MAY 2022 | POSITION PAPER

MONITORING OF NO_X EMISSIONS AS PART OF THE PTI

CITA aisbl | Rue du Commerce 123, B-1000 BRUSSELS (Belgium)
TEL. + 32 (0)2 469 06 70 | secretariat@citainsp.org | www.citainsp.org

Consultative Status Category II to the Economic and Social Council of the United Nations

CONTENT:

1 MOTIVATION

After particulate matter, nitrogen oxides (NOx) are the second largest cause of premature death out of the various pollutants. Within the EU (EU 27), NOx emissions caused 40,400 premature deaths in 2019 and 47,700 in all 41 European countries. Road transport was responsible for 39% of these NOx emissions, making it the largest contributor of this pollutant from all sources. This results in a calculated 18,600 premature deaths per year caused by NOx emissions from road transport in Europe /1/, /2/.

In 2021, the World Health Organization (WHO) published new air quality guidelines to protect human health. Here again, NOx is identified as one of 4 key air pollutants that are particularly relevant to human health.

Although air quality has improved in most European cities, urban areas - where two-thirds of Europe's population lives - are particularly affected.

Vehicles should not exceed their emissions level throughout the vehicle's lifetime. The emission level is specified by the respective requirements from the type approval.

The additional RDE tests (Real Driving Emissions) have significantly tightened the requirements of the type approval. For vehicles in real operation and in the hands of vehicle drivers, the regular PTI of each individual vehicle is an essential element in addition to other measures such as CoP and ISC in order to achieve the goal of constant emission levels of the vehicles without deterioration.

The monitoring and control of NOx emissions from traffic is currently not part of the Periodic Technical Inspection (PTI). However, the above figures clearly show that this is imperative and can be of great benefit to the environment and health. In the EU, the minimum requirements of the PTI - and thus also of the regular emission test - are regulated in Directive 2014/45/EU.

Each year, more than 100 million vehicles are subject to PTI. This offers a unique opportunity to verify the correct functioning of the vehicles engines as well as emission controlling and reduction systems such as the catalysators.

Directive 2014/45/EU recital (9) states: “During the last two decades, requirements in respect of vehicle emissions for type-approval have been continuously strengthened.

However, air quality has not improved as much as predicted with the tightening of emission standards for vehicles, especially in respect of nitrogen oxides (NOx) and fine particulate matter.

Possibilities for improving test cycles to match on-road conditions should be closely examined in order to develop future solutions, including the establishment of test methods for the measurement of NOx levels and of limit values for NOx emissions." /3/

Due to the gradual tightening of the requirements and limit values, modern vehicles emit significantly fewer pollutants than vehicles of earlier Euro levels.

However, when malfunctions occur or when the vehicles are subject to tampering, they will emit as much, or even more than older vehicles. This is confirmed by /4/, according to which a large proportion of the total emissions fall to a minority of vehicles with defective emission control systems. 5% of the vehicle fleet is responsible for 25% of all pollutant emissions and 20% of the vehicles are responsible for 60% of pollutants.

It is therefore particularly relevant and important for the environment to detect these high emitters as part of the PTI.

This report identifies and evaluates fundamentally feasible methods and procedures for the monitoring of NOx emissions under the special and given framework conditions of the PTI. A recommendation is made on how the emission behavior can be efficiently evaluated for both current vehicles and future vehicle technologies.

2 LEGAL FRAMEWORK IN THE EU

The reduction of road transport emissions is a declared goal of the EU Commission. With the introduction of Directive 91/441/EC in 1991, the limit value level "Euro 1" was defined and the "New European Driving Cycle" (NEDC) was laid down as the basis for emissions testing for light passenger cars and commercial vehicles in Europe. Since the introduction of Euro 1, the limits for exhaust emissions in Europe have been continuously tightened. In 2007, Regulation (EC) No 715/2007 defined the Euro 5 limits and the current Euro 6 limits. Figure 1 shows the European emission type approval limits for light passenger cars and commercial vehicles in Europe in schematic form. /5/, /6/, /7/, /8/, /9/

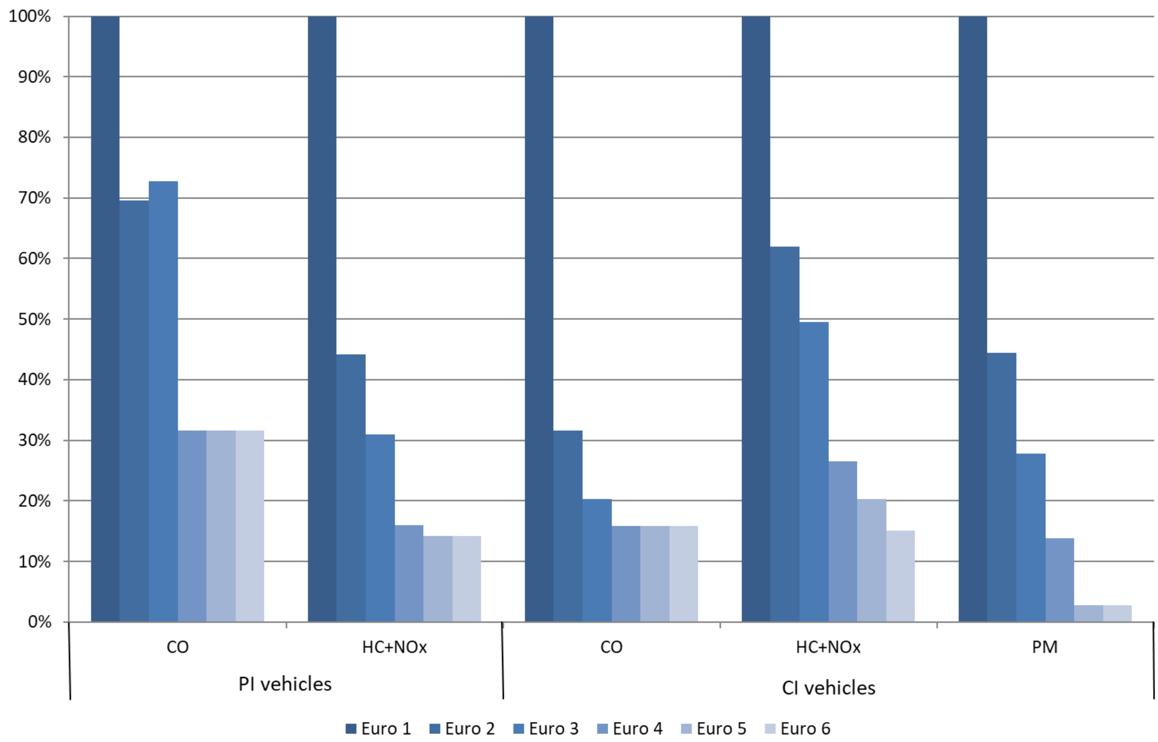


Figure 1: European emission type approval limits for light passenger cars and commercial vehicles from Euro 1 to Euro 6, schematic diagram /5/, /6/, /7/, /8/, /9/

Whilst a significant reduction in emissions of most pollutants has been achieved by these measures, the expected reduction in nitrogen oxide emissions has not been observed under real traffic conditions for passenger cars and light duty trucks. Therefore, the measurement of Real Driving Emissions in European was introduced starting with Regulation (EU) 2016/427. In addition to the laboratory measurements, exhaust emissions are measured under real traffic conditions. Due to the European requirements for air pollution, the focus is on nitrogen oxide emissions and particle number emissions.

In Commission Regulation (EU) 2017/1151, the Worldwide harmonized Light vehicles Test Procedure (WLTP) was introduced to replace the "New European driving Cycle". /10/, /11/

Also, for heavy-duty vehicles, the limits for exhaust emissions have been significantly tightened during the past years. Besides measurements on the engine test bench, exhaust emissions are also measured in real traffic on heavy-duty vehicles.

Now in Brussels the Euro 7 and EURO VII regulations are discussed for emission type approval. Major topics of the discussion are tightening the type-approval limits, define limits for up to now non-limited emission components, emissions in real traffic, on board monitoring and lifetime compliance.

In the current European emission type approval legislation, carbon monoxide (CO), hydrocarbons (THC, NMHC), nitric oxides (NOx), particle mass (PM) and particle number (PN) are limited for light passenger cars, light commercial vehicles, and heavy-duty vehicles. The periodic roadworthiness tests for motor vehicles are defined in Directive 2014/45/EU. Up to now, limits are set for carbon monoxide and opacity only.

Several European countries are about to start measuring particle number within periodic roadworthiness tests for motor vehicles. However, up to now there is no measurement of NOx defined during periodic inspection.

Therefore, CITA investigated several methods to evaluate NOx emissions during periodic roadworthiness tests.

3 RESEARCH OF SOLUTIONS, METHODS AND APPROACHES

A general orientation is the Type Approval (TA) procedure, using roller dynos, Real Driving Emission (RDE) methods and equipment with high accuracy and resolution for measurement of the regulated emission components and the CO_2 -emissions.

Each new emission measuring procedure for PTI must be compared with the TA procedure with respect to its potential to find failures and not to allow exceeding limits for in-use vehicles.

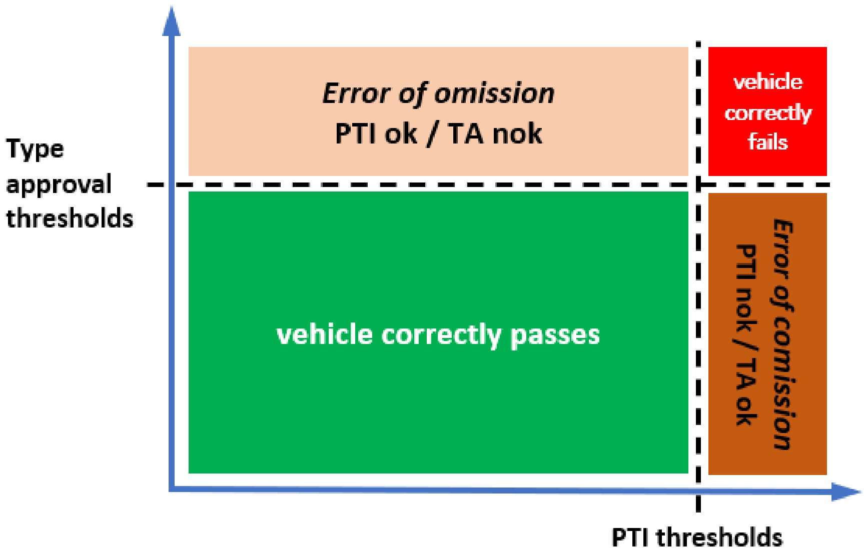


Figure 2: evaluation of pass/fail at PTI and Type Approval – Limits/methods

Error of omission describes the situation in which a gross polluter is not detected by the PTI measurement. From an environmental point of view, this should be avoided, as the vehicle continues to drive on the road. Error of commission describes the situation that a vehicle has failed the PTI but meets the TA requirements; this must be avoided for legal reasons, as the vehicle would be subjected to an unjustified repair. If both threshold values are exceeded, the vehicle is correctly identified as outside acceptable emission limits. If neither are exceeded, the vehicle passes the test.

To have the same detection efficiency on gross polluters, it is proposed to compare different methods with dedicated thresholds by both measurements (Type Approval vs. PTI Test).

3.1 OVERVIEW OF EXISTING SOLUTIONS, METHODS AND APPROACHES

The purpose of the periodical technical inspections about exhaust emissions is to detect defective, excessive wear, improper repairs and possible manipulations on individual vehicles, which lead to the exhaust emissions increasing disproportionately compared to a corresponding vehicle without these negative conditions. Since it is an inspection of the entire vehicle fleet (100%), which must be carried out regularly and is carried out at different locations under different environmental conditions, this test specifies certain framework conditions. In addition to neutrality and independence, the most important requirement is efficiency (effectiveness in relation to the effort). Furthermore, it has to be robust and reproducible.

These aspects (and others) must be considered when developing a suitable method for PTI. In an internal combustion engine, NOx emissions (NO + NO2) occur at very high temperatures and when the two reactants, nitrogen and oxygen (air), are present. High temperatures are generated in the internal combustion engine at high loads. Due to the temperature dependence of NOx, the maximum concentrations are measured at correspondingly high engine loads. The aftertreatment systems must be designed for these circumstances and a PTI process monitoring such systems should take this into account.

In terms of methods, a distinction is made between static methods (vehicle with stationary wheels) and more dynamic methods (rotating wheels). The dynamic methods have the potential to better map the real driving conditions of a vehicle. However, the practical implementation is to be assessed as difficult under the stated requirements for the PTI.

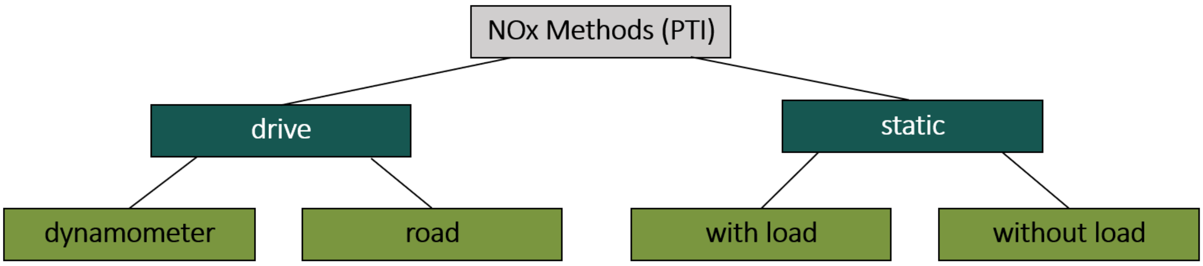


Figure 3: Structuring of NOx methods

The use of OBD, diagnostic functions and OBM (On-Board Measuring/Monitoring) is of great relevance. On-board diagnoses and, in particular, the use of existing on-board sensors could make monitoring of NOx much easier and supportive for newer vehicles and especially in the future. An inspection using this technique would be an efficient inspection.

However, it is necessary that the access and availability of the information is given under all states and conditions and ensure the accuracy of the measurements made by the vehicle's own NOx sensors by verifying them during the PTI with exhaust measurements.

3.2 METHODS STUDIED BY CITA MEMBERS

The methods examined in this report are described in Annex 1. Further references can be found under the Literature heading (Chap. 7). The methods are evaluated and rated in Chapter 4 below.

Further Investigations for the measurement of NOx emissions on a performance test bench were commissioned by the French Ministry of Transport and carried out by UTAC. The results of this study have not yet been published, so it is not possible to evaluate this possible method within the scope of this report.

A program concerning the evaluation of NOx emissions during PTI on behalf of the German Umweltbundesamt (UBA) is still in progress. This program focuses on dyno tests and on-road measurements in combination with the use of OBD information. Publication is foreseen in Q2/2023.

GOCA Vlaanderen is in Belgium on behalf of the Flemish Environment Agency investigating a NOx PTI test who can easily and quickly been implemented in the Flemish centralized PTI centres. They are investigating among others the static load test as described here as (1) and a “corrected NOX/CO2 ratio” idle test. Publication is foreseen in Q2/2022.

