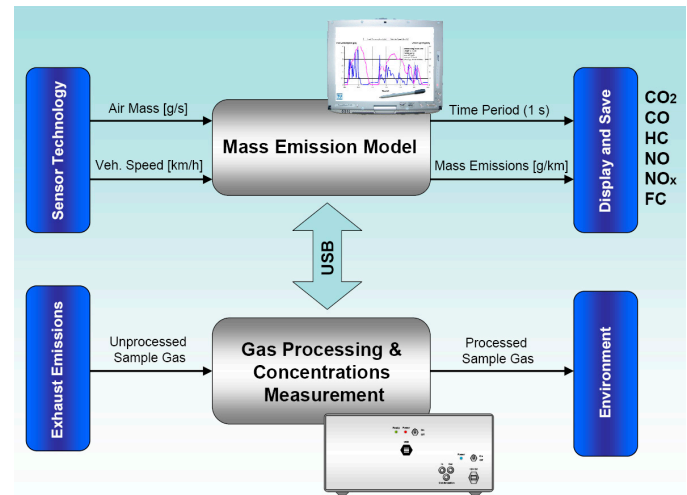


Figure 2: Exhaust gas mass calculation flow diagram

The distance related mass emissions are then calculated by means of equation 1, adopted from the European Council directive 91/441/EEC relating to measures to be taken against air pollution by emissions from motor vehicles [5].

$$M_i = \frac{V_{EG} * Q_i * k_H * C_i * 10^{-6}}{v} \quad (1)$$

where:

M_i ... mass emission of the pollutant i in gram per kilometer,

V_{EG} ... volume of the undiluted exhaust gas expressed in liters per second and corrected to standard conditions (273.2 K and 101.33 kPa),

Q_i ... density of the pollutant i in gram per liter at normal temperature and pressure (273.2 K and 101.33 kPa),

k_H ... humidity correction factor used for the calculation of the mass emissions of nitrogen oxides,

C_i ... concentration of the pollutant i in the undiluted exhaust gas expressed in ppm,

v ... vehicle speed corresponding to the operating cycle in km per second.

The fuel consumption is calculated by means of carbon balance method according to the following equation, from EU Commission directive 1999/100/EC

$$FC_{norm} = \frac{CH_f}{D} * (0.273 * CO_2 + 0.429 * CO + 0.749 * HC) \quad (2)$$

where:

FC_{norm} ... fuel consumption in kilogram per 100 kilometer,

CH_f ... fuel blend factor depending on carbon and hydrogen content in the fuel blend,

D ... density of the fuel at 15°C,

CO_2 , CO , HC ... exhaust emission masses in gram per kilometer.

To link the geographic data of the drive test with the distance related mass emissions of the exhaust gas components a GPS tracking was used. The next two figures show a typical section in the city center. The color of the trace on the map in Figure 3 shows the measured vehicle speed along the route.



Figure 3: GPS tracking of the route "City Center" in Vienna

The most road-test sections started and finished at the same place to minimize the effect of the slope on the measurements like Figure 4 shows.

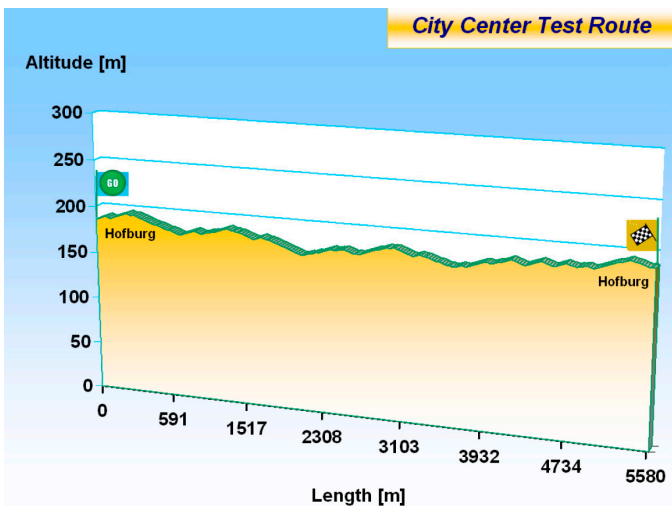


Figure 4: Altitude profile of the route "City Center"

TEST VEHICLES – A total of six test vehicles with CNG powertrain (tables 1, 2, 3) were measured for the emission monitoring. The fleet consisted of three light duty vehicles (Figure 5) and two passenger cars (Figure 6) as well as one medium duty vehicle (Figure 7). To evaluate the potential of the propulsion system for long-term operation the test vehicles were selected with different service performance. The high mileages of the vehicles oscillated between 80000 km and 300000 km.

Table 1: Specifications of the light duty test vehicles

Opel Combo 1.6 CNG ECOTEC	
Power train / transmission	
Combustion engine	
No. of cylinders, arrangement	4 Cylinder in-line engine
Working principle	4-Stroke naturally aspirated CNG engine
Fuel-mixture preparation	Intake manifold fuel injection
Number of valves per cylinder	4
Displacement	1598 cm ³
Bore / Stroke	79/81.5 mm / mm
Compression ratio	12.5:1
Rated output	71 kW at 6200 rpm
Max. torque	140 Nm at 4200 rpm
Exhaust after treatment	3-way catalytic convertor
Emission standard	EU3/D4
Fuel consumption	6.6 kg/100km (ECE) 3.9 kg/100km (EUDC) 4.9 kg/100km (NEDC)
CO ₂ -Emissions	133 g/km (NEDC)
Transmission	5-speed manual gearbox
Chassis	
Chassis design	5-seat van
Drag coefficient, c_w	0.35
Net weight with 75 kg Driver	1292 kg
Test Vehicle 1	
Measured in-test weight*	1630 kg
Mileage	210000 km
Test Vehicle 2	
Measured in-test weight*	1620 kg
Mileage	132000 km
Test Vehicle 3	
Measured in-test weight*	1640 kg
Mileage	300000 km

* The measured in-test weight includes driver+copilot+equipment



Figure 5: Light duty test vehicle with the OBM device