Consistency Tests of Remote Emission Sensing for Vehicle Exhaust Emissions

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Introduction

During the last decades TNO has investigated vehicle emissions of a large number of light and heavy duty vehicles. The aim is to check whether vehicles meet the legal requirements, and more importantly to collect data and gain insight in the real world emission behaviour of vehicles. The results are used to derive emission models, emission factors for emission registration and to support policy makers in making type approval requirements more effective. Engine and vehicle emissions are measured on the engine test bed, chassis dynamometer and by using a portable emission measurement system (PEMS). This equipment provides detailed and accurate information of the emission behaviour of engines and vehicles under different conditions. The number of engine types and vehicles that can be measured is limited because of the relative high costs per vehicle test.

A very interesting additional measurement method to collect vehicle emission data is remote emission sensing (RES). TNO recently performed measurements with RES. The remote emission measurement system used by TNO (RSD 4600) is capable of measuring emission gas concentration ratios of passing vehicles of NO/CO_2, CO/CO_2 and HC/CO_2 optically. Although the emission rates for individual vehicles are only measured for one specific speed and acceleration combination, thousands of passing vehicles can be measured. Then the fleet-average vehicle emission behavior can be determined (cf. e.g. Ekström, e.a., 2004, with a comparison with COPERT III, and Sjödin, e.a., 2008). In this paper, we describe the experiments with RES and discuss what conclusions may be drawn from them about the consistency of RES. The leading dependency of the gas ratios is the legislative class, however, some systematic variation with acceleration and, in lesser extent, velocity can be found.

In this paper, the RES measurement results are validated by performing two consistency tests. The first is a comparison between TNO's VERSIT+ instantaneous, dynamical, emission model (Ligterink and De Lange, 2009) and PEMS measurement results. TNO has developed this VERSIT+ emission model over the past years. VERSIT+ is a piecewise linear model which predicts the instantaneous emission rate using the dynamic variables of instantaneous speed and acceleration. VERSIT+ gives a prediction of the emission rate for groups of cars that fall in the same emission legislation categories and fuel types.

The second is a comparison between RES measurements and the results from a simultaneous measurement with a portable emission measurement system (PEMS) (Semtech DS). (See also Vescio, 2004). For the first comparison, it was necessary to cast the RES signal, which is a concentration ratio of the pollutant with respect to CO_2, into an absolute emission number, for which we used the VERSIT+ model itself.

The remote emission sensing technique

A RES system is positioned next to a road (see Figure 1). To measure the emissions, it

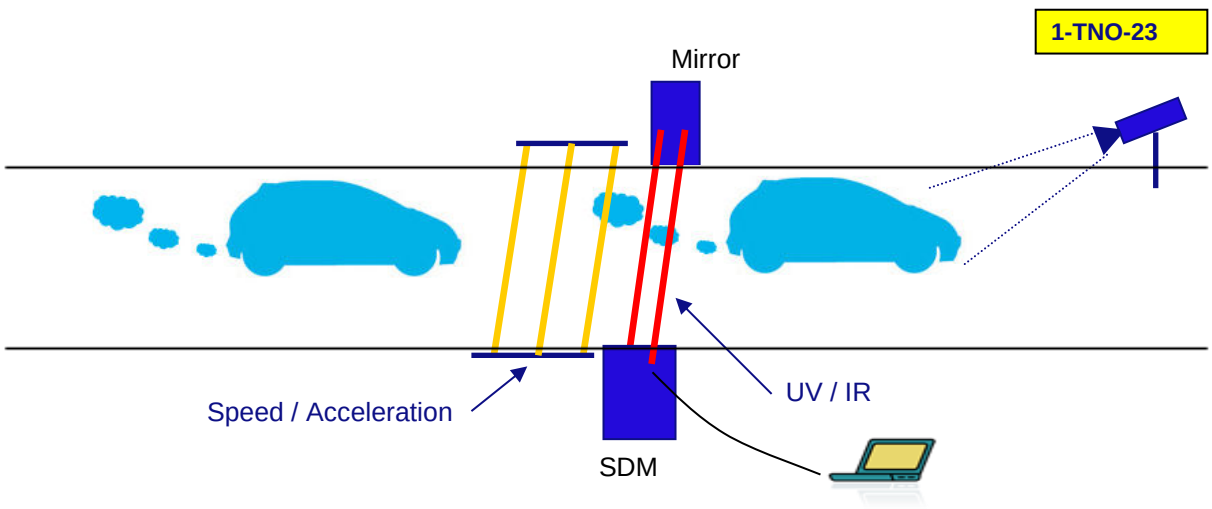

Figure 1: Outline of the measurement set-up.

makes use of an IR beam that passes twice through the exhaust plume. On the other side of the road the beam is reflected in a mirror. The reflected beam is detected and the IR absorption by the plume is determined. Thus a measure for the chemical composition of the plume is obtained.

