Determination of temporaly highly resolved passenger car emissions of important exhaust components by means of on-board measurements under real traffic conditions

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ABSTRACT:
As part of the BMBF-funded MOBINET project a latest technology three-way-catalyst car (Ford Mondeo, D4-exhaust regulation standard) was equipped with on-board measurement systems for CO, HC, NO_x and fuel consumption. On-board measurements were performed in the city of Munich in summer 2001, and a large data set was obtained which consists of each more than 70000 individual measurements. From the whole data set of the Munich measurements, a new chassis dynamometer driving cycle ("MOBINET-cycle") was constructed which is representative for the Munich driving conditions with respect to its distribution of speed, acceleration and driving power.
Although fuel consumption and CO2 emission of the MOBINET-cycle driven at a chassis dynamometer and the respective real-world driving are in very good agreement, the emission behaviour with respect to the regulated compounds NOx, CO and HC differ by up to half an order of magnitude. By far the best description of real-world emission behaviour of our test car is derived from emission functions (calculated from the whole Munich dataset), which represent the whole variety of driving situations.
It is also concluded from our findings that the use of emission data from chassis dynamometer measurements of catalyst cars for the model prediction of ozone concentration is rather uncertain. It is planned conduct further on-board investigations with different cars to achieve representativity of our findings.

Key words: Traffic exhaust, realistic emissions, on-board measurements

1 INTRODUCTION

Road traffic is a dominant source of air pollution. Exhaust emissions from new passenger cars are regulated within the EC by directives since more than a decade. For this purpose, decreasing limit values are set for total hydrocarbons (HC), for nitrogen oxides (NO_x), for carbon monoxide (CO) and for particulate matter.
As a result of the regulation procedures, it is reported from the emission inventories for Germany (UBA, 1998) that traffic related HC emissions contribute to less than 30% to the total HC emissions for Germany. From our investigations, however, dealing with the evaluation of an emission inventory by experimental studies (Augsburg experiment, Klemp et al., 2002, Mannschreck et al., 2002), we have observed a substantial underestimation of HC contributions from road traffic and an overestimation of HCs from solvent usage compared with the results of the emission inventory.
One possible reason for this finding may be attributed to the fact that traffic emission calculations in emission inventories are based on the results of approval tests on chassis dynamometers. Those tests are obviously indispensable for the approval of new passenger cars under standardized conditions. On the other hand, there are several hints (Nelson and Groblicki, 1993, De Vlieger, 1997) that this type of procedure does not yield a realistic picture on the emission behaviour under real traffic conditions.

As part of the BMBF-funded MOBINET project a latest technology three-way-catalyst car (Ford Mondeo, D4-exhaust regulation standard) was equipped with on-board measurement systems for CO, HC, NO_x and fuel consumption. On-board measurements were performed in the city of Munich in summer 2001, and a large data set was obtained which consists of each more than 70000 individual measurements of the compounds listed above. Also studied was the emission behaviour of our "MOBINET" test car when operated under different chassis dynamometer test conditions. Following, a brief description of the on-board-system will be given, and the results of our on-road measurements will be compared with those from the dynamometer studies.

2 EXPERIMENTAL

2.1 On-board system

In fig. 1 a flow chart of our MOBINET on-board measurement system is given. The fuel consumption (PLU 401-108, Pierburg Corp.), the vehicle speed, the lambda value and the signal from the air mass sensor were recorded every second by our data acquisition system. As pointed out by Lenaers, 1996, the current total exhaust gas mass flow can be calculated from the signals from the air mass sensor, the respective lambda value and the momentary fuel consumption.

