Regulated and unregulated exhaust emissions from nine passenger cars

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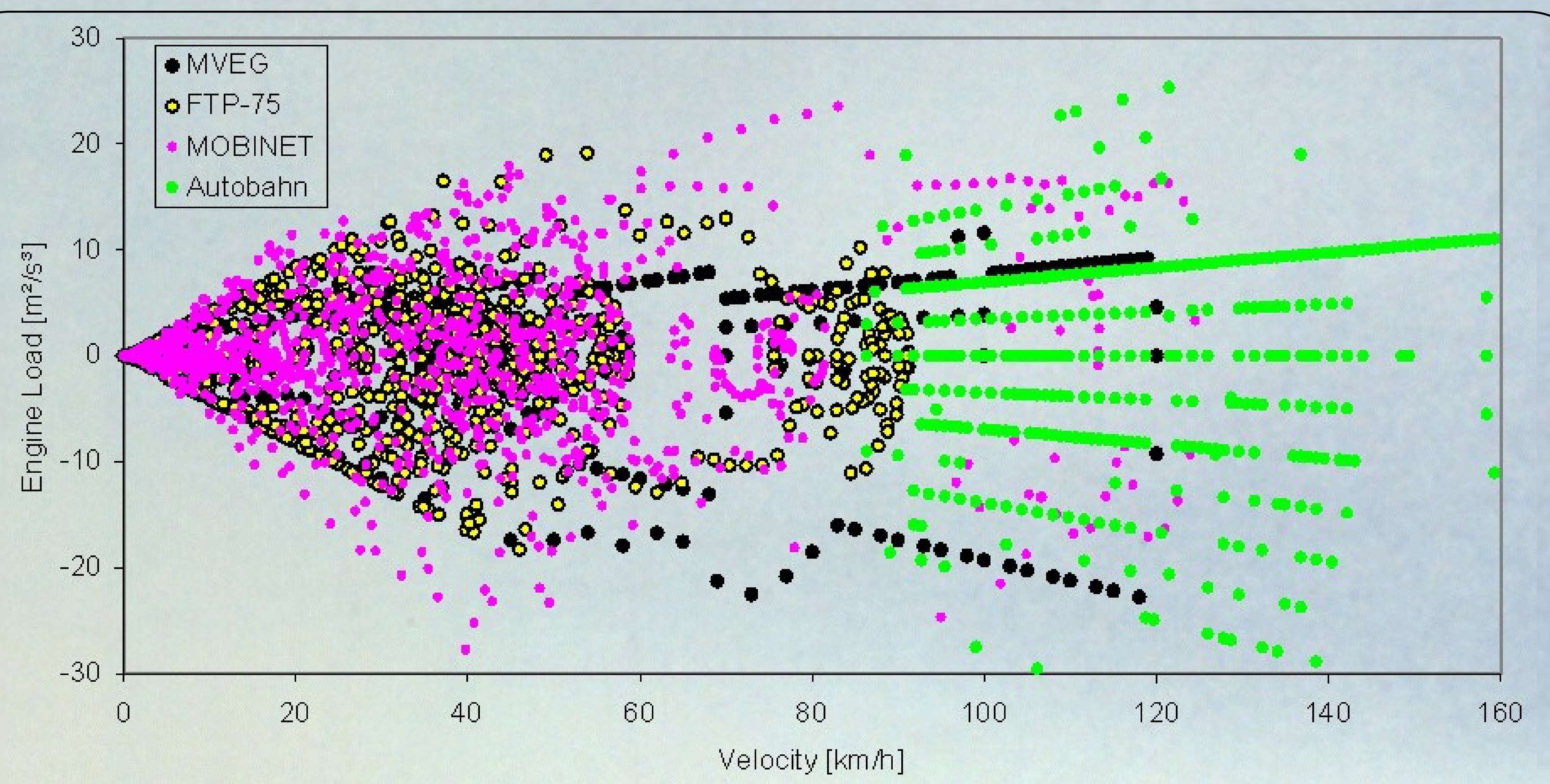
Motivation

- The approval testing cycle MVEG of the European Community is quite undemanding, therefore type approval emissions do not necessarily reflect real world emissions.
- Not only the regulated compounds CO, NO_x, HC and PM are important for air quality. For example, NO and NO_2 are recorded as sum NO_x, regardless of their complementary roles in ozone chemistry.
- For reliable calculations in air chemistry there is a need for precise knowledge of both the amount and the speciation of pollutants from traffic.



