

Real-World Performance of a CNG Heavy Duty Articulated Truck

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ABSTRACT

In this study the performance of a monofuel compressed natural gas articulated truck was investigated under real-world conditions. To analyze the CNG vehicle due to fuel consumption and exhaust emissions a representative road-test route was conducted, including sections with significantly different driving conditions. Moreover, driving tests on freeway under higher load were carried out.

As experimental equipment, a new ultra compact on-board system measured the in-car exhaust mass emissions in real time. Every second, a full dataset of CO₂, CO, HC and NO_x emission rates was provided. The real-world emission 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. In combination with the vehicle speed, the emission rates in g/s are then calculated in gram per kilometer. Furthermore, the fuel consumption in g/s or kg/100 km is calculated with the carbon balance method according to the EU Commission directive 1999/100/EC.

The gained distance related emissions and the derived mean values are based on the several thousand individual datasets measured at the drive tests. In order to link the measured exhaust emission data with geographical information of the road-test route a GPS tracking was implemented as well.

Additionally, the application of new calculation and experimental methods in this investigation allowed developing characteristic maps of the CNG powertrain based on the real-world measurement data.

INTRODUCTION

Global challenges such as increasing energy efficiency, reducing greenhouse gas emissions as well as improving air quality lead worldwide to ambitious goals and mandatory targets for energy saving, emissions standards and security of energy supply. Gaseous energy sources, like natural gas and biogas should become an essential fundament as fuel, which offer lower CO₂ and pollutant emission even because of their chemical composition, higher energy density and knocking resistance [1].

This paper is based on the research project “CHD” - Clean Heavy Duty - within the Austrian Advanced Automotive Program (A3). The project addressed the reduction of CO₂ and pollutant emissions of heavy duty vehicles to decrease the air pollution alongside transit routes and industrial areas.

The transportation of goods is responsible for a considerable share of the climate relevant emissions resulting from road traffic. On the one hand, goods traffic is contributing significantly to local air pollution, specially caused by nitrogen oxides and particulate matter from diesel engines. On the other hand, in Europe alternative powertrains for heavy duty vehicles with engine power outputs greater than 150 kW are marginal and the share of this truck class in overall emissions is rising. For heavy duty vehicles, spark ignition gas engines with catalytic exhaust treatment represents an interesting alternative to diesel powertrains regarding exhaust emissions and driving performance.

Engines for heavy duty vehicles are emission certified by running engines according to specified load pattern or duty cycle. In the US, the US Heavy-Duty Transient cycle has been in use already for a number of years, and Europe is,