4 EVALUATION OF THE METHODS

The methods proposed and studied by or with the assistance of CITA members are described in Chapter 3.2 / Annex 1. These methods are evaluated in the matrix below, primarily from a practical point of view.

A prioritization of the criteria was deliberately not done, as this partly depends on the point of view and, overall, each criterion was identified as relevant and important. Rather, care was taken to ensure that the criteria were balanced and that no one area (e.g., economic area, technical area) was given a higher weighting.

The rating is * = not good / ** = good / *** = very good

	Criteria	Static load test (1)	QNOx ratio (2)	Speed pumping (3)	short drive (4)	ASM20 ASM2050 (5)	Accel. drive (6)	OBD/Diagnostic Functions/ OBM (7)	Comments (Annex 1)
1.	Time for inspection (complete)	***	***	***	*	**	*	***	
2.	Required area for inspection	***	***	***	*	**	*	***	
3.	Cost of equipment (complete)	***	***	**	**	*	**	***	
4.	Feasibility	***	***	***	*	*	*	***	
5.	Usability and requirem. for staff/inspectors	***	***	*	**	*	**	***	
6.	Reproducibility	***	***	**	**	***	**	***	
7.	Dependence on weather/environ. conditions	***	***	***	*	***	*	***	
8.	Recognition rate (fail / pass)	**	***	**	***	***	***	***	
9.	Independence method from vehicle	**	*	*	***	**	***	*	
10.	Applicable to all vehicles	**	***	***	***	*	***	***	
			No.10: only for future vehicles					No.10: only for future vehicles	
	Total:	**27**	**28**	**23**	**19**	**19**	**19**	**28**	

Table 1: Evaluation Matrix for NOx Methods

The evaluation gives a relatively clear result for the procedure according to (1) (static, load), (2) (QNOx) and the use of OBM (7). For the QNOx and OBM methods, there are requirements for the vehicles and thus for the specifications from the type approval test. These must be defined and included in the relevant regulations. Assuming this, these two methods can only be used for future vehicles.

The method according to (1) (static, load) could be implemented in the short term, since it does not require any special provisions, no special innovations in measurement technology and only very small investments. Normally, an update of the existing exhaust gas analyzers (Directive 2014/32/EU- Annex XII MI-010) with a chemical NO/NOx sensor is necessary. Calibration requirements would be relatively easy to implement. The method can also be used on current vehicles, for example from Euro 5 . It must be taken into account that this method has not yet been sufficiently investigated on HDV. It is only assumed that it can also be used and expediently applied to these vehicles. However, further investigations are needed for this category of vehicles.

A PTI method for checking NOx emissions, which can be used in the short term on current diesel internal combustion engines - and therefore has a major impact on the environment - but which is also sustainable (new vehicles, future vehicles), should ideally use the methods (1) and (2)/(7) combined.

5 SUMMARY AND RECOMMENDATIONS

Nitrogen oxides (NOx) are pollutants which are responsible for the premature death of many people. It is estimated that in Europe alone (in total) there are over 47,000 direct deaths each year. Road traffic has the largest share of all NOx sources /1/, /2/. It is therefore absolutely necessary and equally sensible to limit and control NOx emissions from on-road diesel.

CITA therefore strongly recommends monitoring NOx emissions during regular PTI.

It is known that only a small number of vehicles are responsible for a disproportionally high amount of pollutants /4/. Therefore, it is particularly important and effective to identify these high polluting vehicles and to repair them later. Since the PTI is independent and represents a 100% test of each individual vehicle registered on public roads, it is very suitable for detecting high emitters. This is a very important measure to control the respective emission level of vehicles during their entire life cycle and is therefore an important instrument for a sustainable environmental policy.

In internal combustion engines, NOx emissions are generated at high temperatures. The reduction systems are designed to effectively reduce NOx in these temperature ranges. Therefore, the most sensible way to test NOx-reducing systems is by applying an engine load. In order to realistically check the function of the entire EATS (Exhaust After Treatment System), the working conditions of the EATS (such as the temperature conditions) should be met during the PTI. This is a particular challenge for the PTI, as this is necessarily limited in terms of time and effort.

This report represents the current status of investigations. Some other studies on NOx PTI are ongoing. Seven potential methods are identified, presented, and evaluated that could be considered for checking NOx emissions and NOx after-treatment systems as part of a periodic technical exhaust inspection (PTI). The methods and procedures were developed or co-developed and studied by different CITA members.

The PTI Emission Check is an important part of the concepts to ensure that road vehicles comply with their respective emission levels throughout their entire lifetime and those emissions do not increase significantly. The uniqueness of the PTI is that every single vehicle is checked regularly. Ideally, by an independent effectiveness check of the systems.

From a theoretical point of view, a method on a dynamometer or real road driving might be the best method to identify vehicles with emission related problems. For PTI purposes practical issues, such as time to implement or investments are relevant and must be considered. At least the concept with the best cost/benefit ratio should be used. The fact that the complete fleet must be covered means that the inspections must be carried out in many different locations, in varying conditions, on a large number of vehicles with a wide range of technical conditions and with limited time available. The quality of the test results must be guaranteed under all these varying boundary conditions. This limits the possibilities of the PTI, and the best possible result should be achieved in relation to the effort. However, the requirement is that significant deterioration due to significant defects, improper repairs or manipulations are detected.

The potential methods described here were discussed and evaluated trying to take all these requirements into account.

The assessment and evaluation of the possibilities resulted in a relatively clear outcome, namely a feasible concept that covers current vehicles – starting with the Euro 5 standard - and is as universally applicable as possible according to vehicle types. Such a concept has the greatest positive impact on the environment - especially in inner cities, which are particularly stressed - in view of the presumably evolution of the vehicle fleet towards electromobility..

Nevertheless, the concept should be modern, and the effectiveness should be further improved for new and future vehicles. Therefore, CITA recommends using the possibilities of on-board diagnostics (OBD), related diagnostic functions already available, and even more on-board measurement/monitoring (OBM) for future vehicles.

The method (1), developed in Spain by ITEVELESA in cooperation with the University of Zaragoza, was evaluated and identified in the context of this report, as an effective concept for possible application on current diesel vehicles from Euro 5 upwards.

For future vehicles, this method can be combined with or replaced by the "QNOx" method (2) developed in Austria by ÖAMTC and the University of Graz.

The same equipment can be used for both methods. This applies to exhaust gas analysers as well as OBD devices.

Taking into account the best cost/benefit ratio, the combination of these two methods is identified by CITA as currently the most effective concept for regular inspection of NOx emissions.

The number of periodical inspections in the European Union can be estimated at over 125.000.000 per year /12/.

For an efficient PTI, access to the necessary vehicle information such as NOx on-board sensors, exhaust gas temperatures, vehicle load, air mass, reagent injection and other information on the OBD interface of the vehicles must be available under all conditions. In addition, the PTI functions that will be formulated in the specifications for type approval in the future could be very efficient and helpful, such as the QNOx factor proposed here. The identification and integrity of the exhaust-relevant software (parts), including their safety mechanisms, is extremely important to detect manipulations.

As part of the type approval test according to Regulation (EC) No 715/2007, the so-called Type II test should be replaced or supplemented by the respective PTI method according to Directive 2014/45/EU - Annex 1, No. 8.2. This also includes checking and evaluating the PTI limit value. This both verifies that the vehicle type passes the PTI (see Chapter 3: The vehicle in Figure 2 “green area” passes type approval and PTI correctly) and ensures that the PTI method can be applied to the respective vehicle type and that the necessary information is available.

From CITA's point of view, the combination of OBD/diagnostic functions/OBM data assessment, a validity check of the relevant software, a future introduction of QNOx (roughly analogous to OBFCM) and an exhaust measurement with certified and regularly calibrated instruments to validate the on-board sensors, is the most reliable and effective solution to detect the high emitters of the entire vehicle fleet on European roads.

6 PROPOSAL FOR A POSSIBLE INTEGRATION AND AMENDMENT OF REGULATION 2014/45/EU, ANNEX 1

8. NUISANCE					
8.2. Exhaust emissions					
8.2.1 Positive ignition engine emissions					
8.2.2 Compression ignition engine emissions					
8.2.2.1. Exhaust emission control equipment	Visual inspection	…			
8.2.2.2. Opacity	…	…			

Item	Method	Reasons for failure	Assessment of deficiencies		
			Minor	Major	Dangerous
8.2.2.3. Particle number	…	…			
8.2.2.4. Nitrogen oxides NOx	For vehicles from emission class Euro 5 or newer: NOx concentration at no load and with applied load at idling speed. Readout of information available on the vehicle interface (OBD and diagnostic functions) and further developments thereof, specified in accordance with the type approval regulations. Measurement procedure: STAGE 1 Engine speed: idling Load demand: none STAGE 2 Engine speed: idling Load demand: connected STAGE 3 Engine speed: 2500rpm Load demand: connected STAGE 4 Engine speed: idling Load demand: connected STAGE 5 Engine speed: idling Load demand: none Vehicle preconditioning: Engine shall be fully warm, what should be measured by OBD.	(a) Estimated maximum NOx concentration exceeds the value specified by the manufacturer. If this value is not applicable/available: The estimated maximum NOx concentration exceeds the value of 1500 ppm. (b) Vehicle interface readout indicating significant malfunction.		X	

7 LITERATURE

/1/ https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

/2/ https://www.eea.europa.eu/publications/air-quality-in-europe-2021/health-impacts-of-air-pollution

/3/ DIRECTIVE 2014/45/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 3 April 2014 on periodic roadworthiness tests for motor vehicles and their trailers and repealing Directive 2009/40/EC

/4/ Impact assessment of the European roadworthiness package SWD (2012) 206 final

/5/ Council Directive 91/441/EEC of 26 June 1991 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles

/6/ Directive 94/12/EC of the European Parliament and the Council of 23 March 1994 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC

/7/ Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC

/8/ REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20th June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information

/9/ COMMISSION REGULATION (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information

/10/ COMMISSION REGULATION (EU) 2016/427 of 10 March 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

/11/ COMMISSION REGULATION (EU) 2017/1151 of 1 June 2017 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Commission Regulation (EC) No 692/2008

/12/ CITA's own analyses

/13/ Eugenio Fernández Cáceres 5-6-2021: GRUPO ITEVELESA - IDLING NOx MEASUREMENT with internal load for PTI (pdf document)

/14/ Fernández, Eugenio, Alicia Valero, Juan J. Alba, and Abel Ortego. 2021. "A New Approach for Static NOx Measurement in PTI" Sustainability 13, no. 23: 13424. https://www.mdpi.com/2071-1050/13/23/13424

/15/ ÖAMTC_T-2021-01 or: FVT-015/21/SL EM 20/11/6790.

/16/ CITA Webinar on February 23, 2021. New Approaches to Vehicle Emissions Inspections. https://citainsp.org/2021/02/25/new-approaches-to-vehicle-emissions-inspections/

/17/ CITA Webinar on June 30, 2021. New Approaches to Vehicle Emissions Inspections – Part 2: Estimation of Pass/Fail Limits. https://citainsp.org/2021/07/02/new-approaches-to-vehicle-emissions-inspections-part-2/

/18/ Full 1-hz emissions profile of all the vehicles included in the CITA Webinar on June 30, 2021. Available as PDF file from 3DATX by email. Soon to be uploaded to 3DATX website.

/19/ REGULATION (EU) 2018/858 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC

/20/ Regulation No 49 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines and positive ignition engines for use in vehicles

/21/ Regulation No 83 of the Economic Commission for Europe of the United Nations (UNECE) — Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements [2015/1038]

/22/ EN ISO 18541 series; Road vehicles - Standardized access to automotive repair and maintenance information (RMI)

/23/ COMMISSION IMPLEMENTING REGULATION (EU) 2019/621 of 17 April 2019 on the technical information necessary for roadworthiness testing of the items to be tested, on the use of the recommended test methods, and establishing detailed rules concerning the data format and the procedures for accessing the relevant technical information

/24/ Application of OBD equipment for inspection of heavy trucks; Teknologisk Institut and Danish Road Traffic Authority; https://www.fstyr.dk/en/-/media/FSTYR-lister/Publikationer/Application-of-OBD-final.pdf

/25/ CITA RAG E Meeting on November 17. 2021; Presentation of Danish Road Traffic Authority; https://citainsp.org/wp-content/uploads/2021/11/5-CITA-17-11-2021-for-upload.pdf

/26/ CITA paper "FUTURE EU LEGAL FRAMEWORK FOR ACCESS TO IN-VEHICLE DATA" of January 2022

8) DESCRIPTION OF THE SEVEN INVESTIGATED METHODS

A) STATIC IDLING LOAD TEST (ITEVELESA / UNIVERSITY OF ZARAGOZA)

PROCEDURE

The method of Static Idling with internal load NOx measurement is based on the analysis of the variation of the NOx concentration at the vehicle exhaust pipe and its relation to the variation of the engine load demand at idling. Variation of the engine load demand is produced with vehicle equipment. Both parameters, if the other variables are fixed, are related by a linear function that can be used to define the maximum value of NOx emissions at idling. Further descriptions of the method can be found, among others, in /13/. Detailed information on the scientific development of the method can be found in /14/.

The measurement procedure is carried out in four steps:

1.) **Preparation**
As a first step, it is necessary to prepare the vehicle. This is the same opacity test preparation, including the verification of the vehicle conditions and the preconditioning (temperature) of the engine.

2.) **Measurement**
The measurement of NOx concentration at exhaust pipe while the engine is idling, according to the conditions indicated in Table 1.

	Stage 1: Unloaded	Stage 2: Loaded	Stage 3: Loaded & Accelerated	Stage 4: Loaded	Stage 5: Unloaded
Engine speed	Idling	Idling	2500±500 rpm	Idling	Idling
Vehicle equipment	Disconnected	Connected	Connected	Connected	Disconnected
Engine load value	<25%*	>25%*	Irrelevant	>25%*	<25%*

*Reference values, depending on the vehicle.

Table 1. Vehicle conditions for measurement.

The vehicle equipment to be connected in stage 2 is, in this order (in reverse order in stage 5):
- Air conditioning system

- Lighting and signaling system
- Rear window heating system and windshield demister system

3.) Aggregation

Data from stages 1 and 5 are joined into the "Unloaded State", and data from stages 2 and 4 are joined into the "Loaded State".

In this way, variation of NOx concentration and "% engine load" of the whole test is analyzed.