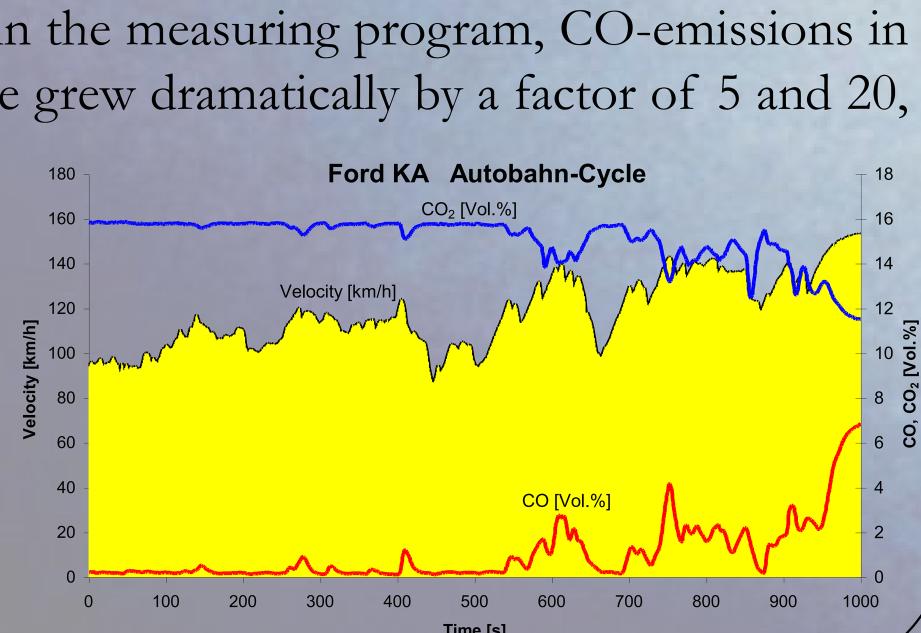
Distribution of engine load (velocity times acceleration) vs. velocity of the different driving cycles. This distribution is an appropriate measure to charakterize the driving behaviour (Hassel 1994).

Comparison of the different driving cycles

	Limit D4	MVEG	FTP-75	MOBINET	Autobahn
Ford Mondeo					
CO [g/km]	0.70	0.43	0.89	3.37	2.89
NO_x [g/km]	0.07	0.09	0.19	0.09	0.18
HC [g/km]	0.08	0.08	0.08	0.05	0.08
VW Golf IV					
CO [g/km]	0.70	0.20	0.74	0.50	0.47
NO_x [g/km]	0.07	0.04	0.06	0.06	0.04
HC [g/km]	0.08	0.02	0.04	0.01	0.01
Ford KA					
CO [g/km]	0.70	0.59	0.82	3.10	13.07
NO_x [g/km]	0.07	0.07	0.06	0.08	0.13
HC [g/km]	0.08	0.05	0.09	0.08	0.09

A comparison of the three vehicles with conventional gasoline engines, all compliant with the D4-exhaust regulation level, shows the bandwidth of emissions that exist in the broad range of velocities and engine loads which are present in the four different driving cycles:

- Only the Golf IV exceeded the D4-limits in neither driving cycle. Both the MOBINET-cycle with quite demanding urban driving and the Autobahn-cycle with its high velocities yield emissions comparable to the MVEG. Relatively large differences can be found between MVEG and FTP-75. This might be due to the fact that the FTP-75 includes a whole cold start, whereas in the MVEG the first 40 seconds after the cold start are omitted. MOBINET and Autobahn do not include cold starts.
- In the Autobahn-cycle with velocities up to 160 km/h, both the Ford Mondeo and the Ford KA exceed the D4-limit for NO_x substantially. The emissions relative to distance exceed the ones from the MVEG by a factor of 2-3.
- The most significant exceedances of the D4-limits happened for CO with the Ford Mondeo and Ford KA in the two demanding cycles MOBINET and Autobahn. The Ford Mondeo exceeded the D4-limits by a Factor of 5 in the MOBINET-cycle and by a factor of 4 in the Autobahn-cycle. For the Ford KA, who had the lowest-powered engine in the measuring program, CO-emissions in MOBINET-cycle and Autobahn-cycle grew dramatically by a factor of 5 and 20, as compared to MVEG.
  In the last part of the Autobahn-cycle, CO-emissions reached 7 Vol. % (see right-hand-figure), probably due to full power enrichment. Such emission levels are known to be reached by non-catalyst-cars.