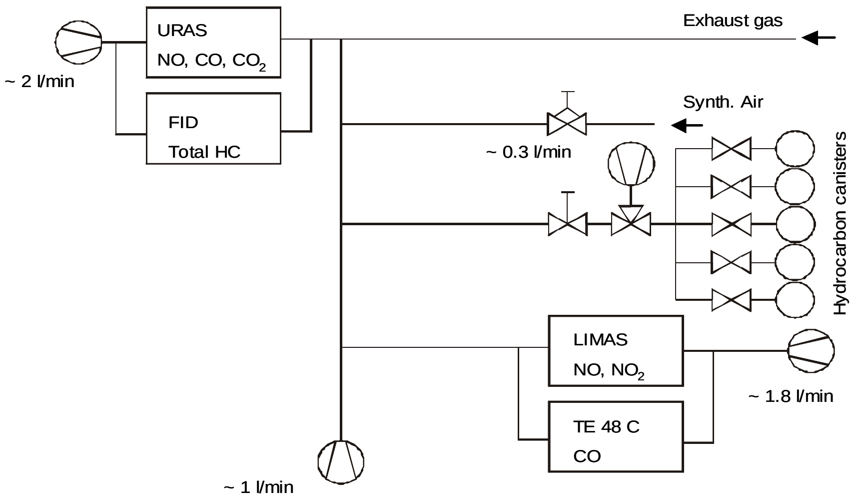


Figure 1: Flow chart of the MOBINET on-board measurement system.

From the exhaust stream a flow of around 5 L/min is sucked in and analyzed by our gas analytics. CO, NO and CO_2 mixing ratios in the exhaust gas are measured by means of commercially available gas analyzers (URAS, ABB Corp.) using non-dispersive infrared (NDIR) detection principle. The NO and NO_2 content of the exhaust gas is analyzed by UV-absorption (LIMAS, ABB Corp.). The total HC content is measured by a FID system (ABB Corp.). Low mixing ratios of CO were also measured by a modified trace gas analyzer (TE 48 C, Thermo Instruments). Emission values of CO, CO_2, NO, NO_2 and HC in $g \cdot s^{-1}$ and $g \cdot km^{-1}$ were calculated from the measured mixing ratios using the respective total exhaust gas mass flows, taking into account the individual time shifts between engine exhaust output and analyzing time for the different gas analyzers.

The exhaust gas is also analyzed for the speciation of hydrocarbons, using stainless steel canisters (Restek Corp.). For this means, for around 20 to 30 seconds exhaust gas is sucked in the previously evacuated canister. Hereby, the exhaust gas is diluted with synthetic air in a way that the sample is held constantly proportionate to the total exhaust gas flow (**c**onstant **v**olume **s**ampling, CVS). The results of our hydrocarbon speciation (containing around 80 different compounds) will be subject of a separate paper and is therefore not discussed here.

2.2 Intercomparison of the on-board system with chassis dynamometer measurements

From an intercomparison of the MOBINET on-board system with chassis dynamometer measurements performed at RWTÜV Fahrzeug GmbH in Essen, a quite good agreement between the CVS system and our on-board system was found. Based on the comparison of the regulated compounds NO_x, CO, HC and of CO_2 an agreement of always better than 10 % were observed for two different driving cycles (Figure 2).

