Real-World NO_x Emissions of Euro VI Vehicles under Urban Driving Conditions

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Summary

NO_x emissions have been measured under everyday operation of four Euro VI heavy-duty vehicles, which typically operate at low-speed, urban driving conditions.

The results of the measurements show that the tested Euro VI vehicles are cleaner than previous generations, but still can show strongly varying NO_x emissions during typical urban driving; at low average speeds and under challenging conditions. Out of four vehicles tested, two have higher NO_x emissions than can be expected based on the type approval limit and emissions tests on long-haulage trucks TNO performed earlier (Vermeulen et al., 2014). The two other vehicles are very clean, even in low-speed urban driving conditions.

The current in-service conformity procedure, which is based on real-world measurements with PEMS, therefore does not guarantee low NOx emissions of Euro VI vehicles under urban driving conditions. The reason is the fact that for the evaluation of EU in-service conformity factor, data is excluded. This data mainly concerns low-speed operation which, for some applications, may in fact be representative operation.

The urban low-speed driving conditions are known to be potentially problematic for NO_x reduction with SCR. For some applications average speed and engine load during urban driving can become so low that exhaust temperatures may fall below the temperature which is required to enable efficient reduction of NO_x in the SCR system which in turn may lead to an increase of the real-world NO_x emission. Measures that decrease the NO_x emission can increase fuel consumption. The manufacturers are therefore constantly challenged to optimize fuel and AdBlue consumption on the one hand and NO_x reduction on the other.

For derivation of reliable emission factors and insight into real-world performance for these types of vehicles, more measurement data are needed from vehicles which operate in typical urban low-load driving conditions. Furthermore, longer periods of measurement are needed to cover a wider scope of real-world operation. The autonomous SEMS measurement system, which is based on a NO_x sensor, can fulfil this task.

Introduction

Commissioned by the Dutch Ministry of Infrastructure and the Environment, TNO regularly performs measurements to determine the in-use emission performance of vehicles in the Netherlands. The main goal of the measurement programme is to gain insight into real-world emissions of heavy-duty vehicles under conditions relevant for the Dutch situation.

In 2013 and 2014 Euro VI heavy-duty vehicles formed the centre of attention in the testing programme. Euro VI is expected to deliver a lot when it comes to the reduction of especially NO_x and PM emissions. Emission testing with Euro VI long-haulage applications has already shown the large potential of this new legislation for this category of vehicles. However, vehicles which typically operate in an urban environment, like buses and distribution vehicles, have only just started to arrive on the market. Given the importance of these vehicles for urban air quality and the problems with the earlier Euro V generation of vehicles, the programme's last part focused on the execution of real-world emission tests to find out how Euro VI vehicles perform on their real-world NO_x emissions, especially during their typical urban operating conditions.

The focus is on NO_x emissions as in the Netherlands at hot spots the limits for ambient concentrations of NO_2 are still being exceeded. In the Euro VI emission legislation (as of 2014) large improvements have been made compared to Euro V (2009-2013). Especially, the test procedures of Euro VI substantially improved. This includes, amongst others, a new, more representative engine test cycle (WHTC) and in-service conformity tests on the road with PEMS (Portable Emission Measurement System), which are mandatory as of Euro VI. Furthermore, the limits for NO_x are lowered from 2.0 to 0.46 g/kWh. These measures are expected to significantly reduce the discrepancy between the real-world emissions of NO_x under low-speed urban driving conditions and the demanded type approval emission level, that existed for Euro V heavy-duty vehicles. Given the improvements in EU heavy-duty emission legislation Euro VI could therefore potentially prove to be an effective instrument in helping the Netherlands fulfil European air quality requirements.

The first Euro VI vehicles to appear on the market early 2013 were the main-stream long-haulage trucks. TNO has tested six of those trucks with PEMS, under representative conditions. The tests revealed promising low NO_x emission levels for all tested Euro VI long-haulage trucks, even under representative urban driving conditions. At the end of 2013, next to the long-haulage trucks, more types of Euro VI vehicles started to enter the market. The Ministry and TNO selected two Euro VI city buses, a garbage truck and a 12t distribution truck for emission measurements under real-world conditions representative for those vehicles.

Measuring emissions under urban driving conditions

To assess the emission performance of the city buses, the garbage truck and the 12t distribution truck the vehicles were tested in everyday operation, with a focus on NO_x emissions. The buses were PEMS tested at predefined low, medium and high payload on a variety of test trips, including two bus lines in the city of Utrecht. One bus line consisted of urban roads and roads outside the urban area; the other route predominantly consisted of urban operation in and around the city centre of Utrecht. Additionally, to check the in-service conformity of these specific buses, they were tested on a Euro VI M3 Class I trip, as prescribed by Euro VI legislation (582/2011/EC and amendments).