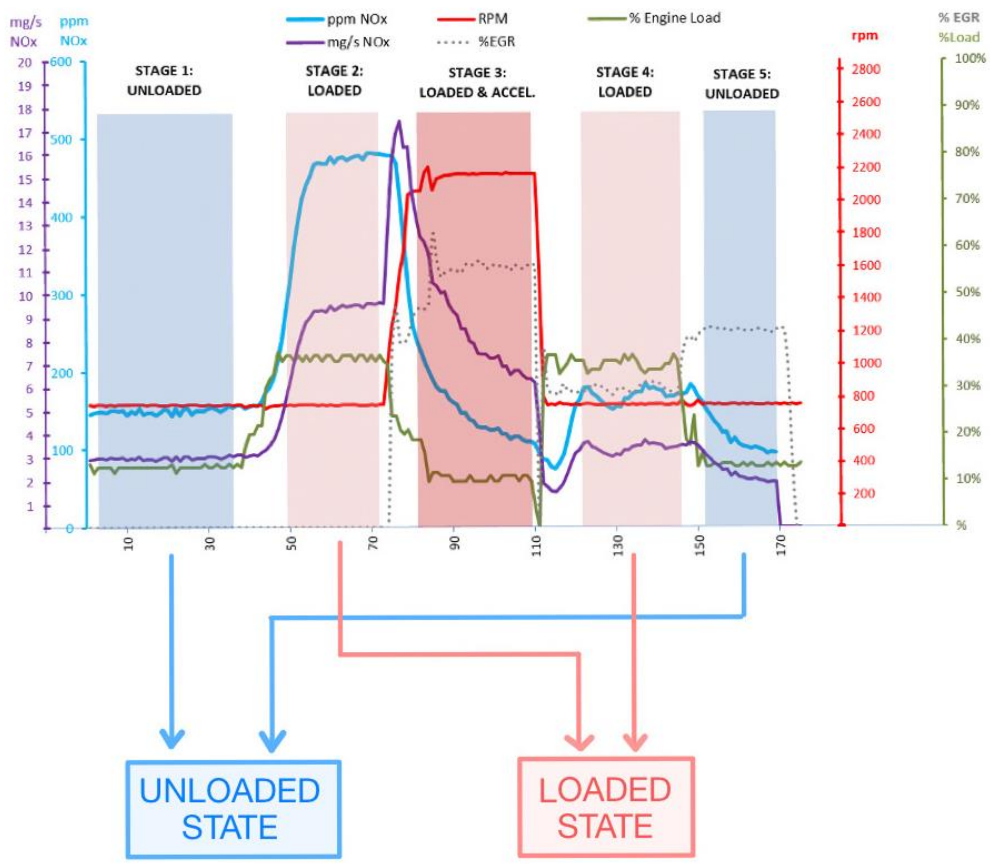


Figure 4. Data aggregation from the measurement process.

4.) Extrapolation

From the aggregated data of the previous step, two linear functions can be built for the NOx concentration (ppm NOx) related to "% engine load", and for the NOx mass emission flow (mg/s NOx) related to "% engine load".

From this extrapolation, the final result can be provided with the estimated maximum value of emissions at idling condition (TMV, Theoretical Maximum Value) in concentration (ppm) and mass flow (mg/s) of NOx.

	NOx (mg/s)	NOx (ppm)	"% Engine Load"
Avg. Idle Unloaded	2.72	136	13
Avg. Idle Loaded	6.10	306	36
Maximum value Read	9.59	481	37
TMV	**21.84**	**1096**	**100**

Table 2. Results from Static NOx measurement

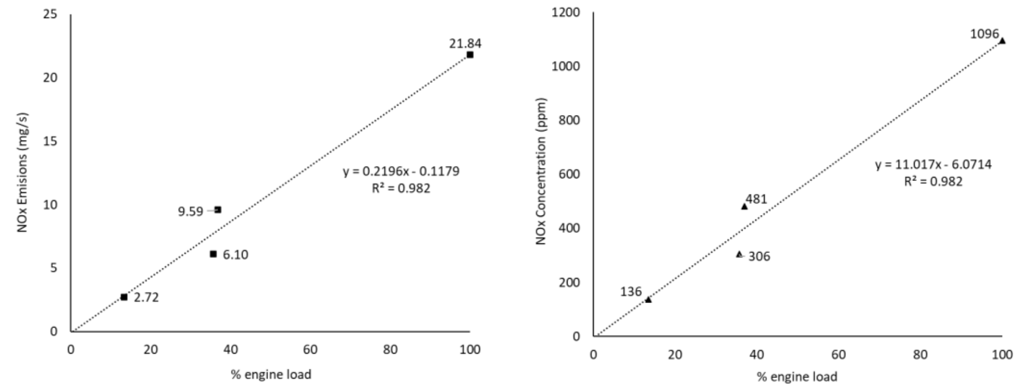


Figure 5. Linear function for NOx mass flow (left) and NOx concentration (right)

Limits for inspection

It is estimated that most pollutant emissions come from a proportionately small number of vehicles, which are known as "high emitters" or "gross polluters". Concerning NOx emissions, according to /4/, if 5% of the most polluting vehicles were identified, it would reduce approximately 25% of the polluting emissions. Therefore, it becomes key to develop a system that allows detection of this 5% of vehicles that account for 25% of total emissions.

From the data of the measurement campaign developed with this measurement method on more than 1850 vehicles, it can be concluded that fleet NOx emissions seem to follow a Normal Distribution. This can be used to define the threshold rejection at 1σ or 2σ, depending on how strict it is necessary to set the rejection level.

The proposal, if the objective is to detect and reject approximately 5% of the vehicles with the highest NOx emissions, a 2σ rejection threshold may be most appropriate. That means the NOx concentration limit will be set at 1500 ppm for the TMV. If the limit is established by flow mass emission, it would be set for a value of 29 mg/s of NOx for the TMV.

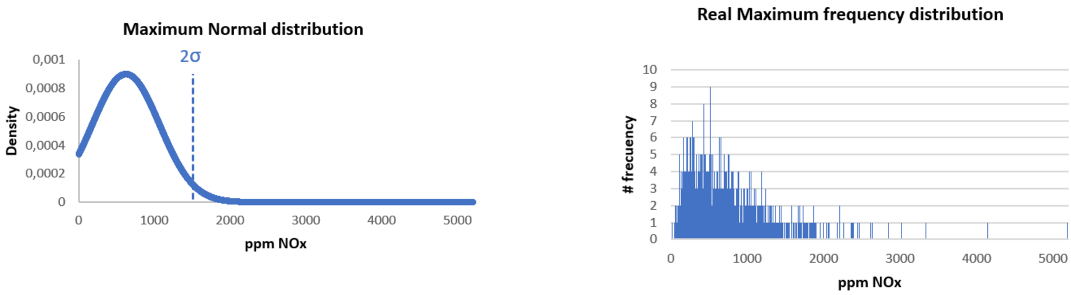


Figure 6: Normal distribution of NOx emissions from sample size in measurement campaign in Spain.

Necessary test equipment

The equipment necessary to carry out the test is a Gas Analyzer with a (electrochemical) NOx sensor (or NO and NO2 sensors) and an eOBD reader capable of synchronized recording of data with the Gas Analyzer.

Advantages and disadvantages

The main advantages of this method are:

(1) Feasibility: fast and easy to incorporate into PTI

(2) Accuracy: measurement at natural engine idle speed guarantees the stability of engine functioning and provides a stable and accurate measurement of NOx concentration.

(3) Repeatability: conditions for the test are easy to reproduce (idle rotation rate, and OBD reading of "% engine load"). For the intended purpose good repeatability.

(4) Safety: reduced number of manipulations on the vehicle implies a higher probability of error-free tests, a lower probability of mechanical failure, a reduced probability of safety incidents during the inspection, and less severe consequences in case of an accident.

(5) Requirements: it does not need additional equipment such as a Chassis Dynamometer, nor expert staff, so it is inexpensive.

(6) Maintenance: the equipment's maintenance cost, both mechanical and metrological, is lower than other systems.

(7) Type of Vehicles: it can be applied in the same way to any kind of passenger car or light-duty vehicle with the same equipment (e.g., 4 × 4 vehicles,

automatic gearbox vehicles, non-disconnectable traction control vehicles, hybrid vehicles, etc.).

(8) Representativity: It closely simulates one of the worst situations according to the NOx emissions in urban areas: standing at a red traffic light or in a traffic jam. The time a vehicle is idling when it is in real on-road conditions for urban circulation is significant. In congested urban situations with a high level of stopping time, this time can be 40%-50% of the traffic time and even up to 60%.

Finally, it allows comparing NOx emissions from diesel vehicles with different characteristics from Euro 4 to Euro 6 in a fast, reliable and easy way.

Presentation of some results/measurements without/with defects

The method allows detecting the difference between NOx emissions with or without defects on vehicles if the emissions in both situations are compared, in the same way as any other method. In Figure 5, it can be appreciated the differences in the results of the Static idling load test on the same vehicle (Volvo V40) with the EGR connected (left) and the EGR disconnected. The engine load levels in % are the same, but the NOx concentration shows great differences between both situations, due to the inactivity of the EGR system. This vehicle showed the same differences in on-road measurements.

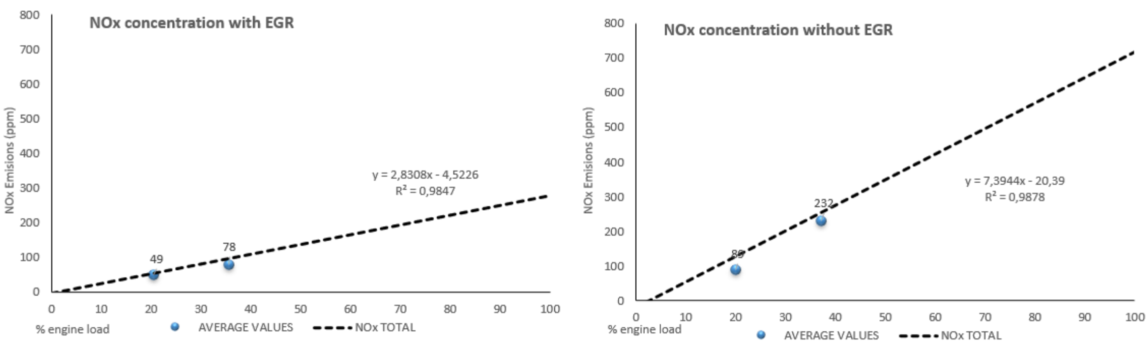


Figure 7. NOx concentration with (left) and without (right) EGR in the same vehicle.

Duration of the measurement including preparations

The preparation time corresponds to the preparation time for the opacity test, so it can be defined as zero (additional work). The measurement time is 5 steps of 20 sec. each, which means 100 sec. Including data entry, the total time required for the test is between 2 and 2.5 minutes (excluding preparation time).

Cost estimate of investments/equipment (in €)

The estimated extra cost for an equipment with NOx measurement capacity is 500-1000€ compared to an existing gas analyzer, depending on manufacturers.

B) Q_{NOX} RATIO (ÖAMTC / FVT GRAZ)

The following description of the Q_{NOx} ratio method is summarized from the scientific report /15/

Method

OBM and OBD represent useful instruments for monitoring exhaust emissions compliance over the life of a vehicle. Additionally, these instruments can be used for PTI. This can be done by simply linking the existing information in the vehicles (by a simple software adaption). For this task, a simple indicator for possible malfunctions of the NOx emission control system has been elaborated, which does not need any new sensors → with the sensors available in modern cars, it is possible to determine the NOx emissions at the end of the tailpipe. CO2 emissions can be calculated from the fuel consumption.

If the efficiency of after treatment systems (especially SCR and EGR) of conventionally driven cars are insufficient, the NOx-emissions increase without significant increase in CO2 emissions and the ratio between CO2 and NOx emissions ($Q_{Nox} = \frac{g\ CO2}{g\ NOx}$) decreases. This ratio can be measured during real world operation and stored on the vehicle in a suitable way.

To verify the method, measurements with four EURO 6d Temp diesel cars were performed on the street with an installed PEMS. Vehicle 01 was also tested on the chassis dynameter in the laboratory. The WLTC- and the ERMES-driving cycles with different aftertreatment system settings were measured on the test bench. The measured WLTC with a not working emission control system (AdBlue dosing & EGR off) showed, as expected, the highest NOx-emissions.

Two ERMES cycles with a deactivated AdBlue dosing to the SCR- but a working EGR-system of the car were measured after a WLTC with standard settings (AdBlue dosing & EGR on). The NOx emissions measured for the first ERMES monitoring were quiet low, although the AdBlue dosing did not work during this measurement, the NH3 stored in the catalyst still leads to NOx conversion.

The second ERMES cycle, with the same settings for SCR- and EGR-systems, was measured afterwards and the NOx emissions were about 7 times higher than the first ERMES cycle, while the measured CO2 for both cycles was nearly the same.

To get a representative threshold value of this ratio (QNOx = g CO2 / g NOx), a dataset of measured EURO 4, 5, 6d Temp & 6d (diesel & petrol) was used with the assumption that a not working aftertreatment system of EURO 6d Temp & 6d cars leads to a similar emission behavior like EURO 4, 5 standard vehicles.

Data evaluation for threshold value

The CO2 emission ratios were calculated from the RWC (Real Word Cycle) data of 20 cars (10 EURO 6, 10 EURO 4 and 5).

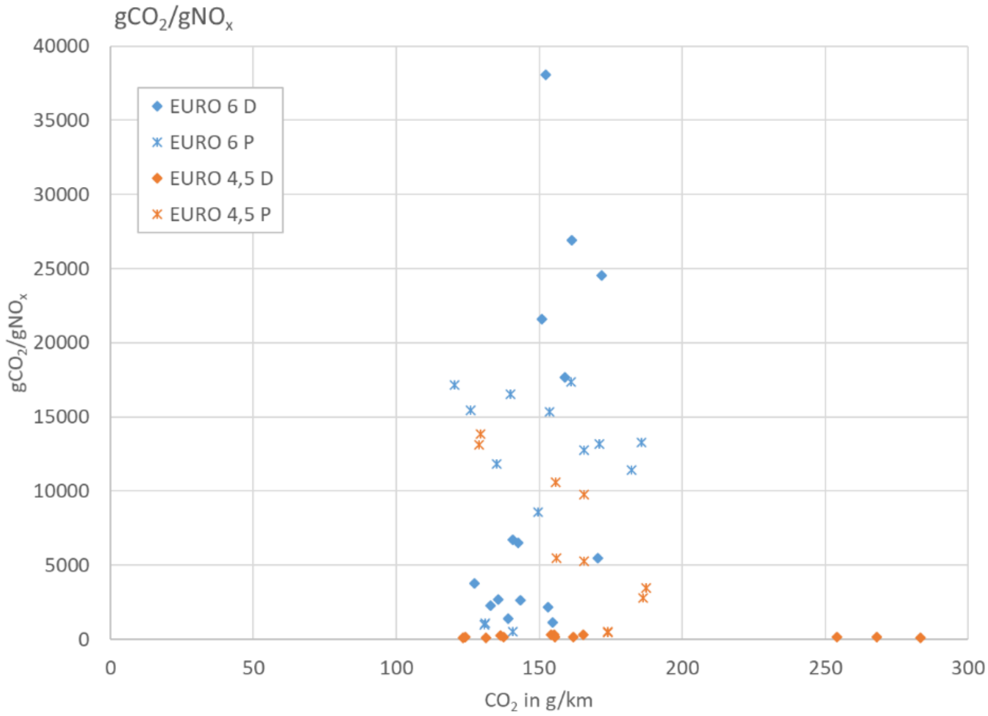


Figure 8: gCO_2/gNO_x ratio for data set cars

Figure 8 shows the ratio between measured CO2 and NOx for the analyzed EURO 6 and EURO 4 and 5 cars. “D” stands for diesel and “P” for gasoline cars. The trend shows that the ratio for EURO 6 cars is above the EURO 4, 5 values.