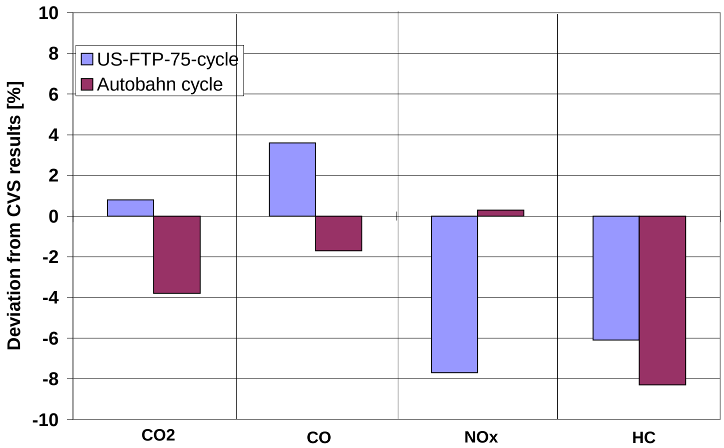


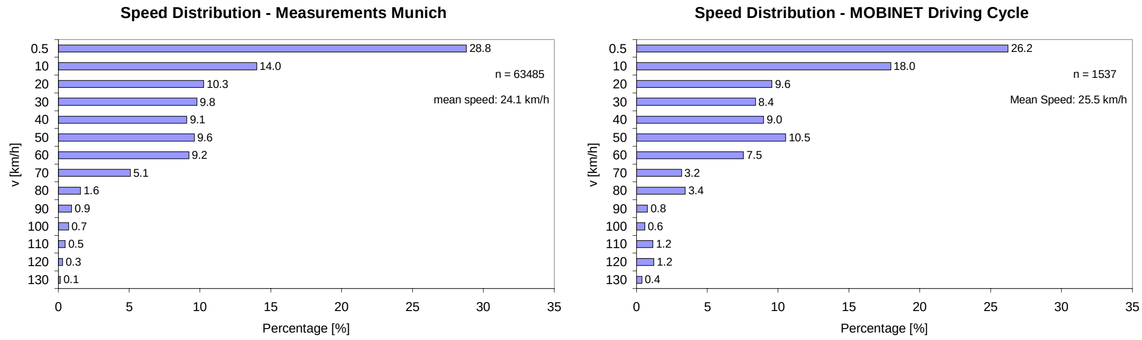
Fig.2: Results of the intercomparison of the MOBINET on-board system with the CVS system of RWTÜV Fahrzeug GmbH Essen. Results for CO, NO_x, HC and CO_2 are shown for two different driving cycles (US-FTP-75-cycle and Autobahn cycle (Hassel et al, 1995)).

2.3 Driving behaviour in Munich and development of a representative chassis dynamometer driving cycle from the on-road measurements

On-road measurements were performed on Munich streets during the morning and evening rush hours, respectively. In order to get a representative pattern of the traffic conditions in Munich three different driving courses were selected containing stop-and-go-phases, driving conditions regulated by traffic-lights and also the usage of an inner-city motorway. The driving behaviour for the different courses was always adapted on the normal traffic flow conditions. Emissions were recorded second by second starting either with a cold or a warm engine. The data set consists of more than 70000 values of CO, CO_2, NO_x, HC, speed consumption and of driving parameters (travelled distance, speed and acceleration).

From the whole data set of the Munich measurements, a new chassis dynamometer driving cycle (“MOBINET-cycle”) was constructed which is representative for the Munich driving conditions with respect to its distribution of speed, acceleration and driving power, given by the product of speed times acceleration (fig. 3)

Fig. 4 shows a plot of speed vs. time of our MOBINET driving cycle. The MOBINET cycle is built up from real traffic situations recorded during our on-road measurements in Munich and is representative (cf. Fig 3) for the whole dataset from Munich. It consists of 3 parts: (I) driving conditions regulated by traffic-lights, (II) stop-and-go driving and usage of an inner-city motorway (III). The total length of the driving cycle is 1537 s.



