Stationary NO_x measurements
A way to detect high NO_x emitting vehicles

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Summary

Background and project aim

In recent years a growing number of trucks with a faulty or manipulated exhaust after treatments system have been detected in Europe. With the main motivation relying in environmental and public health, the Danish Road Traffic Authority in connection with the Danish Police are continuously developing methods to track down and prosecute operators of manipulated vehicles.

Since heavy-duty vehicles operating on roads in Denmark as well as the rest of Europe are responsible for a significant part of the airborne emissions, it is important to closely monitor changed behavior in the truck fleet. With the introduction of the Euro VI legislation [1], new heavy-duty vehicles have been equipped with a selective catalytic reduction (SCR) system in order to reduce the exhaust emissions. This catalytic system works with a high efficiency in reducing the amount of nitrogen oxides (NO_x) in the exhaust. However, SCR systems are sensitive, require maintenance and use a consumable, called AdBlue®, to work properly.

A faulty or non-working system can result in emission levels 40 times higher in regards of NO_x compared to a healthy and working system. In accordance to the type approval, it should therefore not be possible to operate the vehicle over longer distances when the system breaks down or AdBlue® is missing.

For operators of heavy-duty vehicles, this is estimated to induce costs of up to 2000 euro on a yearly basis. When major services are needed costs can be even higher. In the highly competitive European road transport market, it is not surprising that a market has raised for solutions that overrides the trucks diagnosis systems, making it possible to operate the vehicle as if the systems were working.

These so-called defeat devices are cheap and easy to install. The driver can thereafter operate the vehicle without any restrains such as torque or speed reductions.

Tracking down the devices has become an increasing and prioritized challenge for law enforcement. As the systems are getting smaller, smarter and more sophisticated demands for instruments that make screening and fast detection possible has increased, supplementing traditional methods of detecting high emissions.

The performed study was therefore arranged in order to investigate the methodology and feasibility of performing stationary NO_x measurements with the goal of detecting faulty or not functioning exhaust aftertreatment systems.

Studies Conducted

The main focus of the study was to analyze an already existing database which contained the emission data from 49 conducted emission tests. These tests were performed according to the requirements for In-Service Conformity test for heavy-duty vehicles. It is expected that the emissions during standstill periods increase, mainly due to decreasing exhaust temperature and engine management strategy. Thus, the objective of the database analysis was focused on looking to standstill periods and identifying at which point the emissions start to increase and in which emission level they are. This gave the possibility of defining the risk for false-positives.

In addition to the database study, a market available instrument has been sourced and practical tests have been carried out, for checking it usage and reliability for standstill measurements. In other words, the focus of the practical tests was to evaluate the usage and handling of the instrument during stationary measurements. The testing was performed on trucks with healthy as well as manipulated exhaust aftertreatment systems.

Results

The results of the database analysis have shown that engine behavior during idling differs, since there are different strategies for emission control between different manufacturers and vehicles.

Generally, the emissions during standstill stayed on a constant level for the majority of the tests and did not raise significantly. Out of 49 analyzed tests, 12 tests showed an increase of emissions. However, the emissions in no case reached the level of engine out emissions, which are expected for a not functioning exhaust aftertreatment system. In 6 out of 49 tests, the emissions started to raise before 5 min, however with levels not going higher than 45 ppm. Hence, the emission data from manipulated vehicles, as well as engine out NO_x emissions data, show at least 4 times higher values during idling.

The study on the practicability of the mobile analyzer showed the reliability of the equipment. In addition, it was easy to handle and allow usage with minor introduction.

Conclusions

It is reasonable to use stationary NO_x measurements to identify unusual high emissions during standstill periods. Nevertheless, it is significant to know how the vehicle was driven prior to the stationary measurements. The exhaust temperature itself is not enough as a single indication to determine if the SCR has reached its working temperature. To ensure that the SCR is functioning during the stationary measurement, the control point for these measurements must be chosen carefully.

There are different types of AdBlue emulators, some that switch on the SCR during low vehicle speed or low engine speed. This fact makes it not possible to use a mobile NO_x analyzer during stationary measurements as a single indication for whether a vehicle is possibly tampered or has a nonfunctioning SCR.

Instead, the stationary NO_x measurements should be performed in combination with other methods like, for example, plume chasing.

Sammenfatning

Content

1. Introduction

This report presents the background and results of a project focused in investigating the usability and methodology of performing roadside stationary NOx measurements with mobile instruments. The project was carried out by AVL by appointment of the Danish Road Traffic Authority and conducted in quarter 4 of 2019.

The main focus of this study lays on the feasibility and the methodology of conducting stationary NOx measurements. Therefore, the main task was a database analysis of already existing data. However, a mobile NO_x analyzer was acquired, and tests were carried out on vehicles at AVL premises. The tests were designed close to how an actual roadside measurement during a control would look like.