The average value for CO2 in g/km is about 149 g/km for the gasoline and 151 g/km for the diesel cars. For EURO 6d and 6d Temp cars, the regulated NOx emission limit for RDE is a CF (Conformity Factor) multiplied by the NOx emission limit for the WLTC. The use of a CF of 2.1 for EURO 6d Temp cars and 1.5 for EURO 6d cars leads to a RDE-NOx limit value of 168 mg/km (EURO 6d Temp) and 120 mg/km (EURO 6d d) for diesel cars. For petrol driven cars the NOx-emission limit for road tests is 126 mg/km (EURO 6d Temp) and 90 mg/km (EURO 6d).

To calculate a possible threshold value, the NOx emission limits for RDE tests for EURO 6d Temp and EURO 6d diesel cars were divided by the average CO2 emissions of these cars.

To obtain a threshold value for the CO2 to NOx ratio, the average of both values (6d Temp and 6d) was built, resulting in a threshold ratio of 1100 gCO2/gNOx. Since the gCO2/gNOx ratio for gasoline cars in the dataset does not show critical values, only diesel cars are considered in the rest of the report.

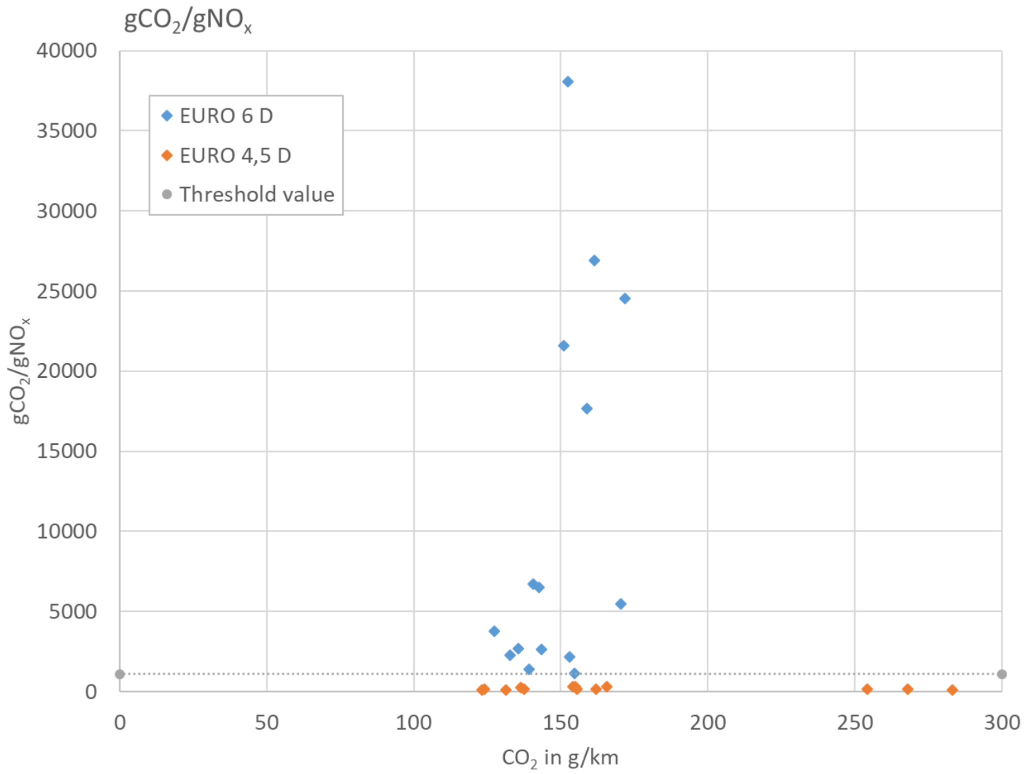


Figure 9: gCO_2/gNO_x ratio for diesel cars including threshold value

Figure 99 shows that for a threshold value of 1100 gCO_2/gNO_x, no EURO 6 car (blue dot in the diagram) is below this threshold line. None of the measured EURO 6 cars had malfunctions in the indicated exhaust control. This threshold value for the detection of an insufficient aftertreatment system on a EURO 6 car can therefore be used for further investigations.

The same elaborations were made for the gCO_2/gCO, gCO_2/gNO and gCO_2/#PN ratios.

Emission Measurements - Chassis Dynamometer

Table 3 shows the measured results for CO2, NOx, NO and PN on the chassis dynamometer with the VW Golf.

Cycle	Starting Cond.	Cycle duration	Settings	CO_2	NO_x	NO	FC	PN
		[s]		[g/km]			[l/100km]	[#/km]
WLTC	cold	1800	SCR & EGR off	102.52	1.26	0.76	3.90	5.32E+09
WLTC	hot	1800	SCR on & EGR off	100.13	0.41	0.36	3.81	9.28E+09
WLTC	hot	1800	SCR off & EGR on	100.74	0.05	0.05	3.83	6.12E+09
WLTC	hot	1800	Regular (SCR and EGR on)	100.69	0.02	0.02	3.83	1.84E+10
ERMES	hot	1193	SCR off & EGR on	104.89	0.02	0.02	3.99	3.95E+09
ERMES	hot	1193	SCR off & EGR on	105.15	0.11	0.08	4.00	9.26E+09

Table 3: Measured results chassis dynamometer

Different settings concerning the aftertreatment system (SCR and EGR) lead to different emission results. Figure 10 and Figure 11 show the CO2- and NOx-emissions in g/km for the measured WLTCs for different vehicle settings.

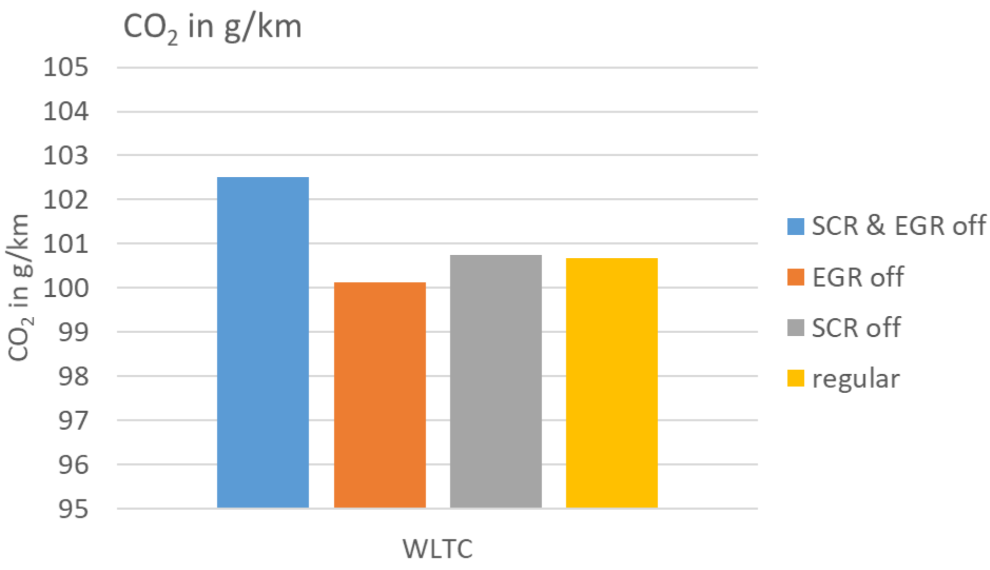


Figure 10: Measured CO_2 in g/km for the WLTC with different vehicle settings

The measured CO_2 for the WLTC with SCR & EGR off has the highest CO_2 value. The effect of a non-functioning SCR and EGR should not primarily affect the CO_2 measured from the car, but rather the NO_x measured. Thus, the higher CO_2 for this WLTC is most likely because this driving cycle was measured with a cold engine and the following WLTCs with a hot engine. In the CoC (Certificate of Compliance) document for the VW Golf, a CO_2 of 110 g/km for the WLTC is specified.

Figure *11*11 shows the measured NOx emissions in g/km for the WLTC measurements on the test bench.

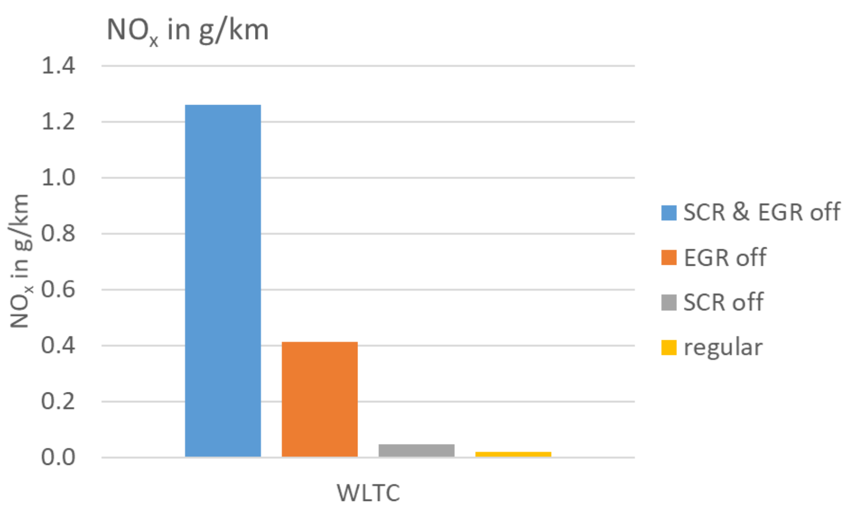


Figure 11: Measured NO_x in g/km for the WLTC with different vehicle settings

For a EURO 6d TEMP diesel car, the regulated NO_x emission limit for the WTLC measured on the chassis dynamometer is 80 mg/km. The first measured WLTC (cold and without an aftertreatment system in operation) shows the highest measured NO_x of the test bench with approximately 1259 mg/km. This cycle would therefore exceed the regulated emission limit by about 16 times. The NO_x values measured for the WLTC with a functioning SCR and a non-functioning EGR shows higher values than those for the WLTC with a functioning EGR and a non-functioning SCR (both tests started with a hot engine). One might assume that a non-functioning SCR system produces higher NO_x emissions than a non-functioning EGR, but for the WLTC this assumption is not correct.

On one hand, it is possible that the higher engine emissions caused by the deactivation of EGR were not compensated by a higher AdBlue dosage in the SCR system and herefore these additional emissions passed the SCR system without conversion. On the other hand, in tests with a deactivated SCR, it is possible that NH_3 is still stored in the SCR, which lead to continuous NO_x conversion in the test. This thesis is supported by the results in the ERMES cycle described below.

The regular measured WLTC with a functioning SCR- and EGR-system shows NO_x-emissions of about 21 mg/km and is clearly within the regulated limit.

Figure 1212 shows the NO_x emissions measured for two ERMES cycles where the SCR system was disabled. The first ERMES shows about 15 mg/km of NO_x and the second about 106 mg/km. The difference between the NO_x measured in both ERMES cycles is rather high. The SCR system was by closing the Ad Blue metering valve for the SCR system. For the first ERMES measured (follow up cycle to a regularly measured WLTC), it is obvious that enough Ad Blue was stored in the catalyst to maintain high NO_x reduction for most of the cycle. For the second cycle, the SCR system was almost empty and therefore the NO_x emissions could not be reduced by the SCR.

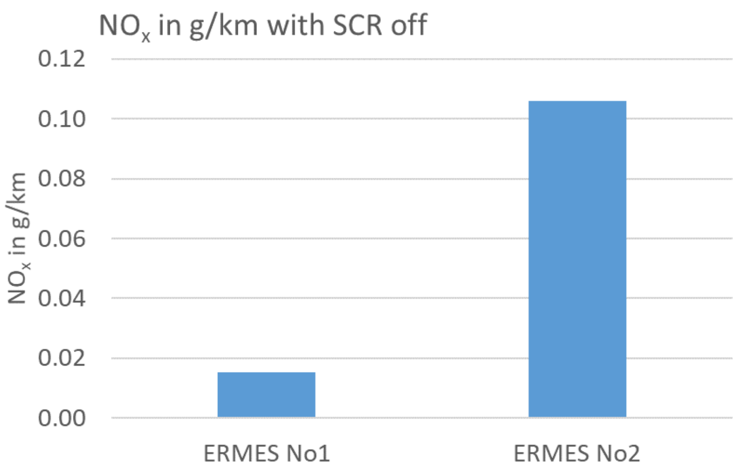


Figure 12: NO_x emissions in two consecutive EMRES cycles after deactivation of the AdBlue dosing with EGR on

Real World Driving Emissions

As described, the RDE measurements were carried out with four EURO 6d TEMP vehicles.

		Average speed	Average temperature	CO2	NOx	QNOx	RDE NOx emission limit (CF 2,1)	PN
Vehicle / Cycle No.	cycle	km/h	°C	g/km	g/km	gCO2/gNOx	g/km	#/km
V01	RDE Wien	53,56	28	116,53	0,0207	**5629**	0,168	1,33E+12
V01 after deactivation AdBlue dosing	RDE Wien	53,64	26	99,928	0,1434	**697**		2,10E+08
V02	RDE Wien	53,86	19	147,33	0,0535	**2755**		2,39E+09
V02 after deactivation AdBlue dosing	RDE Wien	56,51	18	125,13	1,2030	**104**		3,45E+08
V03	RDE Wien	54,05	20	153,721	0,0553	**2781**		9,26E+08
V03 after deactivation AdBlue dosing	RDE Wien	54,54	22	164,29	0,3855	**426**		7,40E+11
V04	RDE Wien	54,67	28	210,787	0,0144	**14597**		9,27E+10
V04 after deactivation AdBlue dosing	RDE Wien	54,88	19	200,005	0,3246	**616**		2,22E+10

Table 4: Results of Real-World Driving Emission measurements

For vehicles V01, V02 and V04, the CO_2 emissions in the test runs with functioning exhaust gas aftertreatment were lower than those in the runs without SCR. The difference was between -5 and -15%. For vehicle V03, the CO_2 emissions increases at the test run without SCR System. A detailed examination of the measurement data showed that the DPF regenerated during the test drive. The regeneration started during "extra urban" test phase and lasted until the end of the test. **Error! Reference source not found.**4 gives an overview of the measurement data.

In all test conducted with standard series conditions the NO_x emissions were clearly below the RDE NOx emission limit of 0,126 g/km.

With the deactivated SCR system, the NO_x values were at least one order of magnitude above the limit value.

The calculation of the Q_{NOx} values shows that the test-runs with the SCR system deactivated could be clearly identified. For these test-runs, the Q_{NOx} value lies below the proposed threshold value.