When the vehicle passes the RES system, next to the exhaust plume, simultaneously the dynamic variables speed and acceleration are measured optically. Also the licence plate is photographed. Using information from the vehicle registrar for the vehicle with this licence plate, the emission legislation category (fuel type and EURO category) of each vehicle can be determined. Thus the applicable VERSIT+ model can be selected that is evaluated to find the absolute CO_2 emission rate for the conversion of a the RES relative signal into an absolute number, as discussed below. In summary, a RES measurement event results in a quantification of the chemical composition of the plume, the dynamical variables of the car and a technical characterization of the vehicle.
The detailed methodology for emission measurement and data processing is as follows. By measuring the absorption with the detection module, the concentration ratios of pollutants (CO, NO, HC) and CO_2 are determined. In fact, the absorption is measured twice, just before and just after the passage of the car. The actual signal used is (CO example):

$$(CO_{rear} - CO_{front})/(CO_{2\,rear} - CO_{2\,front}).$$

The rationale behind this calculation is that the ambient air always contains a certain amount of the pollutant gases due to the local traffic. This amount already present is enhanced by the exhaust gasses of the car under study. To determine the amount caused by the single car, one has to correct the amount measured at the rear of the car, for the amount already present. The latter is estimated by the amount in front of the car. So, the amount of gas is estimated by (gas_{rear} – gas_{front}). The ratios are used to evaluate the vehicle emission performance: it is not known to what extent the exhaust plume has been diluted, so only a ratio of emissions is a relevant quantity. To turn emission ratios of pollutants with respect to the CO_2 emission into absolute numbers, as alluded to before, we use the VERSIT+ predictions for CO_2 for the vehicle category the car belongs to and evaluate it for the speed and acceleration measured. Thus an absolute CO_2 figure can then be determined using VERSIT+ and if this is multiplied with the concentration ratio (pollutant/CO_2) obtained from the RES measurement, an estimate of the absolute emission rate of the pollutant is obtained for every separate vehicle passing the RES system. This is an approximation, since we do not multiply by the actual emission of the vehicle, but by the mean emission of the legislation category of the car.

Measurement session in an urban environment

A measurement session with RES has been performed in a large city in the Netherlands. The measurements were performed at a road with a single lane beyond a junction. The traffic on this specific location was travelling at almost constant speeds between 30 and 50 km/h. This may have caused that the RES signal was not very high. Another explanation for this might be that drivers released the accelerator when seeing the measurement set-up, resulting in lower engine power and lower exhaust gas emission. This reduced the number of valid registrations. In the measurement session, about 1650 valid observations for petrol cars and 300 valid observations for diesel cars were obtained. As described above, we have cast the concentration ratios as measured by the RES system into an absolute emission rate. By dividing this emission rate by the velocity, we obtain the emission factor (total mass of pollutant emitted per distance travelled). This is an emission factor without a cold start: we do not know what distance the cars have travelled before passing the junction, so it is unknown over what distance the single cold start should be distributed. We assume that also cars that started outside the city are present in the city population, therefore we assume there to be no cold start contribution. This choice will be maintained throughout the paper.

We averaged the absolute emission factors thus obtained per legislative class. These averages were then compared to emission factors as derived from VERSIT (again without a cold start). See Figure 2.

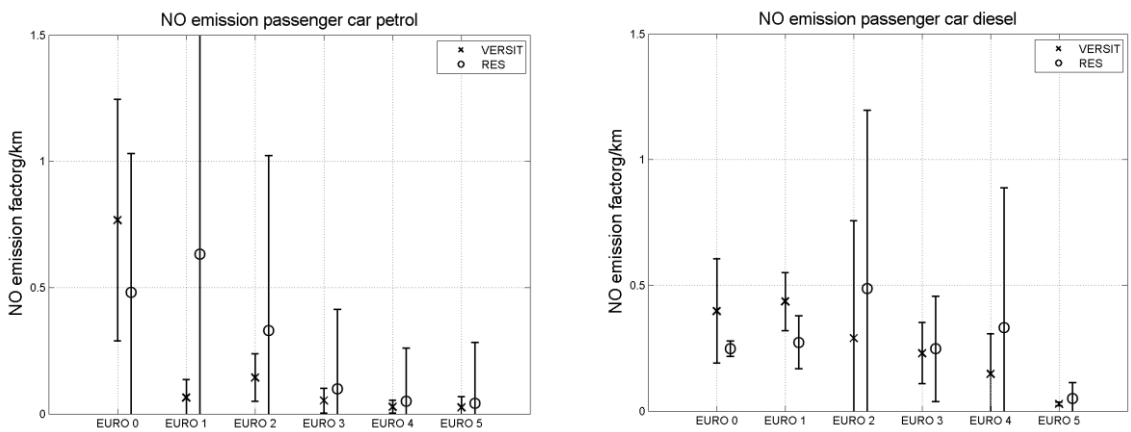

Figure 2: NO emission factors of petrol (left) and diesel (right) vehicles as measured with RES and as predicted by VERSIT+ for successive EURO classes for the dynamics beyond a crossing in an urban environment. This reproduction of the trend behaviour of VERSIT by the processed RES data illustrate its potential for local fleet emission characterization.