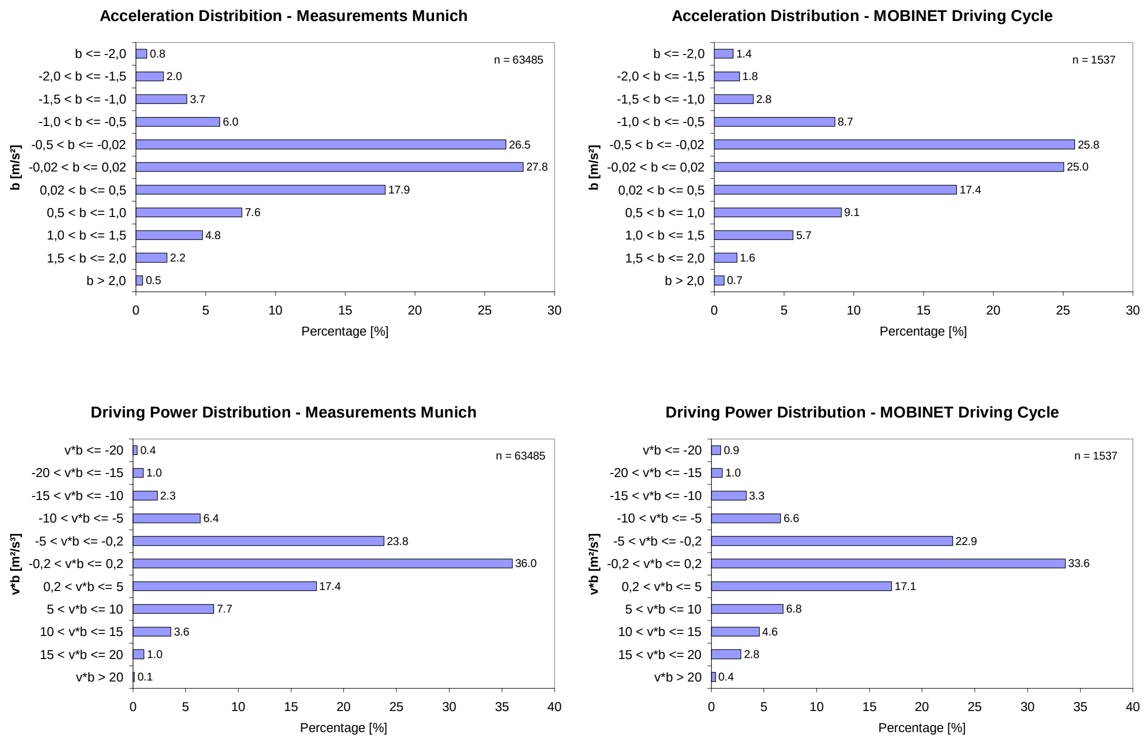


Fig. 3 Distributions of speed, acceleration and driving power for Munich measurements (left) and the MOBINET driving cycle (right).

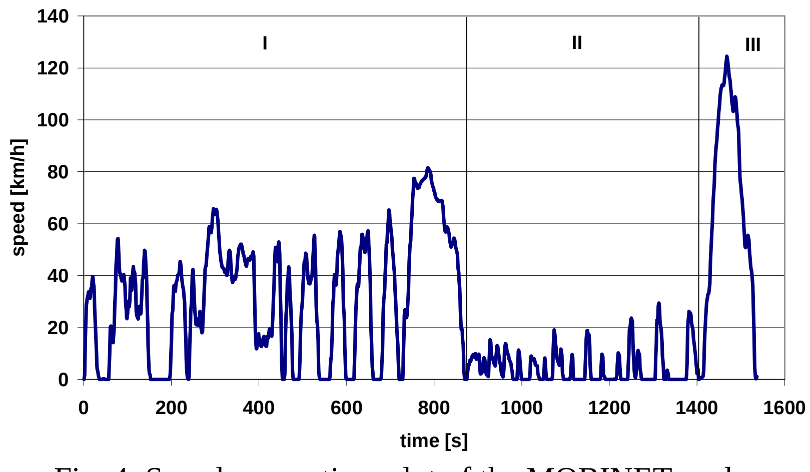


Fig. 4: Speed versus time plot of the MOBINET cycle.

It is apparent from Fig. 5 that the MOBINET cycle covers the plane of momentum values of speed and driving power (i. e. v [m/s] times b [m/s^2]) from real-world driving much better than the MVEG cycle. Whereas the MVEG cycle exhibit only driving powers of around 10 m^2/s^3 in real-word driving respective values of more than 20 m^2/s^3 are observed. Also, maximum accelerations for the MVEG cycle are substantially smaller than for real world driving conditions (c. f. m_Max).