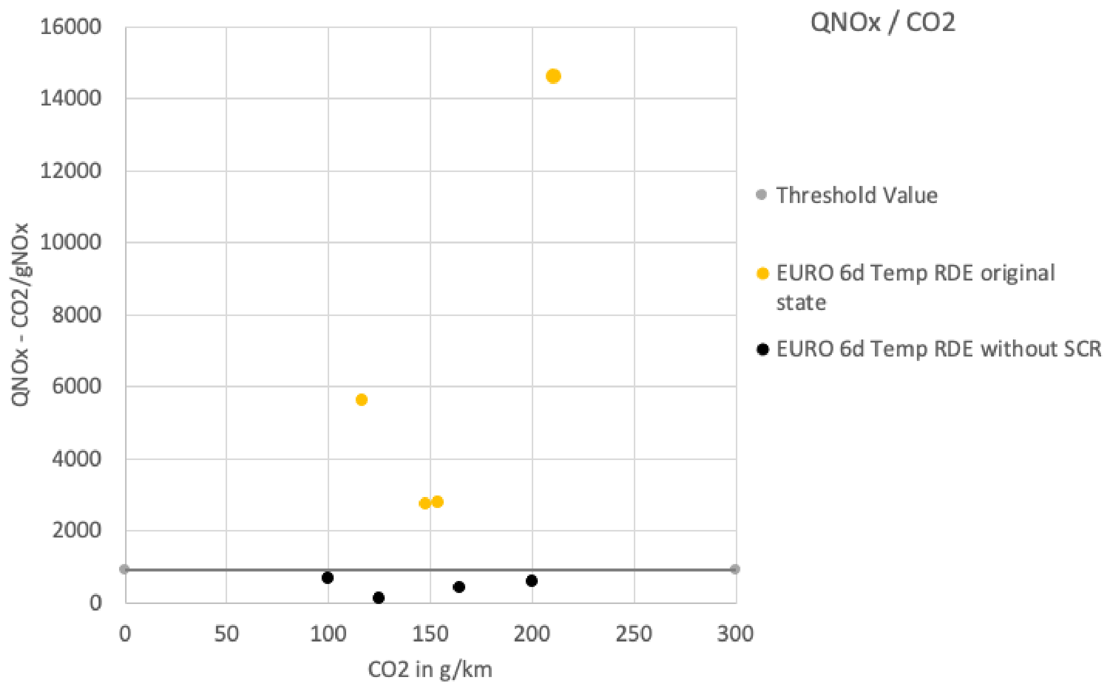


Figure 13: Q_{NOx} Factors at the RDE Test-Runs

During the RDE test-runs, the vehicles with deactivated SCR system could be clearly identified by the QNOx method. These QNOx factors were below the QNOx threshold value only for the vehicle settings with simulated defects in the exhaust gas control. The analysis proves that defective exhaust systems can be identified with the QNOx method with a high probability.

An open issue is the definition of a proper test length and also test conditions (e.g., hot after treatment system) for a robust determination of QNOx. To define the time window for the QNOx determination at real driving, further development would be necessary to also define the threshold values.

One more open issue is the definition of "undershot thresholds".

That means that the number of QNOx factors per trip or per week etc. is below the limit until the MIL is activated.

Advantages of implementing Q_{NOx} measurement:

- NO_x emissions can be normalized to the vehicle's CO_2 emissions.
- Q_{NOx} monitoring can guarantee compliance of NO_x tailpipe emissions over the lifetime of a vehicle.
- NO_x emissions can be monitored at different load profiles during real-world operation of vehicles.

- The results of the Q_{NOx} calculation could be used for detection of relevant defects / to activate the malfunction indicator.

To avoid any uncertainty as to the reliability of this system throughout the whole lifetime of the vehicle, regular checks should be carried out, which can be included in the periodic technical inspection:

- To ensure the Q_{NOx} functionality, the vehicle internal NO_x sensor must be checked regularly within PTI.
- During such a check, the vehicle's internal NO_x sensor must deliver the same level via OBD / OBM as the NO_x tailpipe exhaust value measured with an external device at idle speed.

C) SPEED ACCELERATION / SPEED PUMPING

The approach of this method is as follows: due to type approval specifications, there are increasingly different NOx aftertreatment systems, which are adapted to specific load ranges.

EGR systems and NOx storage catalytic converters (NSC) cover the lower to medium load range, while SCR systems (installed under the vehicle, away from the engine) cover the high load range.

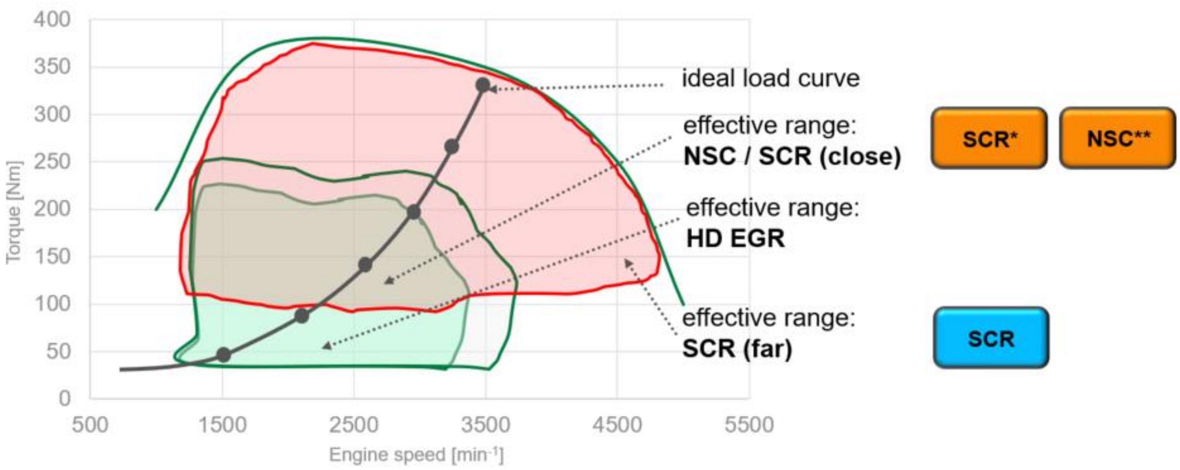


Figure 14: Effective Ranges of NOx Aftertreatment Systems (exemplary)

The figures 15-17 provide an overview of possible applications for Euro 6.

Euro 6a / Euro 6b

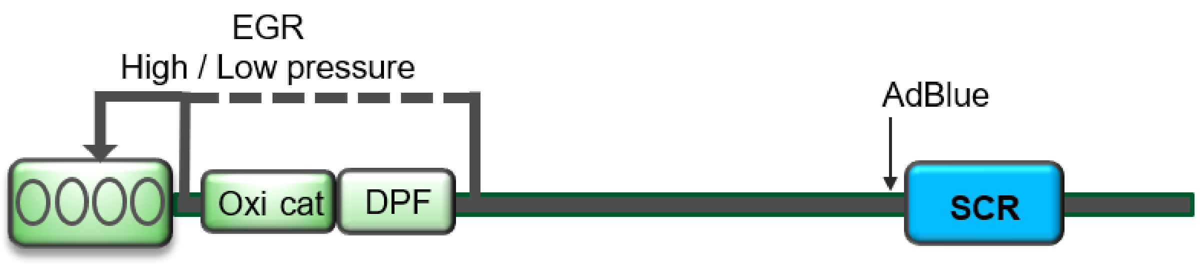


Figure 15: Possible NOx Concept for Euro 6a / b

Euro 6 c / Euro 6 d-temp

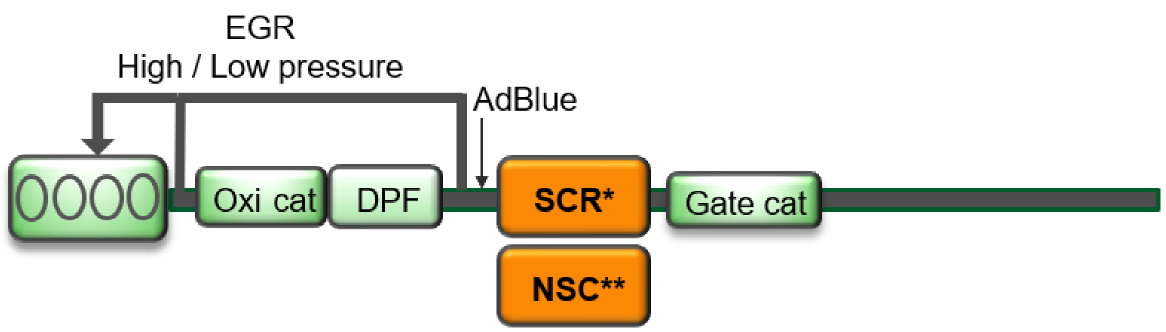


Figure 16: Possible NOx Concept for Euro 6c / 6d-temp

Euro 6 d / (and following)

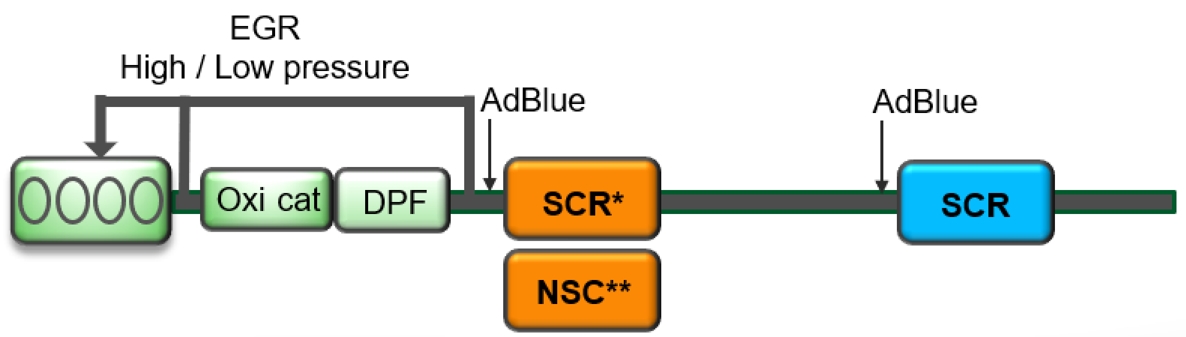


Figure 17: Possible NOx Concept for Euro 6d and following (?)

With the "speed pump" method, different load ranges are covered in the load diagram (Figure 14) by gradually increasing the speed up to the cut-off (maximum) speed.

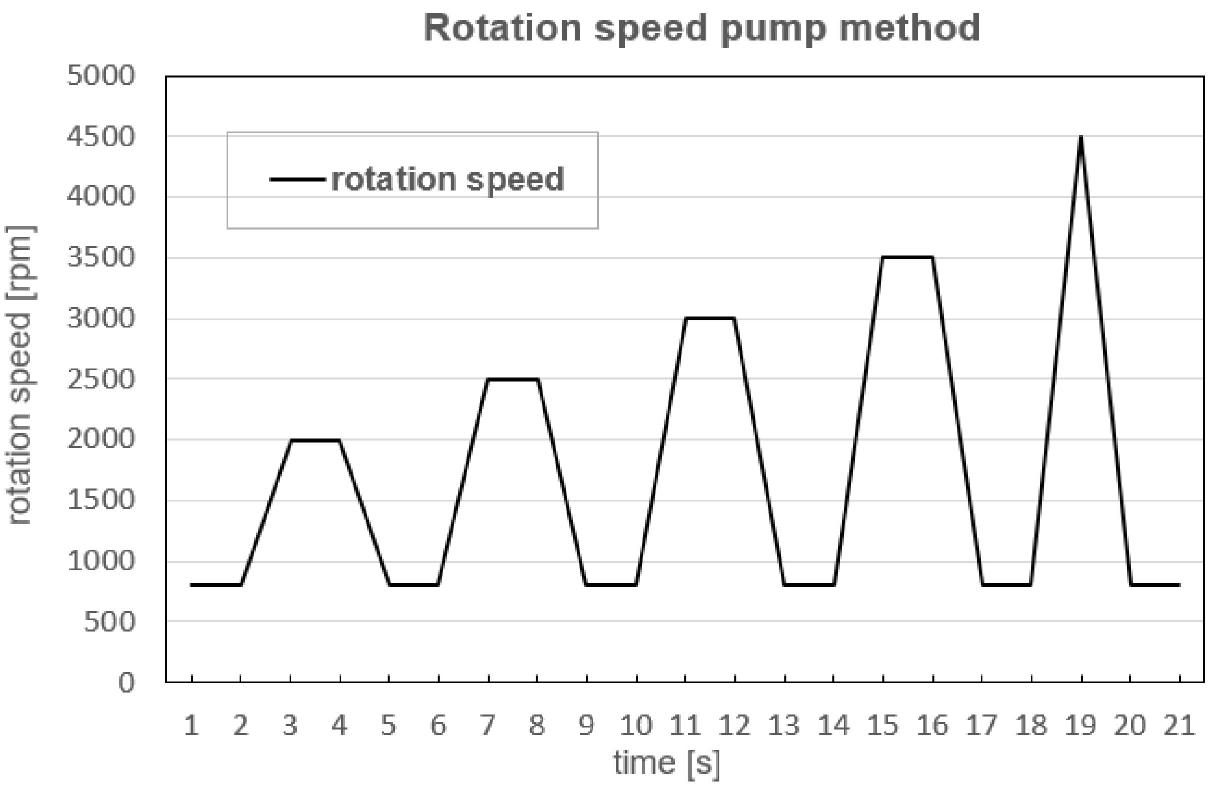


Figure 18: Method of "Speed Pumping"

Figure 19 shows some of the results of investigations with manipulated EGR systems at different stages. The detection of defects/tampering is very clear.

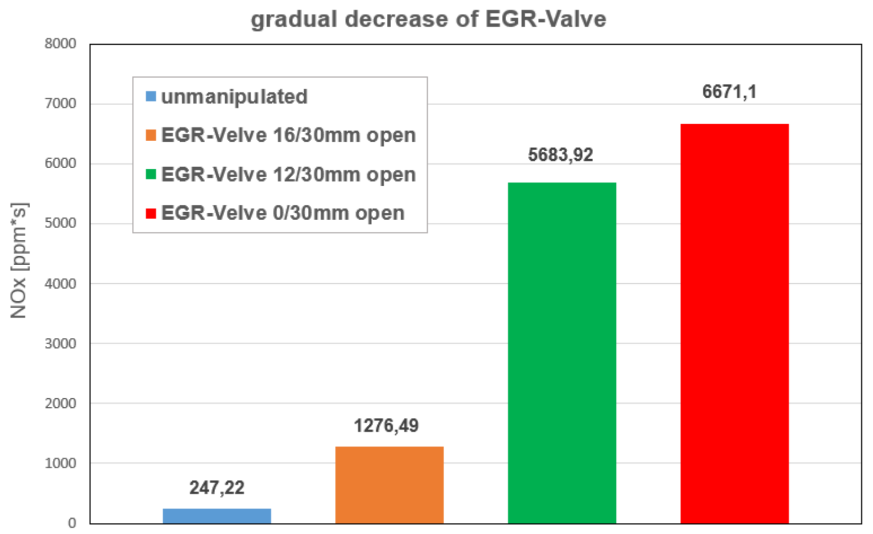


Figure 19: Results of Speed Pumping Method at Manipulated EGR System

A faulty (or manipulated) SCR system can also be detected very well, as shown in Figure 20 on a Euro 6 d temp vehicle.