In this figure we see that, within a EURO class, there is a spread –indicated by the error bars- due to several causes. For the RES measurements, one cause is that different dynamics gives a different emission rate and in addition there is the effect that various types of cars have –even at the same dynamics- various emission behaviour. For the VERSIT+ predictions, only the varying dynamics plays a role and there is no spread due to several types of cars being present (in VERSIT+, the average car in a category is described), so that the spread is smaller for VERSIT+ than for RES. By comparing the RES experimental data, which depends on the dynamics of the vehicle, to the VERSIT+ prediction, which takes the dynamics of the vehicle into account, the traffic behaviour at the measurement location is taken into consideration and compensated for in the comparison between RES and VERSIT+.

From Figure 2, we conclude that within the error bars the mean emission factors of VERSIT+ and RES are equal. We also see that, both for diesel and petrol, the emission factors follow the same decreasing trend. The categories EURO-0 and EURO-1 seem to be a deviation off this trend, but these averages are based on a very small number of observations. Hence, if there are a few vehicles with very deviating emission behaviour, there is a large difference between VERSIT+ and RES. Therefore, these classes should have limited weight in the comparison.

Comparison with PEMS

In another measurement session, a single heavy duty vehicle that was equipped with a PEMS passed the RES system many times at various speeds and accelerations. By a PEMS, the exhaust gas is probed in a time resolved way. That means that for a trip, for all consecutive time steps, a value for the emission rate is recorded. The measurements with the RES system are time recorded so that it is known when the vehicles passed the RES system. After synchronisation, it is possible to relate passages past the RES system with PEMS measurements. Consequently one can compare the ratio of instantaneous emission rates from the PEMS signal with the concentration ratio as measured by RES. In Figure 3, the mass ratios of NO and CO_2 at the various passages are plotted (the RES concentration ratios are translated into mass ratios).

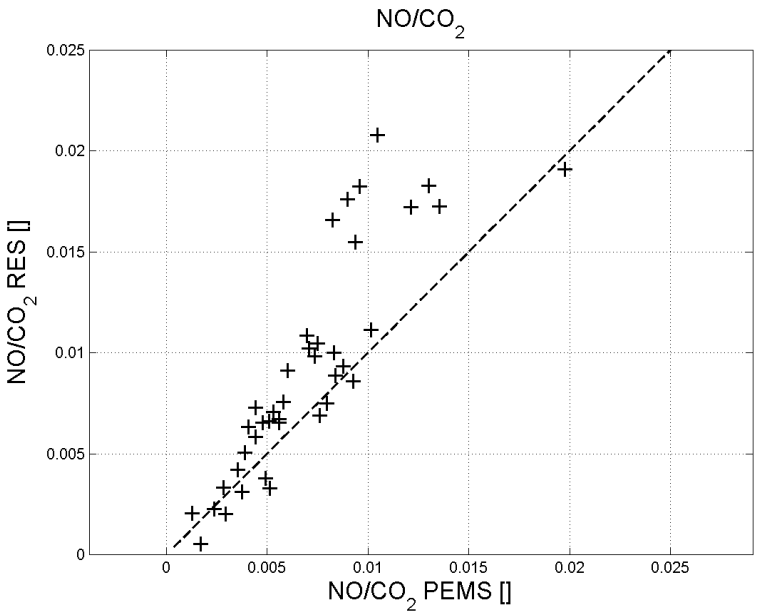

Figure 3: Mass ratio of NO and CO_2 as determined with the RES system versus with PEMS.

We see that the NO/CO_2 ratio for RES is to a large extent equal to the PEMS ratio. From this observation, we conclude that RES is a viable way of assessing emission ratios. Some deviation between the measurements can be seen at high NO/CO_2 ratios. This could be attributed to the low load where the absolute emissions are small and strongly diluted, or the result of high dynamics, which also lead to higher ratios. The deviation between RES and PEMS may then be caused by effects in the PEMS at very low or very high NO concentrations. This is a topic for further research.

Conclusions

From the results obtained in our comparison between RES and VERSIT+, we conclude that for a fleet, RES is a powerful tool to obtain locally global, fleet average, emission properties. The method of comparing with VERSIT+, which is dependent on the dynamics, works, as by that procedure, the varying driving behaviour is accounted for. From the comparison between RES and PEMS, we conclude that the RES measurement is reliable. Further research, with more vehicle passages events, is necessary to build a database of measurements that enables the definition of the fleet composition from the perspective of real world emissions. A set of measurement locations with more vehicle dynamics around the average driving behaviour relevant at that location is desirable to improve the sampling in that database. A measurement location with a higher engine load (for example on a road with slope) is profitable to give a better signal, and sample conditions contributing significantly to the total emission. Both experiments, with the corresponding analysis and comparison, validate RES as a means to determine vehicle emission properties.

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