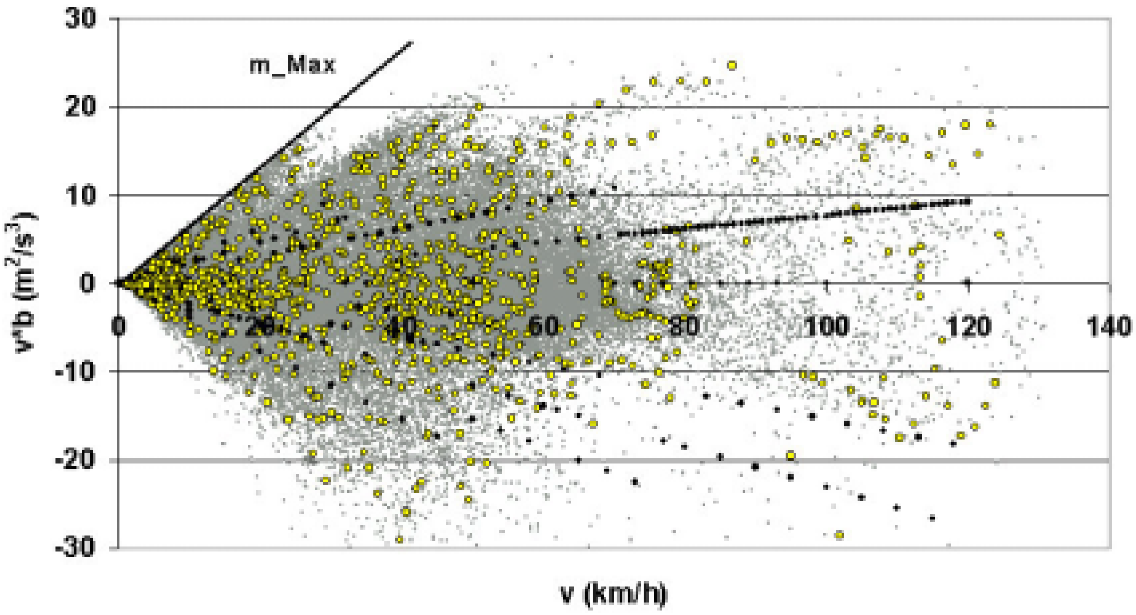


Fig. 5: Speed and driving power (i. e. speed times acceleration) for all on-road measurements performed in Munich based on measurements second per second, for the European certification cycle (MVEG, black circles) and for the MOBINET driving cycle (white diamonds). The black line (m_Max) points out the maximum acceleration observed for real-world driving.

3. RESULTS

3.1 Conformity test of the test vehicle

During the measurements the gross weight of the car was almost 1.8 tons, whereas the curb weight is 1477 kg. To make sure that the car does not exceed the exhaust limits under these conditions, the legal certification cycle MVEG (99/100/EG) was driven at the chassis dynamometer of RWTÜV Essen (Germany). The RWTÜV Essen is entitled to confirm the compliance with exhaust regulations. For CO and NO_x the regulation regulations where met, whereas the hydrocarbons emissions exceed the D4-values by 4% (Table 1). The EURO4-values are easily met.

	Certification RWTÜV Essen	D4-exhaust regulation	EURO4 exhaust regulation
CO_2 [g/km]	208	-	-
CO [mg/km]	335	700	1000
NO_x [mg/km]	61	70	80
HC [mg/km]	83	80	100

Table 1 Comparison of German exhaust regulation limits for D4-cars and of the EURO4-limits with exhaust measurements of Ford Mondeo certified by RWTÜV Essen using the European exhaust certification cycle MVEG.

3.2 Development of velocity-dependent and engine load-dependent emission functions from the on-board measurements in Munich

As shown by Hassel et al., 1995, the emissions of a passenger car can be described as a function of its velocity and its engine load. Using this approach, emission functions were calculated from our Munich data set for CO, CO_2, NO_x, HC and for fuel consumption. According to the driving parameters depicted in fig. 5, the velocity range is chosen from 0 to 125 km/h and is clustered by 10 km/h. The respective values for the driving power yield from –20 m^2/s^3 to 20 m^2/s^3 clustered by 5 m^2/s^3. In order to discriminate from cold-start conditions only data from later than 500 seconds after start were included. As an example, the emission function for total HC is shown in fig. 6.

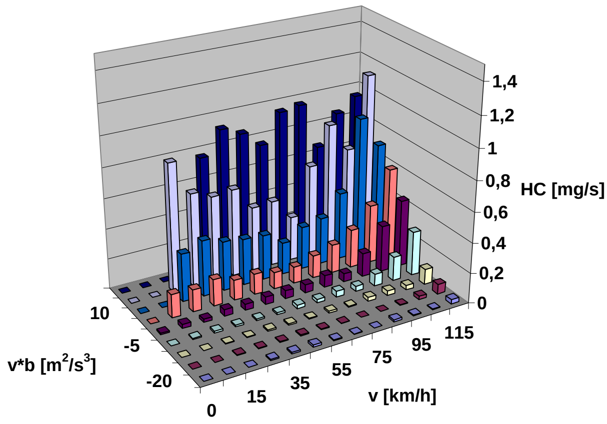


Fig. 6: Total HC emissions [mg/s] from on-board measurements of Ford Mondeo as function of velocity v [km/h] and driving power $v \cdot b$ [m^2/s^3]