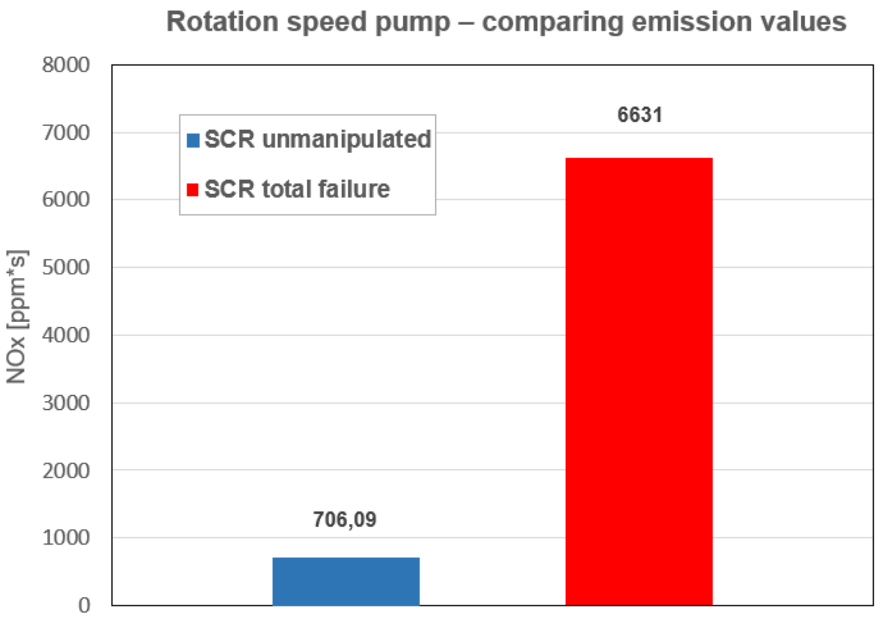


Figure 20: Results of Speed Pumping Method at Defect SCR System

The results show a very high potential for this method. However, further field investigations are necessary and have not yet been carried out.

<u>Advantages and disadvantages</u>

The main advantages of this method are:

(1) Feasibility: fast and easy to incorporate into PTI;
(2) Applicable to all vehicles: older, newer, passenger cars, light duty, heavy duty, 4x4.

The main disadvantages of this method are:

(1) A relatively “fast” NOx measuring system is necessary, with a high recording frequency (>= 5 Hz);
(2) When there are multiple aftertreatment systems: system overlap: a defective SCR system can be "covered" by an existing NSC or, even more so, by the EGR(as part of the method);
(3) The fact that many diesel vehicles limit the maximum speed when the wheels are stationary must be solved (best: by regulation);
(4) Implementing the speed levels is often difficult and requires a lot of experience on the part of the inspector.

A **variant** of this method is the "Free Acceleration Test" (FAT), as used today for testing opacimeter on diesel vehicles. This method does not involve speed steps, which makes the application simpler and more reproducible. The disadvantage (4) is thereby eliminated, and the approach is more general because there are no different load areas covered. See figure /14/

D) "SHORT DRIVE METHOD" (OPUS / 3DATX)

Background

3DATX (EU and USA) collaborated with OPUS (Sweden) to collect gaseous and particulate tailpipe emissions data during real-world PTI testing at OPUS' PTI test center located in Borås, Sweden. The program started with some initial trials during January 2021, followed by multiple rounds of refinements to the test protocol based on test center experience and data analysis.

This test program is ongoing and is expected to continue until April 2022. An initial technical presentation was made to CITA members on February 23, 2021, with a small database of 35 measured vehicles. A second technical presentation was made to CITA members on June 30, 2021, based on a database of over 160 vehicles. As of November 20, 2021, the size of the database has increased to over 250 measured vehicles and approximately 30 vehicles are added weekly.

All emissions data are measured using the 3DATX parSYNC® iPEMS systems.

Some unique aspects of this study are:

No Vehicle Selection Bias: Emissions measurements of customer-owned Euro 4+ vehicles brought to PTI test center for regular inspection. Thus, there is no intentional vehicle selection bias.

No Infrastructure Cost: Emissions data were collected for the vehicle under load during free driving on the road, without use of any load or driving related equipment such as dynamometer.

The only additional equipment used was the parSYNC system with NO+NO2 capability.

Real-World Data: Emissions data are collected during all months of the year and the vehicles are not prepared in any particular way. Thus, the data collected reflects the real-life performance of vehicles in the fleet.

Further descriptions of the method can be found, among others, in /16/, /17/, /18/.

Procedure

The test protocol was refined multiple times, with each new version focused on reducing the additional time required by PTI test center staff for activities such as parSYNC install, uninstall, and any additional driving. The current iteration of the protocol is given below:

Bag No.	parSYNC Location	Description
0	Bench	Sample clean air while parSYNC is on the bench.
Zeroing	Bench	Zero the parSYNC. Idle the vehicle.
0	Vehicle	Move parSYNC to vehicle. Sample exhaust gas for ~10 seconds.
1	Vehicle	PN protocol – 60 seconds of idle – conducted while car is at garage
2	Vehicle	Drive to emissions shed
3	Vehicle	NOx High Idle – Follow standard PTI protocol for gasoline and diesel vehicles
4	Vehicle	Drive to NOx Acceleration test start point
5	Vehicle	NOx Acceleration – *Idle for 10 seconds*, then accelerate quickly to 30 kph, then brake normally (not hard) to a complete stop, *idle for 10 seconds*
6	Vehicle	Drive back to garage.
7	*Vehicle*	*PN protocol – 60 seconds of idle*
8	Bench	Disconnect parSYNC. Sample clean air for at least 60 seconds.
Zeroing	*Bench*	*Zero the parSYNC.*

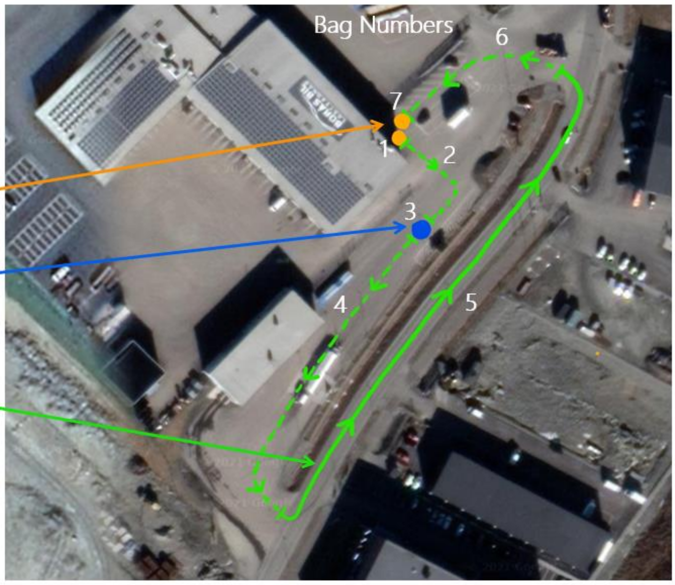


Figure 21: Exemplary Application

This entire protocol adds 5 minutes to the time required to conduct existing standard PTI test. The installation and uninstallation of the instrument is very fast and takes a total of 3-4 minutes.

Since the same protocol is applied to both diesel and gasoline vehicles, approximately 1 minute must be added for the additional test time because in standard PTI, the diesel and gasoline tests are different. It should be noted that the emissions data are collected continuously, including when the vehicle is driven between the test center and emissions shed.

The following figures provide an overview of the 160 vehicles that were measured until June 30, 2021. As more vehicles are measured, these figured will be updated.

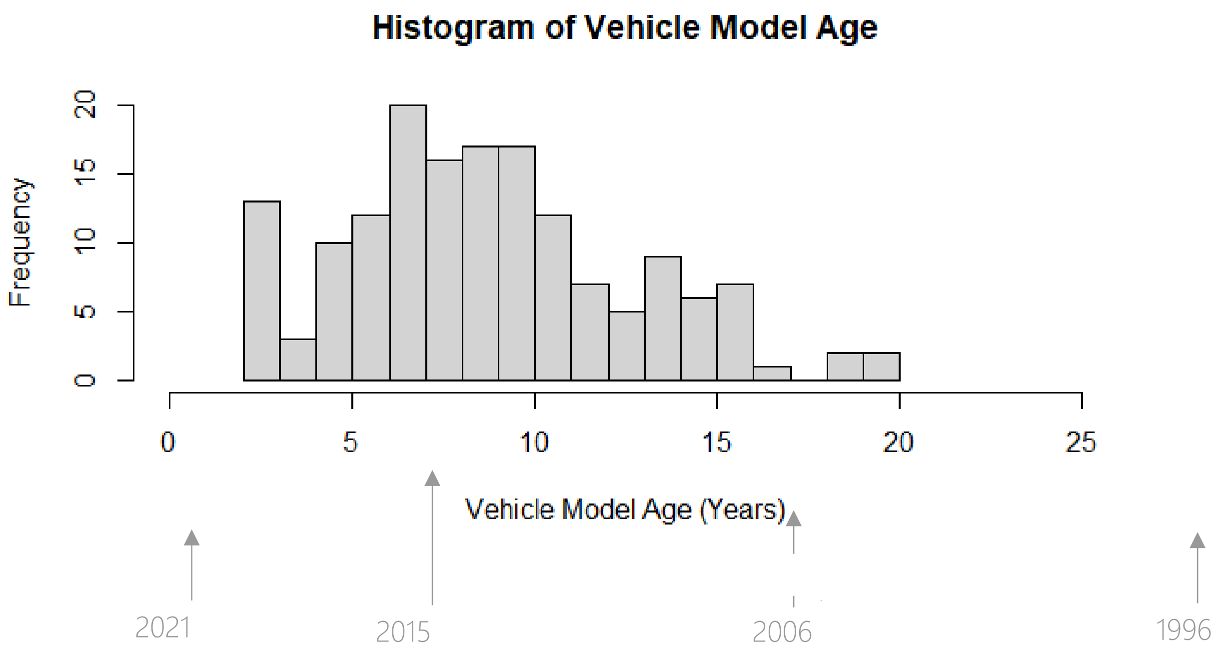


Figure 22: Histogram of Vehicle Age

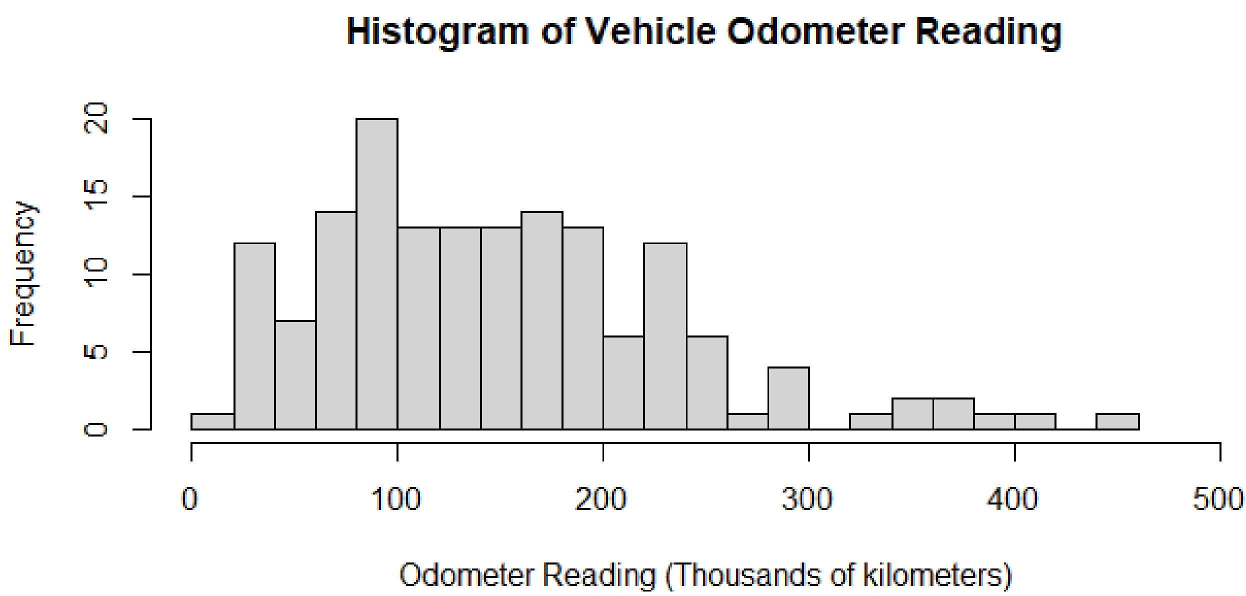


Figure 23: Histogram of Vehicle Odometer Reading

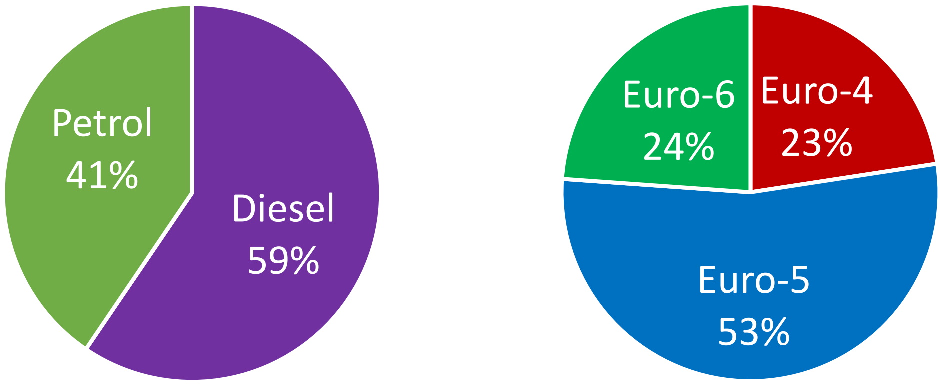


Figure 24: Histogram of Vehicle odometer Reading

Pass/Fail Thresholds

A statistical analysis of the emissions data from all measured vehicles, separated by their Euro standard, is conducted to identify spread and outliers. The table below shows a first proposal of limits that define three levels – mean, 1-sigma above mean, and 2-sigma above mean.

The test program has recently added emissions measurement of vehicles with defects that are expected to adversely affect the vehicle's tailpipe emissions. These vehicles are sourced from a local garage and are not vehicles that arrived at the PTI test center for their annual inspection. The data from these defective vehicles is yet to be incorporated in the thresholds presented here.