The study serves to investigate the potential of market-available hardware solutions in for daily use by the police forces of Denmark.

1.1. Background

In Europe, emissions from traffic and in particular heavy-duty trucks is a growing concern for human health as well as for the environmental impact. The Danish Road Traffic Authority has a history of performing investigative studies focused on emissions from heavy-duty vehicles [2] [3].

In recent years, interest have been growing on developing methods for detecting tampering of SCR systems installed heavy-duty vehicles. As these cheating devices are getting more sophisticated, traditional investigative methods are no longer enough to track down and discover the devices. Therefore, emission measurement solutions, once seen as novelty, is now considered for law enforcement use. Furthermore, The Danish Road Traffic Authority has set up a team to consolidate and coordinate all studies focusing on truck emissions.

1.2. Activities

The project kick-off meeting was held in Odense, Denmark, on the 11th of October 2019.

First stage of the project was a study of existing reports and publications on the subject. Further on, AVL MTC´s database of PEMS tests as well as chassis dynamometer tests and results of engine test beds were analyzed. The focus was on how the emissions behave during standstill periods when the engine is idling. Thereafter the results were further analyzed, and practical tests planned. Collaboration partners were found, test vehicles sourced, and practical tests carried out during CW1949.

1.3. Organisation

AVL was granted the contract of conducting the study after biding on a letter of public procurement announced on the 11th of September 2019. Except from the project group from AVL, expert input has been sourced from industry leading companies as well as participating members from the Danish Authorities.

2. Background

Air quality control is a big challenge for many countries worldwide. The transport sector contributed to 24,6% of carbon dioxide (CO_2) [4] and the road transport contributed to 39% of NO_x emissions [5] in 2017.

To reduce and minimize the emissions, the European Union (EU) has set emission limits that all vehicles need to comply with, not only during type approval but also during normal use [1].

The following sections gives an overview of the emission legislation with a focus on the European Union, information on how and which emissions evolve from internal combustion engines, exhaust aftertreatment systems and emission measurement instruments.

2.1. Legislation

In 1992 Euro I for heavy-duty vehicles as well as Euro 1 for light-duty vehicles were introduced. Since then, the emission limits have significantly been decreased. The directives are typically stated as Euro 1 to Euro 6 for light-duty vehicles and with roman numbers (Euro I to Euro VI) for heavy-duty vehicles.

Figure 1 shows the maximal allowed NOx emissions in mg/kWh for transient test cycles regarding heavy-duty vehicles. Besides lowering the emission levels, the test cycles were changed as well. From the European Transient Cycle (ETC) for Euro III to Euro VI to the World Harmonized Transient Cycle (WHTC) for Euro VI.

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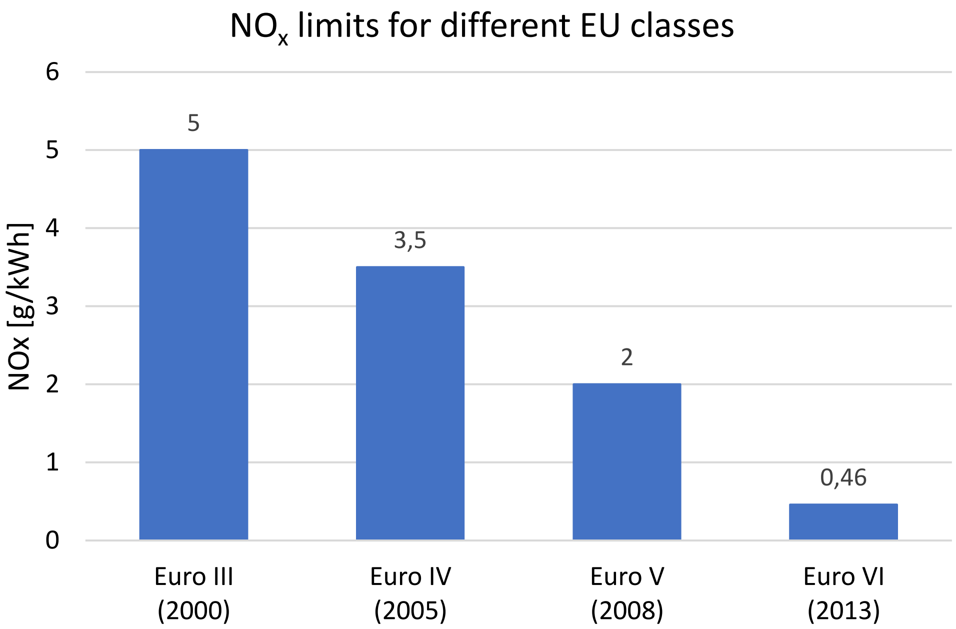

Figure 1 Comparison of NO_x limits for Euro III to Euro VI together with implementation date. The emission limits rapidly decreased with a big step from Euro V to Euro VI [6].