The emission of NO_x of the garbage truck and the 12t distribution truck was screened with an autonomous measurement system called SEMS. SEMS uses an automotive NO_x-oxygen sensor, an ammonia sensor, GPS and data acquisition and a special data evaluation method that enables screening of NO_x emissions of heavy-duty diesel vehicles in every day operation.

Figure 1&2: Left: A NO_x sensor and an NH_3 sensor of the SEMS system installed in the tailpipe of the Euro VI distribution truck. Right: Exhaust flow meter of the PEMS system as mounted on a Euro VI city bus

The autonomous measurement ran for one to two weeks per vehicle. This happened during normal everyday operation, where payload, traffic conditions and driving style varied automatically according to real operation and use of the vehicles.

A dedicated data evaluation method, called 'speed binning' of the CO_2-specific NO_x emissions (equation 1) was used to evaluate the emissions over the operating speeds of the vehicles and to harmonize the results to be able to compare emissions of different vehicles (Vermeulen et al., 2012).

$$gNO_x \ per \ kgCO_2 = \frac{\sum_{v=vi}^{v=vi+5} NO_x[g/s]}{\sum_{v=vi}^{v=vi+5} CO_2[kg/s]} \qquad \text{(Equation 1)}$$

In addition, the trips of the two city buses were analysed according to the in-service conformity requirements as laid down in 582/2011/EC. The requirements prescribe a special pass-fail method to determine the conformity factor.

Measurement results

Below the emission results of PEMS and SEMS measurements are depicted for the four Euro VI vehicles that typically operate in an urban environment. For this graph the speed binning method was used, which calculates the CO_2-specific NO_x emissions over three large speed intervals (>=0-<50, >=50-<75 and >=75 km/h). In addition, in this graph the CO_2-specific emissions are presented for Euro V and Euro VI long-haulage vehicles over these speed intervals for reference and for comparison reasons.

The CO_2-specific NO_x emission of the four tested vehicles that operate in an urban environment varies considerably. In the speed range from 0-50 the CO_2-specific NO_x emission varies from 0.3 for city bus B and the garbage truck to about 3.0 for city bus A and the distribution truck. For both vehicles the CO_2-specific NO_x emission decreases at a higher speed range.

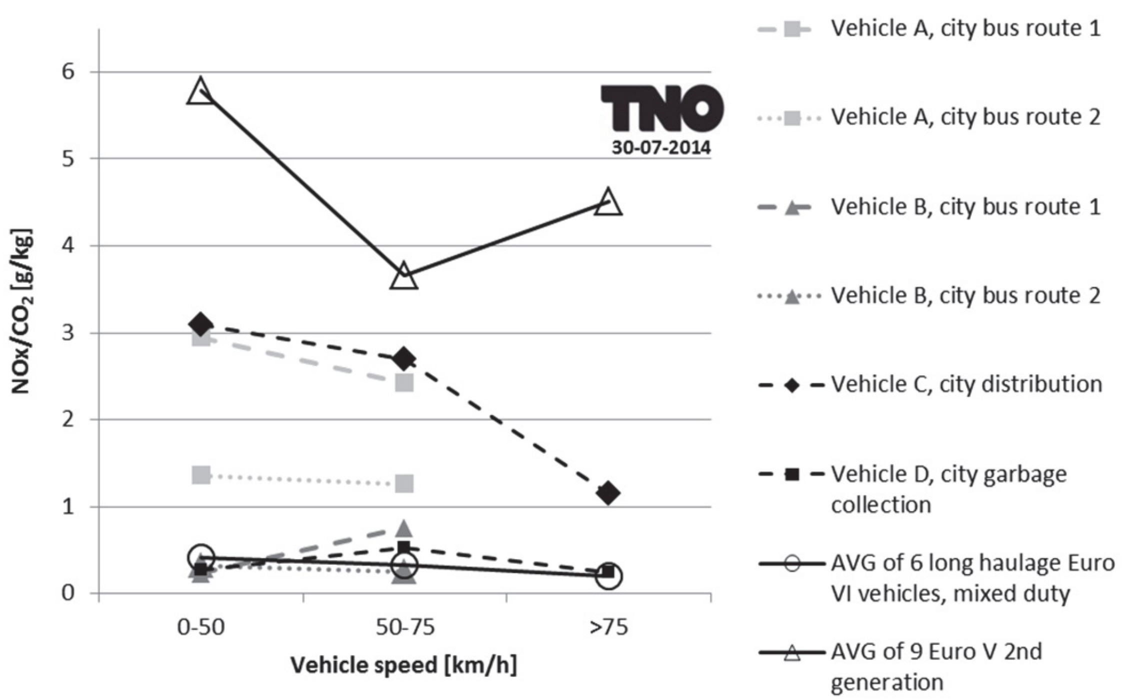
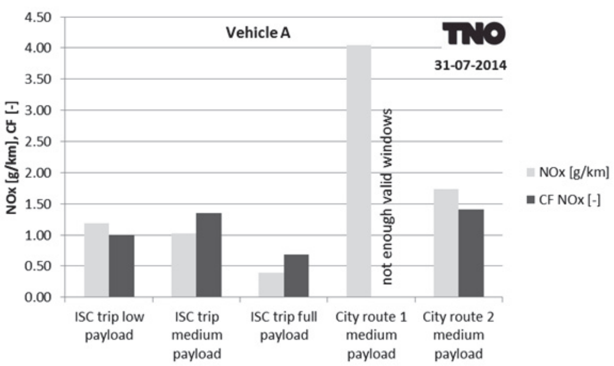