	NOx Idle (ppm)	NOx High Idle (ppm)	NOx Accel (ppm)
EURO4 - Mean	86	89	170
EURO4 - σ	186	183	328
EURO4 - 2σ	287	276	486
EURO5 - Mean	138	123	193
EURO5 - σ	272	208	346
EURO5 - 2σ	406	293	500
EURO6 - Mean	65	63	121
EURO6 - σ	141	124	232
EURO6 - 2σ	217	185	343

Table 5: Suggestion for Pass/Fail Thresholds

Progressive testing path: Perform idle testing for each pollutant; if pollutant values are above the threshold (e.g., 1σ), then proceed to high idle test; if pollutant values are above the threshold (e.g., 1σ), then proceed to acceleration test; if pollutant values still above the threshold (e.g., 1σ), then it fails the PTI.

Cumulative testing path: If the vehicle fails the threshold (e.g. 2σ), for any two of the three tests, then it fails the PTI.

Necessary Test Equipment

The only necessary equipment for this method is an emissions measurement device capable of measuring NOx with a frequency of 1 Hz during idling and driving conditions. The iPEMS (portable emissions measurement system) used in this study – 3DATX parSYNC – measures both gaseous and particulate emissions. A PTI specific equipment, when using economies of scale, is expected to cost less than € 25.000 for both gaseous (CO, CO2, HC, NO, NO2) and PN emissions. The cost of measuring NOx alone would be much less.

There might be additional cost of on-site calibration gases and flow regulators for use during span check calibration, but those are independent of this method and will be applicable to all methods based on official PTI requirements.

Advantages

(1) Very low infrastructure cost – the only cost is emissions measurement equipment.

(2) Can be used on any vehicle type – light or heavy, diesel or gasoline.

(3) Fast and easy – short learning curve for technician; no machinery to service or maintain.

(4) Real-world – captures the emissions during real-world conditions.

(5) Location agnostic – can be implemented at any site.

(6) Variety makes it robust – Correlations between idling and driving are made, so that when driving is not permissible, it is still possible to make fair (if not excellent) pass/fail judgements.

Disadvantages

(1) Requires short driving distance to be available.

(2) Variation in driving patterns might appear as a problem (but is easily solved by using power modes analysis method).

E) DRIVING CYCLE ON TEST BENCH: ASM 20 / ASM 2050

This method is a modification of the ASM methods used in some American regions (ASM2525/ASM2550). The application of the vehicle is very simple (no fixation necessary), and the evaluation is also simplified. The test bench used, and the application are therefore relatively simple.

In the ASM2050 test procedure, a vehicle is accelerated to 20 km/h and maintains this speed for 15 seconds. In the next step, the vehicle is accelerated to 50 km/h and maintains this speed for another 15 seconds. Then the vehicle is brought to a standstill. The speed curve is shown in Figure 25. The nitrogen oxide emissions measured during the respective constant speed phases are used to calculate the mean value. The first five seconds of each constant speed phase are reserved for stabilization.

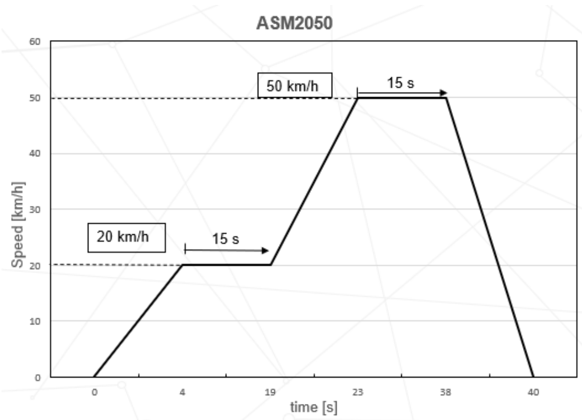
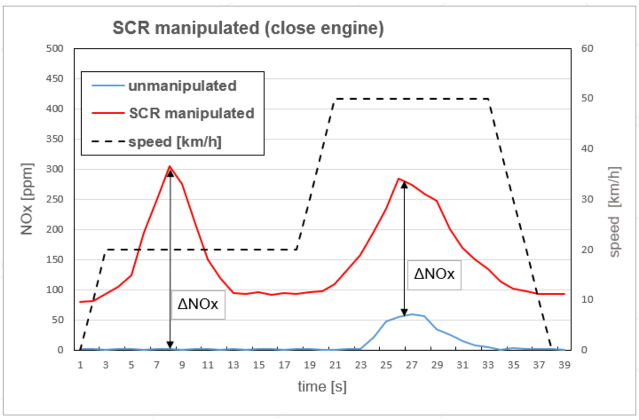
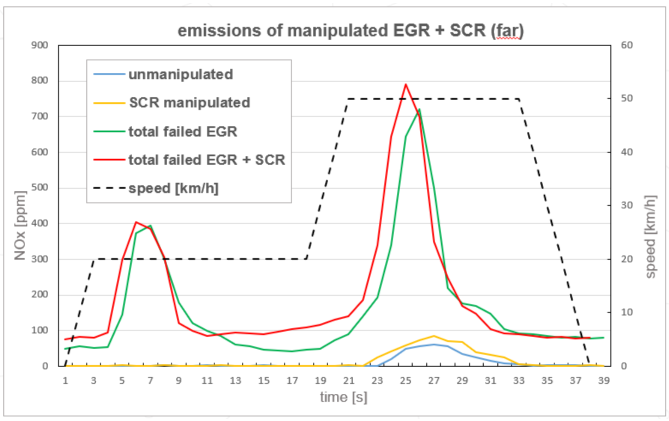


Figure 25 and Figure 26: ASM2050 Driving Cycle

A constant roller load is set for the whole cycle. This can be a fixed load (i.e., 500 N) or a load depending on the weight and the engine power of the respective vehicle. It was found that the built-in fault in the EGR system or SCR system was clearly identifiable even at a low load. The SCR system, on the other hand, requires higher loads until it comes into operation and can be evaluated.





As with the "speed pumping" method (3.2.3), however, there seems to be an overlap of systems with multiple systems (e.g. EGR and SCR). This means that a functioning system can compensate for a defective system in certain areas, so that a defect may not be detected using this method. Higher load specifications of the test bench could bring a significant improvement here.

A variant of this method could be the ASM 20 method, in which only the first stage is driven up to 20 km/h. The acceleration from standstill and the engine load at 20 km/h seems to be sufficient. The 50 km/h step doesn't seem to be necessary. This could make the method even simpler and faster, and possibly the test bench even simpler and cheaper

Advantages and disadvantages

The main advantages of this method are:

(1) Very good fault indication: vehicles with deliberately introduced faults measured four times higher NO_x values than factory condition vehicles [6].
(2) Defined vehicle load and environment conditionsPrecise and defined process.
(3) Very good repeatable.

The main disadvantages of this method are:

(1) Test bench required (although with low requirements) --> space, investments.
(2) Difficult to implement for HD vehicles.

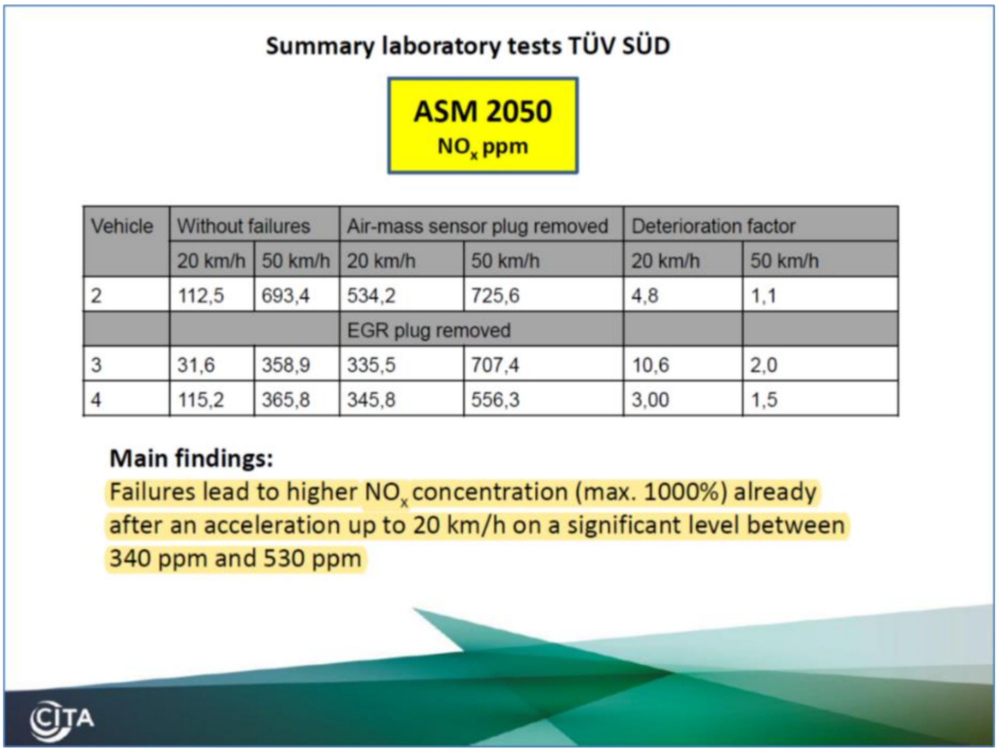
Alternative for performing the ASM 20 on a modified brake tester

Method for testing NOx under load and real road conditions with a conceptual combination brake tester and loaded test stand.

This is a concept study that has already been carried out on a prototype.

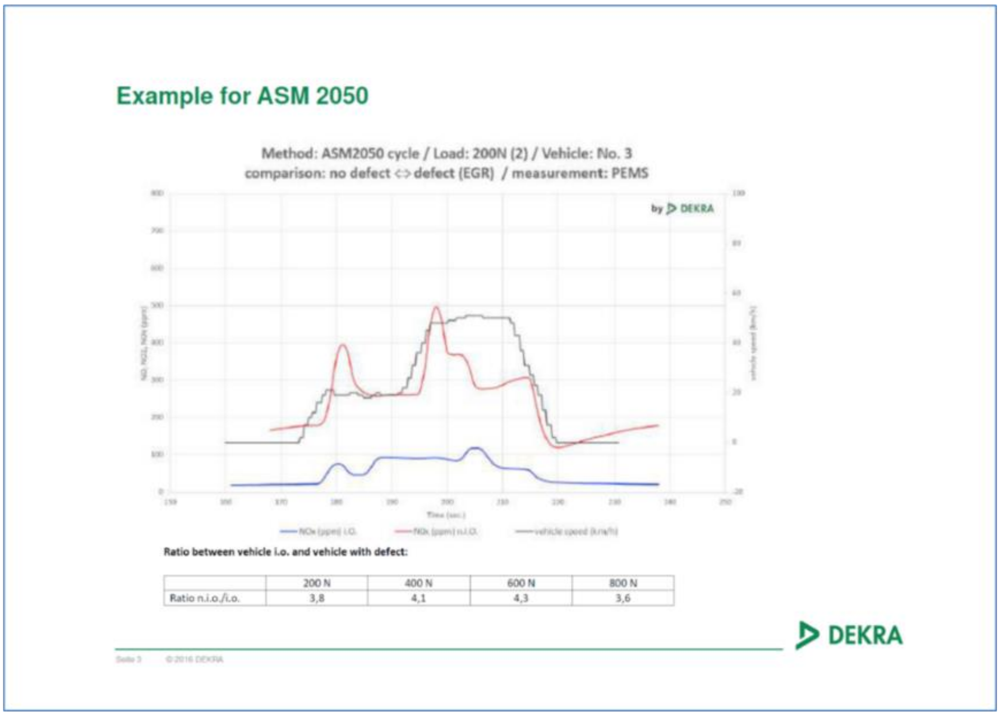
A roller brake test bench was modified in such a way that it generates speeds of up to 20 km/h and acts on the drive axle with a counteracting tensile force with a minimum load of 1,000 Newtons. The integration of the emissions test into a proven brake tester would make it easier for inspection bodies to apply a NOx method without the need for an additional emissions dynamometer.

An upgrade of existing brake testers, as they are usually used for the safety inspection, would be quite conceivable since the function for exhaust gas analysis under load could be added easily and without great effort. The solution would therefore be very practical and saves costs and space by turning one test device into two.



Vehicle	Without failures		Air-mass sensor plug removed		Deterioration factor	
	20 km/h	50 km/h	20 km/h	50 km/h	20 km/h	50 km/h
2	112,5	693,4	534,2	725,6	4,8	1,1
			EGR plug removed			
3	31,6	358,9	335,5	707,4	10,6	2,0
4	115,2	365,8	345,8	556,3	3,00	1,5

Figure 27: ASM2050 on a Combined Roller Brake Tester; Source: CITA SET II Study



	200 N	400 N	600 N	800 N
Ratio n.i.o./i.o.	3,8	4,1	4,3	3,6

Figure 28: ASM2050 on a Combined Roller Brake Tester; Source: CITA SET II Study


Figure 29: Demonstration of the ASM2050 on a Combined Roller Brake Tester; Source: MAHA

F) ACCELERATED DRIVE (START UP)

This method was also developed with the approach of covering the different NOx exhaust gas aftertreatments of the Euro stages using different load conditions. See also 3.2.3 (speed pumping). The method is a short test drive under real road conditions.

The test drive is very short, only a short start up to approx. 20 km/h. The required distance is a maximum of 30 meters.

However, when starting/accelerating, a high engine load is generated with correspondingly high exhaust gas temperatures. The road trip is to be carried out in two stages for having two different load conditions.

- In the first stage, there is gentle acceleration from standstill to 10 km/h,
- then it accelerates a little more up to 20 km/h.

As far as can be influenced, the test drive takes place in the first gear, i.e., no gear shifting.

The test drive and the specified acceleration is shown in Figure 30. The acceleration can be calculated by dividing the vehicle speed (read by the OBD) by the time.

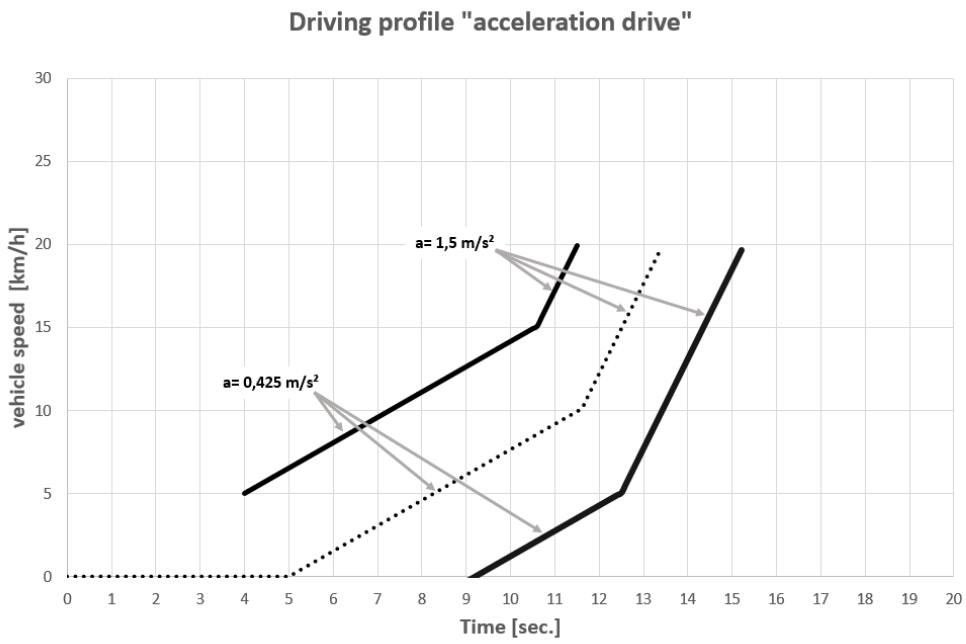
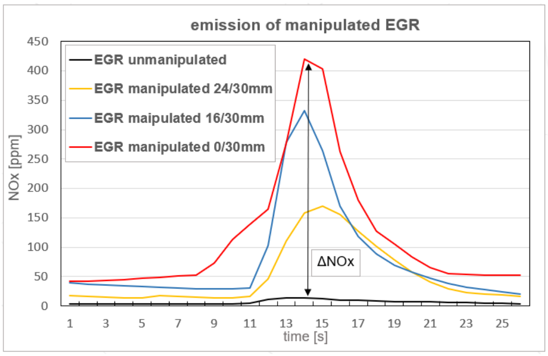


Figure 30: short test drive, two stages

As a measuring device, an existing 4-gas analyzer could be upgraded to a 5-gas analyzer via a chemical NO(x) sensor, which means very low costs. See also Method 3.2.1. However, the gas analyzer must have a mobile power supply. So, a battery. The measuring device can easily be fixed in the trunk. Most of the investigations were carried out with existing PEMS devices, but there are already simpler and more cost-effective measuring devices on the market. See chapter 3.2.4.