With the introduction of Commission Regulation 582/2011 it became mandatory to demonstrate the in-service conformity (ISC) of vehicles upon type approval. In the ISC tests the vehicles operates in their normal driving pattern conditions as well as payload. These tests are performed using a portable emission measurement system (PEMS). In section 2.4.1 the measurement system is further explained. The allowed emission limits for in-service conformity (ISC) are based on the emission limits for the World Harmonized Transient Cycle (WHTC) and a defined conformity factor. Multiplying the WHTC limit with the conformity factor gives the ISC Limit.

Table 1 Euro VI emission limits together with ISC-Limits for heavy duty vehicles

Component	Limit test cycle WHTC	Conformity-factor	ISC Limit
NOx	460 [mg/kWh]	1.5	690 [mg/kWh]
HC	160 [mg/kWh]	1.5	240 [mg/kWh]
CO	4000 [mg/kWh]	1.5	6000 [mg/kWh]
PM	10 [mg/kWh]	-	
PN	$6*10^{11}$ [#/kWh]	-	

2.2. Input from customer

Through discussion during meetings with the Danish Road Traffic Authority and interviews with the Danish Police it was clear that the focus on vehicles of the category N3. These are vehicles that are designed for the carriage of goods and exceed a maximum mass of 12 tons. Therefore, the database analysis was focused on N3 vehicles with some vehicles of the category N2 (maximum mass between 3,5 and 12 tons)

2.3. Emissions

In a complete combustion with ambient air, the exhaust contains carbon dioxide (CO_2), water (H_2O), nitrogen (N_2) and oxygen (O_2). In reality, there are other harmful emissions like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides like NO and NO_2 (NO_x), particles and others. [7]

2.3.1. NO_x

The main concern regarding emissions for diesel engines are nitrogen oxides (NO_x). There are three major chemical mechanism that produce NO_x: thermal or Zeldovich mechanism, prompt or Fenimore mechanism, and the combustion of fuel-bound nitrogen. The Zeldovich mechanism is the most significant one for internal combustion engines, in which Nitric Oxide (NO) is formed in high-temperature burned gases behind the flame front [7]. The percentage of NO in NO_x is around 60-90%. The equations 1, 2 and 3 below show the formation of NO.

$$O + N_2 \rightleftharpoons \mathrm{NO} + N \tag{1}$$

$$N + O_2 \rightleftharpoons \mathrm{NO} + O \tag{2}$$

$$N + OH \rightleftharpoons \mathrm{NO} + H \tag{3}$$

2.3.2. Exhaust aftertreatment system

As mentioned in 2.1, the emission limits were continuously reduced. Fulfilling the requirements and being below the allowed limits is, especially for NO_x, a challenging task. Over the years exhaust aftertreatment systems (EATS) were improved and new technologies developed. A modern EATS usually consists of four components:

- Diesel Oxidation Catalyst (DOC),
- Diesel Particulate Filter (DPF),
- Selective Catalyst Reduction (SCR) catalyst and
- Ammonia Slip Catalyst (ASC).

Sometimes there is an exhaust gas recirculation (EGR) system installed as well. Figure 2 shows schematically the setup and arrangement of the components of an exhaust aftertreatment system of a modern Euro VI truck. In reality, the different components are often together in a one-box design.

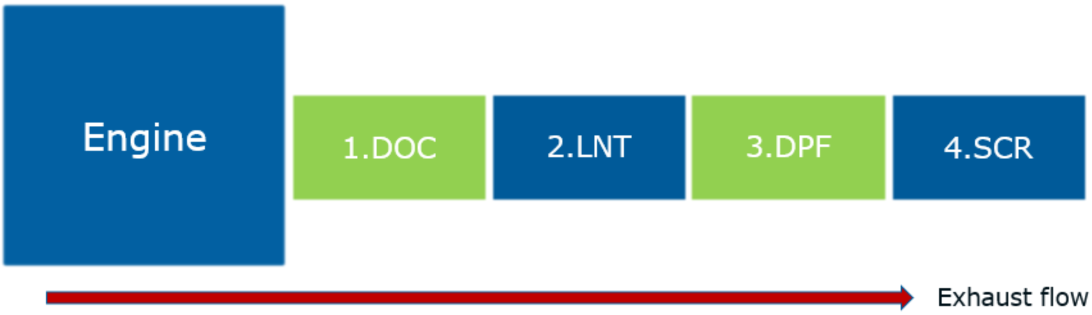

Figure 2 Schematic drawing of an EATS setup and the arrangement of the single components in the exhaust stream