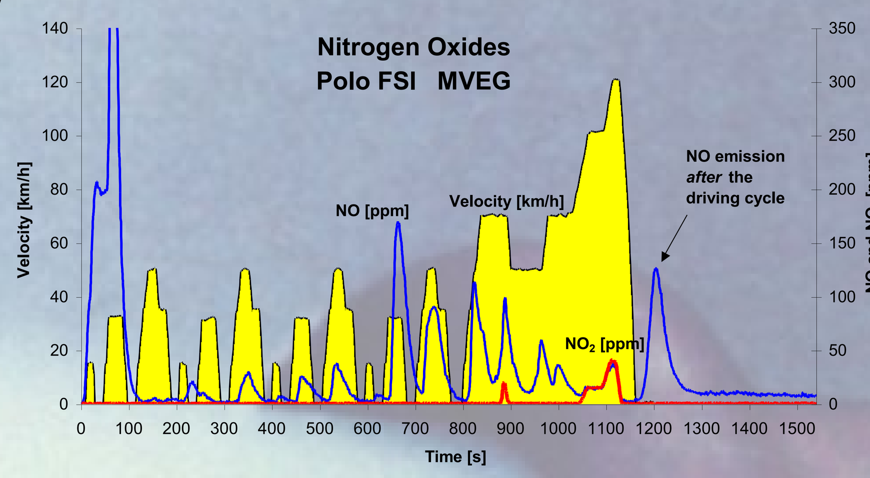


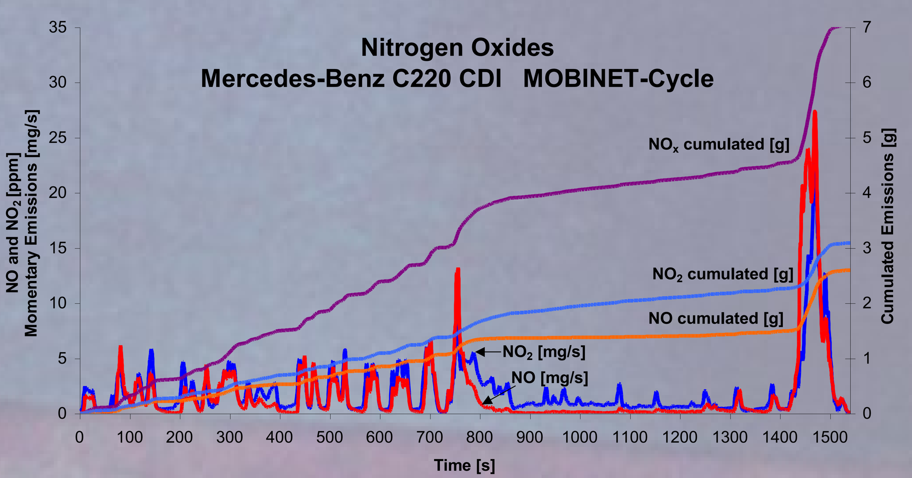
Experimental

The measuring program included eight different cars of the model years 2000 and later together with one older car (model year 1996). Three cars had conventional gasoline engines (spark ignition, SI), three cars had SI-engines with direct fuel injection (SI-DI) and three cars had diesel engines (compression ignition, CI) with direct injection. All SI-engines had three-way-catalysts; the diesel engines were equipped with oxidative catalytic converters. Measurements were performed on the chassis dynamometer of RWTÜV Fahrzeug GmbH in Essen, Germany. They were carried out under the conditions of four different driving cycles:

- **MVEG**: Certification cycle for all new cars in the EU
- **FTP-75**: Certification cycle for new cars in the US and several other countries
- **Autobahn-cycle**: Developed by Hassel (1994), representative for the driving behavior on the German expressways "Autobahn"
- **MOBINET-cycle**: Developed by Klemp (2002), representative for the driving in the city of Munich

Speciated nitrogen oxide analysis





While conventional gasoline engines almost exclusively emit NO (> 99%), the share of NO_2 from NO_x in DI-SI engines (left figure) and CI-engines (right figure) is between 10% and 60%. Both species can be transformed into each other by the reaction with ozone:

$$NO + O_3 \Leftrightarrow NO_2 + O_2$$

During daytime the Leighton relationship holds (Leighton 1961), according to which these species are in balance ($J(NO_2)$ is the photolysis rate of NO_2):

$$\frac{[O_3][NO]}{[NO_2]} = const. \cdot J(NO_2)$$

Therefore, NO-emissions produce and NO_2-emissions destroy ozone. Increasing shares of NO_2 have several effects:

- Less ozone coming from rural background air into the cities will be destroyed due to a smaller amount of NO. This equals rising ozone levels in the cities.
- Ozone is the most important source of the most important daytime radical, the hydroxyl radical OH, which act as initiator of multiple photochemical cycles. Thus, increasing ozone levels result in higher OH concentrations and therefore in an acceleration of many photochemical reactions.
- Nitrous acid HONO is mainly formed heterogeneously on surfaces in the presence of water and NO_2. HONO is another source of the OH-radical. Therefore NO_2 emissions lead to faster photochemistry also via this reaction path.

Worth mentioning is furthermore the emission of NO by the Polo FSI *after* the driving cycle (left-hand-figure above). This car is equipped with a NO_x-storage catalyst, which bases on the reversible reaction of NO with barium oxide:

$$BaO + 2\,NO + 1.5\,O_2 \Leftrightarrow Ba(NO_3)_2$$

It seems that after the cycle the back reaction took place, leading to the emission of NO. Other pollutants have not been emitted during that time.

Summary and Conclusion

- Some cars emit high amounts of carbon monoxide during high engine loads and velocities. Therefore, not only the certification cycle MVEG but also more demanding driving cycles with rather realistic driving patterns must be taken into account, at least for the compilation of emission inventories.
- While modern catalysts effectively convert hydrocarbons, the nitrogen oxides and especially nitrogen dioxide stay a problem, aggregative due to the rising share of diesel engines and gasoline engines with direct fuel injection in the fleet. Increasing NO_2 emissions result in higher ozone levels and faster photochemistry close to the sources.

References

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