3.3 Comparison between real-world emission behaviour and that of MOBINET cycle

The main aim of our investigation was focused on the question whether the real-world emissions of our test car can be represented rather by an appropriate chassis dynamometer cycle (MOBINET cycle) or by emission functions (depending on velocity and engine load), derived from the whole variety of individual driving conditions of the Munich on-board measurements. For this purpose we have compared the emission behaviour of our test car in Munich during those time periods which are used for the assembling of the MOBINET cycle with the results of our emission functions and with the results of the MOBINET cycle, performed on the chassis dynamometer of RWTÜV in Essen.

Fig. 7 shows the emissions of CO_2, CO and NO_x at the dynamometer in comparison to the respective emissions from the on-road measurements in Munich which make up the MOBINET cycle. With respect to CO_2, the good agreement of both the momentum values and of the cumulative emissions per distance is apparent. In contradiction, there are large differences in the emissions of CO (dynamometer-values more than 5 times higher than on-road-values) and for NO_x (on-road-values almost 5 times higher than dynamometer-values).

In Fig. 8 emissions of CO_2, CO, NO_x, hydrocarbons (HC) and fuel consumption during the on-road measurements and the dynamometer measurements are compared with results of our emission functions. CO_2-emissions and fuel consumption are always in good agreement. Emissions of CO, NO_x and HC measured on the chassis dynamometer differ substantially from the ones measured in Munich. Deviations are +455%, -79% and +213%, respectively. Calculated emissions of CO, NO_x and HC are 57%, 29% and 21% lower than on-road measured emissions and therefore meet the real-world emissions much better than the emissions measured at the chassis dynamometer.