Figure 3: The CO_2-specific NO_x emission for the measured Euro VI vehicles that typically operate in an urban environment, for three speed intervals. In addition, the emissions are depicted for Euro V and Euro VI long haulage vehicles. The NO_x emissions of the four tested Euro VI vehicles for city application improve compared to Euro V, although under severe city operating conditions the emissions still scatter and are relatively high for two vehicles.

With two of the vehicles, i.e. both city buses, PEMS measurements have been performed and also trips according to the EU in-service conformity requirements with different payloads. The emissions have been analyzed with the formal pass-fail method using the EMROAD tool. Furthermore, the regular distance-specific emissions were calculated per trip. The results are depicted below.

Both vehicles have NO_x conformity factors below the required value of 1.5. This value of 1.5 equals an emission of 1.5 the Euro VI emission limit as determined according to the pass-fail method (for NO_x 0.46 g/kWh x 1.5 = 0.69 g/kWh). For Vehicle A and B however for some trips no conformity factors can be calculated. This is due to the fact that for those trips, which are in fact trips under representative city bus operation, data is excluded from the pass-fail evaluation. This is data from windows in which the engine load is very low. After exclusion of the data no valid windows remain for the pass-fail evaluation, hence, the pass-fail evaluation ends with no result.



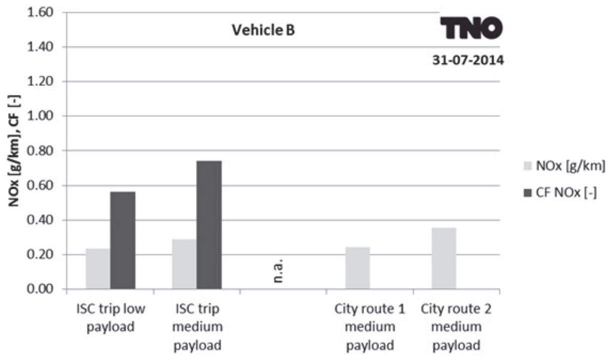


Figure 4 (left) The NO_x emissions in g/km and the NO_x conformity factors as calculated according the pass-fail method for in-service conformity of vehicle A.

Figure 5 (right) The NO_x emissions in g/km and the NO_x conformity factors as calculated according the pass-fail method for in-service conformity of vehicle B.

Conclusions

NO_x emissions of the tested Euro VI vehicles are considerably lower than those of vehicle of a generation earlier. The new and more stringent Euro VI legislation has led to significantly lower real-world emissions of the heavy-duty vehicles. On average, the NO_x emission of Euro VI trucks and buses has decreased sharply compared to Euro V trucks and buses. Manufacturers have made a large step with the reduction of pollutant emissions from the tailpipe.

Not all tested Euro VI vehicles that are used in an urban environment have a low tailpipe emission of NOx under all representative circumstances. Although Euro VI vehicles perform very well compared to vehicles of earlier generations, under urban operating conditions, they show strongly varying NO_x emissions. Vehicle B is very clean in busy urban driving conditions, and the garbage truck is very clean as well. The two other vehicles (A and C) still regularly show high NO_x emissions. For derivation of reliable emission factors and insight into real-world performance for these types of vehicles, more measurement data are needed. It is therefore recommended to focus the Dutch in-service measurement programme on smaller heavy-duty vehicles and applications which operate under more difficult, but still representative conditions, like city buses and distribution trucks.

The Euro VI legislation can be improved, mainly on emissions under urban driving conditions. The emissions of vehicles that typically operate in an urban environment are not explicitly controlled by the Euro VI emission legislation. For instance, for the in-service conformity test with PEMS, relevant data is excluded from the pass-fail evaluation. This data is from low-load, low-speed operation, which for some applications may be representative use of the vehicle.

References

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