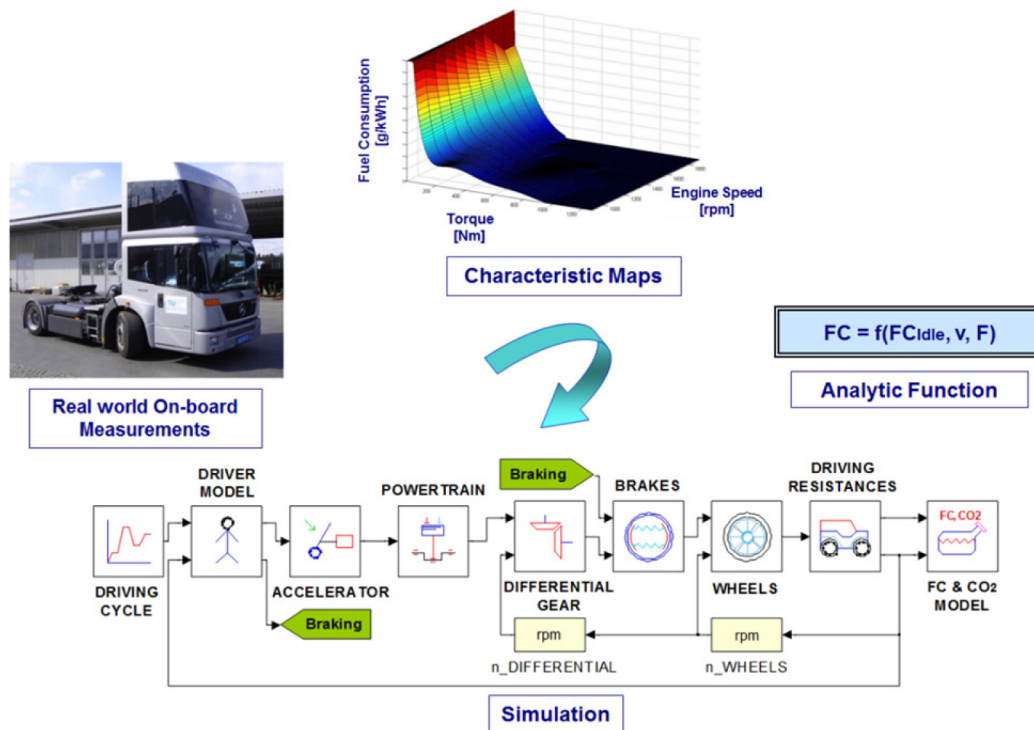


Figure 1. Flow diagram of the methodology

according to the requirements of the Directive 1999/96/EC gradually switching to transient-type testing.

Evaluating the in-use emission performance of heavy-duty vehicles presents a problem. Taking engines out of vehicles for engine dynamometer testing is difficult and costly. In addition, engine dynamometer testing does not take into account the properties of the vehicle itself (i.e. mass, transmission etc.). It is also debatable, how well the standardized duty cycles reflect real-life driving patterns [2]. For these reasons, the use of a portable emission measurement system (PEMS) capable of evaluating the real-world exhaust gas mass emissions of the vehicle without affecting the powertrain and vehicle characteristics constitutes an appropriate method.

METHODOLOGY OF THE REAL-WORLD EMISSION MEASUREMENT

New developed technology applied to portable emission measurement systems (PEMS) leads to high quality testing on-road for establishment of real-world emission factors as well as to verify whether vehicles and engines meet the emission standards. Based on the real-world on-board measurement data, the application of calculation and experimental methods allows developing fuel consumption maps of the powertrain. These maps are the key to calculate further analytical functions of fuel consumption to be entered in longitudinal vehicle dynamics simulation models [3].

ON-BOARD MEASUREMENT SYSTEM

For the exhaust emission measurements under real-world conditions the test vehicle was equipped with a newly, by the research group developed experimental on-board measurement device. The ultra-compact PEMS with a total weight of less than 15 kg (Figure 2) 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. This technology allows real-world in-use testing and provides more detailed data than conventional laboratories or vehicle test cells. The PEMS integrates accurate gas analyzers, exhaust mass flow meter, connections to the vehicle ECU and Global Positioning System (GPS).

Emission components measured by the PEMS were CO₂, CO, THC, NO_x and O₂. The CO₂, CO and total HC concentrations were measured with non-dispersive infrared absorption NDIR. Comparable investigations of HC measurements between NDIR and flame ionization detector FID showed satisfying results regarding the NDIR accuracy. NO_x and O₂ concentrations were detected using electrochemical sensors. The on-board measurement system is equipped with separate NO and NO_x channels. The NO_x channel is based on a laboratory type electrochemical thick film ZrO₂ sensor. However, the post processing of the



Figure 2. Detail of the PEMS installed in the test vehicle.

measurement results was only completed for the total NO_x emissions.

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.

The PEMS 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] or [kg/100 km] by means of carbon balance method according to EU Commission directive 1999/100/EC [4].

To determine the mass emissions, the application of a chemical reaction model [5] is required to calculate the time related exhaust gas mass flow (Figure 3).

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 [6].

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

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.

For vehicles with a positive ignition engine fuelled with natural gas:

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

Where:

- FC_{norm} ... fuel consumption in kilogram per 100 kilometer in case of CNG,
- CH_f ... fuel blend factor depending on carbon and hydrogen content in the fuel blend,
- D ... density of the test fuel at 15°C,
- CO_2 , CO , HC ... exhaust emission masses in gram per kilometer.