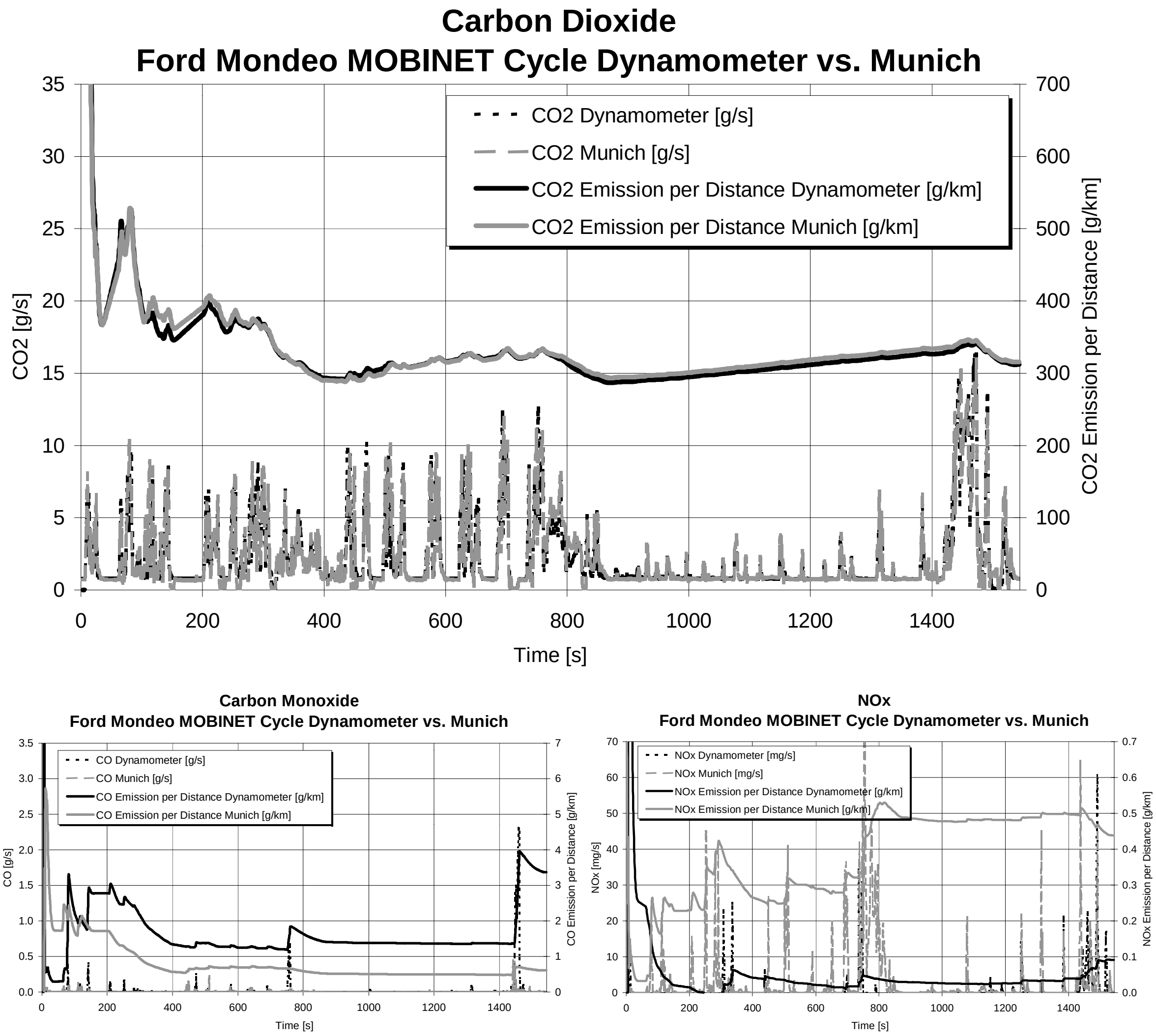


Fig. 7 Emissions of CO_2, CO and NO_x during the MOBINET-cycle at the dynamometer in comparison to the respective emissions obtained from the on-road measurements in Munich.

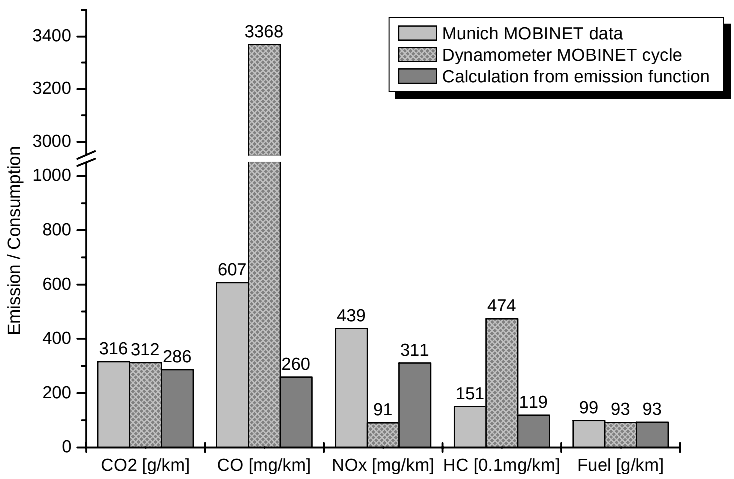


Fig. 8 Emissions of CO_2, CO, NO_x and HC and fuel consumption measured on-road in Munich and during the MOBINET-cycle at the dynamometer in comparison to values calculated from emission functions.

4. CONCLUSIONS

a) It is shown from the comparison of the respective speed vs. driving power plot that the MVEG driving cycle is far away from real-world driving in Munich.
b) Our MOBINET-cycle represents the Munich driving conditions with respect to speed and driving power quite good.
c) Although fuel consumption and CO_2 emission of the MOBINET-cycle driven at a chassis dynamometer and the respective real-world driving are in very good agreement, the emission behaviour with respect to the regulated compounds NO_x, CO and HC differ by up to half an order of magnitude.
d) By far the best description of real-world emission behaviour of our test car is derived from emission functions (calculated from the whole Munich dataset), which represent the whole variety of driving situations.
e) It is concluded that further factors influence the emission behaviour of modern vehicles besides speed and driving power.
f) Observations a) and e) indicate that the use of emission data from chassis dynamometer measurements of catalyst cars for the model prediction of ozone concentration should be evaluated critically. Further on-board investigations with different cars are necessary to achieve representativity of our findings.

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