Figure 31: Trail Application

The Method shows very good results in the detection of NOx systems, which are aimed at the low to medium engine load range. So EGR and systems installed close to the engine (e.g. NSC). See Figures 32 and 33. Aftertreatment systems, which are designed for the high load range and correspondingly high exhaust gas temperatures (rather installed far from the hot engine systems) can only be poorly covered, as the necessary engine load is not achieved with this method.



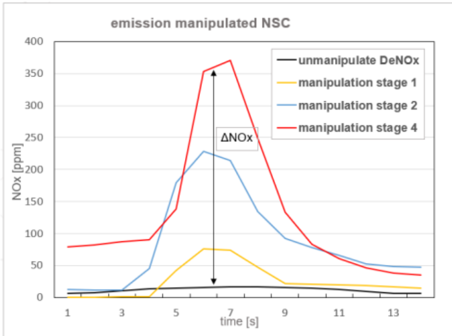


Figure 31 and Figure 32: Results when Examining Different Levels of Defects/Tampering

The potential of this method to detect defects and tampering seems to be very high. Particularly for NOx aftertreatment systems at low and medium engine loads, which are prevalent in inner-city areas, and which are particularly important due to the high population density. However, further investigations are necessary, especially regarding comparability / standardization and environmental influences (cold, heat, humidity).

Advantages and disadvantages

The main advantages of this method are:

(1) Relatively high engine load, so very good detection of defects, errors or manipulations;

(2) Real driving, therefore, absolutely independent test;

(3) The measurement procedure itself is very short (should be repeated at least 3x).

The main disadvantages of this method are:

(1) Driving distance of approx. 40-50 meters necessary (including safety distance). Usually not feasible on public roads (accelerating, braking);

(2) Measuring equipment with battery required;

(3) Attaching the measuring equipment is easy to difficult depending on the shape / kind of the vehicle;

(4) The "duration" (time) is relatively short, so there is not enough exhaust gas temperature and time to activate NOx systems that are installed under the floor of the vehicle.

G) OBD/DIAGNOSTIC FUNCTIONS/OBM

In modern vehicles, the engine- and emission control management is carried out by electronic control units, including their software components. For this, these control units make use of an increasing number of sensors. OBD / OBM systems, as well as today used diagnostic functions are primarily built for workshop diagnostic purposes → they are supposed to find defects and make targeted repair possible. Therefore, it is also possible to detect defects within PTI using these systems.

The emission regulations demand for Type Approval (EU 2018/858) /18/ that the vehicles provide standardized access to the results of the self-tests of the emission control (standardized DTCs and readiness via the standardized OBD interface). UN regulations UN R 49 and UN R 83 provides detailed rules regarding functionality and thresholds. /19/ /20/

The manufacturers also use various not-standardized diagnostic functions (via the same interface) to enable, for example, garages to receive detailed information in the event of a problem. A standardized access to these proprietary functions is defined by the RMI standard (ISO/EN 18541 series). /21/ This standard is anchored in the Type Approval regulation.

In addition, the ePTI regulation (EU 2019/621) /22/ obliges vehicle manufacturers to provide extensive data to the PTI test centers.
Consequently, the emission inspections in PTI should also make as much as possible use of the related information, which is available in the vehicle.

This should include:
- OBD information as current standardized information;
- Use of any current other emission related diagnostic functions; and
- Use of the upcoming measures to overcome current OBD information limitations, which is currently under discussion at the EU legislators under the term "OBM".

Procedure

Make use of emission related information, which is available in the vehicle:

- Emission OBD-DTCs, and its readiness;

- related diagnostic functions, like:

  - Communication with the engine controller and emission controller; (Note: tampering may result in a broken communication)
  - Software number(s) and validity;
  - NOx sensor values, in front of and behind the SCR, if possible;
  - Temp. sensor values (fuel temp, ambient temp, coolant temp, exhaust temp, etc.);
  - Pressure values (air intake, differential pressure over DPF, etc.);
  - Reagent flow values;
  - Injection time (fuel and reagent);
  - Intake air mass (by this: indirect information on AGR-rate);
  - Reagent level in its tank.

The following figure shows a recommended procedure for inspection, defined within a study, carried out by Teknologisk Institut and Danish Road Traffic Authority.

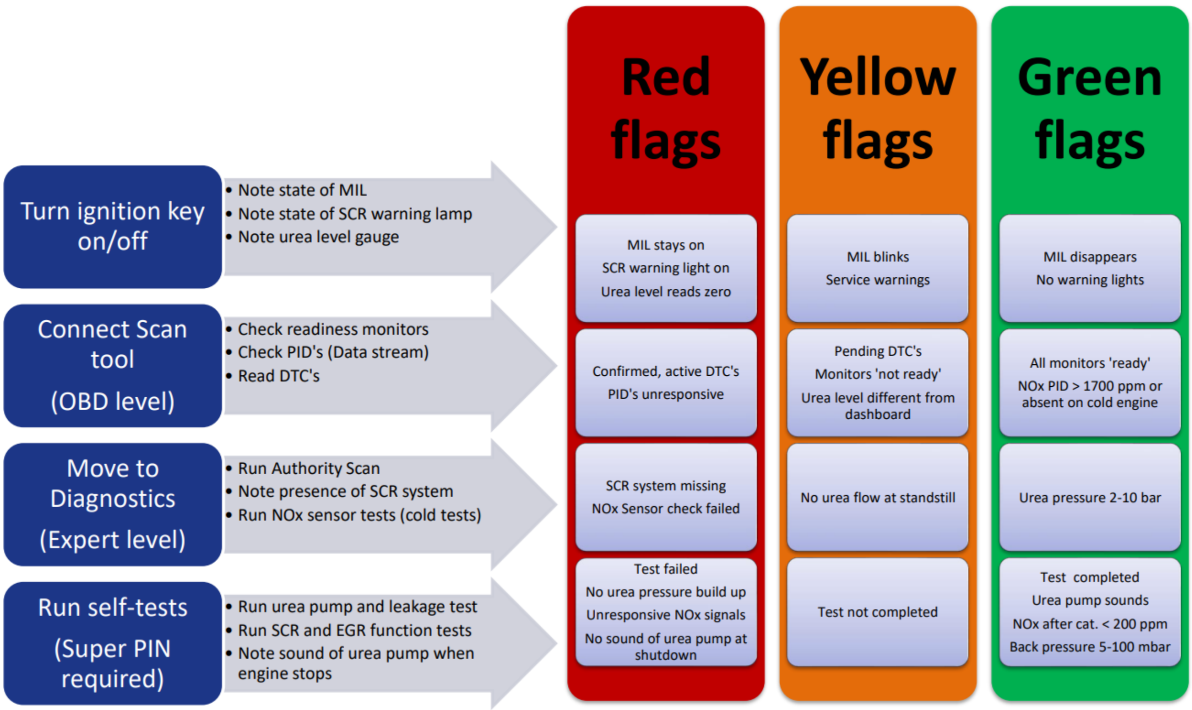


Figure 34: Step-by-Step Method for Inspection via OBD /24/

Even if there are certain boundaries, OBD/Diagnostic Functions/OBM can already today be used successfully within PTI. “The combination of an OBD diagnostics tool with a skilled operator can be used effectively to detect faulty or manipulated emissions system on heavy trucks.” /24/

The data from the vehicle being handled shows a large number of systems that are NOT ready. The data from the NOx sensors are 0 ppm.

Manipulated

$01 - Konstant overvågede komponenter		
Beskrivelse	**overvåget**	**Status**
$10 Fejltændinger klar	Nej	N/A
$10 Brændstofsystem klar	Ja	Ja
$10 Omfattende komponenttest klar	Ja	Nej
$11 Fejltændinger klar	Nej	N/A
$11 Brændstofsystem klar	Nej	N/A
$11 Omfattende komponenttest klar	Ja	Ja
$24 Fejltændinger klar	Nej	N/A
$24 Brændstofsystem klar	Nej	N/A
$24 Omfattende komponenttest klar	Nej	N/A

$01 - Ikke konstant overvågede komponenter		
Beskrivelse	**overvåget**	**Status**
$10 NMHC-katalysator klar	Ja	Ja
$10 NOx/SCR-efterbehandling klar	Ja	Nej
$10 BIT2 klar	Nej	N/A
$10 Ladetrykforstærkersystem klar	Ja	Nej
$10 BIT4 klar	Nej	N/A
$10 Udstødningsgassensor klar	Ja	Nej

Beskrivelse	overvåget	Status
$10 PM-filter klar	Ja	Ja
$10 EGR- og/eller VVT-system klar	Ja	Nej
$11 NMHC-katalysator klar	Nej	N/A
$11 NOx/SCR-efterbehandling klar	Nej	N/A

$10 NOx sensor koncentration Gruppe 1 Sensor 1	0	ppm
$10 NOx-sensorkoncentration, række 1, sensor 2	0	ppm
$10 Gennemsnitligt påbudt reagensforbrug	1,14	L/h

Well-functioning

$01 - Konstant overvågede komponenter		
Beskrivelse	**overvåget**	**Status**
$10 Fejltændinger klar	Nej	N/A
$10 Brændstofsystem klar	Ja	Ja
$10 Omfattende komponenttest klar	Ja	Ja
$11 Fejltændinger klar	Nej	N/A
$11 Brændstofsystem klar	Nej	N/A
$11 Omfattende komponenttest klar	Ja	Ja
$24 Fejltændinger klar	Nej	N/A
$24 Brændstofsystem klar	Nej	N/A
$24 Omfattende komponenttest klar	Nej	N/A

$01 - Ikke konstant overvågede komponenter		
Beskrivelse	**overvåget**	**Status**
$10 NMHC-katalysator klar	Ja	Ja
$10 NOx/SCR-efterbehandling klar	Ja	Ja
$10 BIT2 klar	Nej	N/A
$10 Ladetrykforstærkersystem klar	Ja	Ja
$10 BIT4 klar	Nej	N/A
$10 Udstødningsgassensor klar	Ja	Ja
$10 PM-filter klar	Ja	Ja

Beskrivelse	overvåget	Status
$10 EGR- og/eller VVT-system klar	Ja	Ja
$11 NMHC-katalysator klar	Nej	N/A

$10 Total motor køretid	11106:10	hrs:min
$10 NOx sensor koncentration Gruppe 1 Sensor 1	289	ppm
$10 NOx-sensorkoncentration, række 1, sensor 2	12	ppm

Table 6: Comparison of OBD Data from a Manipulated and a Well-Functioning Vehicle /20/

Necessary test equipment:

- The PTI scan tool, which is mandatory in the EU latest from May 2023, is sufficient.
- No need for extra equipment, like test benches and measurement devices.
- No additional costs for tools.

Advantages:

(1) Duration: less than one min, incl. preparatory work (Note: There may be cases where a sufficient exhaust temp. must be reached. The time to reach it is not included here - but it is no more included than for the exhaust emission measurement, which will need it anyway.).

(2) Very fast (possible even as background task).

(3) Only very little or no cost is involved in training the inspector.

(4) Very low additional cost for the staff.

(5) As a by-product, the same functionalities also detect engine power manipulation using, for example, boost pressure, fuel pressure, rail pressure, or implemented calculation of torque and/or power (if available).

Disadvantages:

(1) Type Approval must become even clearer that all necessary data must be delivered by the vehicle manufacturers (diagnostic data, thresholds).

(2) In Type Approval, the access to the vehicle interface and its information must not be restricted. For details, see /26/.

Note: The relevant diagnostic information is available and reliable in today´s vehicles. Nevertheless, it should be made mandatory for Type Approval, and - like for OBFCM - the deviation accuracy should also be tested in TA.

	CRITERIA	STATIC LOAD TEST (1)	Q_{NOX} RATIO (2)	SPEED PUMPING (3)	SHORT DRIVE (4)	ASM20 ASM2050 (5)	ACCEL. DRIVE (6)	OBD/DIAGNOSTIC FUNCTIONS/ OBM (7)	COMMENTS
1.	Time for inspection (complete)	***	***	***	*	**	*	***	including warm up of vehicle, fixation of equipment/vehicle, test procedure, evaluation
2.	Required area for inspection	***	***	***	*	**	*	***	inside and outside a test hall or workshop
3.	Cost of equipment (complete)	***	***	**	**	*	**	***	including installation, maintenance, etc. in relation to existing equipment
4.	Feasability	***	***	***	*	*	*	***	integration into existing inspection (emissions/safety)
5.	Usability and requirements for staff/inspectors	***	***	*	**	*	**	***	Effort on training, also: influence of the operator (i.e., driver)
6.	Reproduceability	***	***	**	**	***	**	***	
7.	Dependence on weather conditions	***	***	***	*	***	*	***	inside a test hall or workshop: no dependency = very good = ***
8.	Recognition rate (fail / pass)	**	***	**	***	***	***	***	measured values (bad) divided by measured values (OK-state)
9.	Independence method from vehicle	**	*	*	***	**	***	*	Possible restrictions by the vehicle, e.g. engine speed limit, detection / not detection of movement, etc.
10.	Applicable to all vehicles	**	*** only for future vehicle	***	***	*	***	*** only for future vehicle	Cars, LDV, HDV
	Total:	**27**	**28**	**23**	**19**	**19**	**19**	**28**	

CONTACT DETAILS

CITA, the International Motor Vehicle Inspection Committee, is the worldwide not-for-profit association of governmental agencies and authorised private companies active on vehicle compliance.

Address: Rue du Commerce 123 – 1000 Brussels, Belgium
Phone: +32 (0)2 469 06 70
Email: secretariat@citainsp.org