The most crucial component for reducing NO_x emissions is the SCR, it can have a conversion of ratio of above 98%. The SCR system uses ammonia to turn nitrogen oxides (NO_x) to nitrogen gas (N_2) and water (H_2O). Due to the toxicity of ammonia, it is not directly stored on the vehicle and instead formed from an aqueous urea solution called AdBlue®. This solution is injected before the SCR catalyst and ammonia is formed through a twostep process. The equation can be seen below. Temperatures above 180°C are typically required. [1]

$$(NH_2)2CO \longrightarrow NH_3 + HNCO\ (Thermolyse) \tag{4}$$

$$HNCO + H_2O \longrightarrow NH_3 + CO_2\ (Hydrolyse) \tag{5}$$

NO_x is then reduced to N_2 and H_2O through the following equations. Equation 6 and 7 are the dominant one. At low temperatures (< 250°C) the reaction in equation 7 is dominant but is most efficient with a ratio of NO_2/NO_x of 50%. Therefore, a diesel oxidation catalyst is installed upstream of the SCR to oxidize NO to NO_2. [8]

$$4NO + O_2 + 4NH_3 \longrightarrow 4N_2 + 4H_2O \quad (6)$$

$$NO + NO_2 + 2NH_3 \longrightarrow 2N_2 + 3H_2O \quad (7)$$

$$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O \quad (8)$$

As described, for an SCR, AdBlue® is consumed and the consumption is around 4-6% of fuel consumption by volume.

2.3.3. AdBlue Emulators

Fault codes in the emission control system, reagent levels below a certain limit or low reagent quality cause the vehicle to trigger first a low-level inducement system with reduced engine torque and severe inducement system with a reduced vehicle speed to 20km/h (*creep mode*) [9].

To avoid maintenance costs for SCR systems or avoid adding AdBlue®, a larger market has evolved for so-called AdBlue emulators. These AdBlue emulators send a false signal to the engine emission control, confirming to the system that the exhaust after treatment system is working properly and preventing from going into *creep mode*.

These devices are often well hidden and difficult to detect. A comprehensive survey of AdBlue emulators market availability, different types of emulators and control methods has been conducted by [2]. AdBlue emulators can be divided into OBD installations, CAN installations, Passive components and software solutions (Reprogramming). Figure 3 gives and overview of these four main types. The ingenuity and sophistication of AdBlue emulators has evolved significantly over the years and the further they are developed, the more difficult they become to detect.

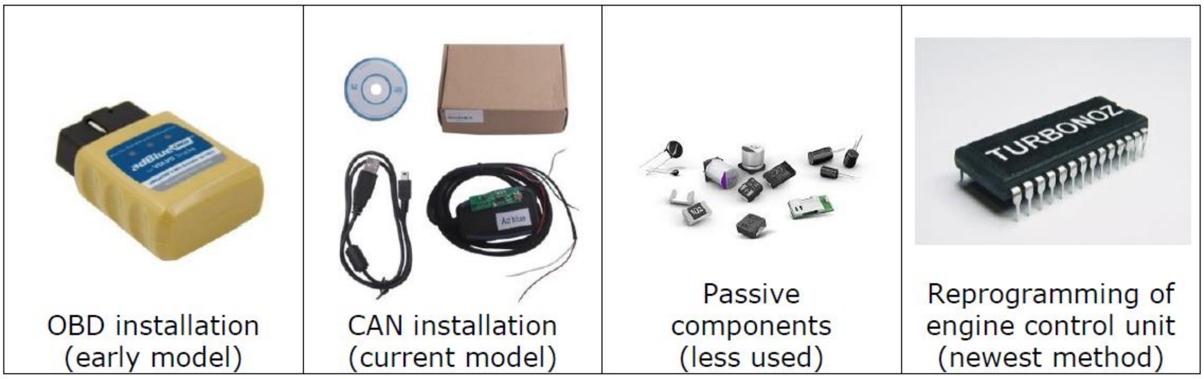

Figure 3 Overview of the four main types of AdBlue Emulators [2]

As written in 0 the efficiency of a well-functioning SCR systems can be up to 98%. Manipulating the SCR system has therefore a high impact on the NOx emissions. 30 times higher emission compared to a functioning SCR is not uncommon during an In-Service Conformity test. Roadside inspections in Denmark, Germany, Switzerland and Norway have shown that driving with a manipulated vehicle is not an uncommon practice [2].
Knowing this, the motivation behind detecting and finding AdBlue emulators is strong.

As AdBlue emulators are getting smaller and more sophisticated it draws new challenges in finding them. Besides the difficulties of physically finding a hidden AdBlue emulator installed somewhere on a large vehicle in a vehicle, there is the big challenge of detecting manipulated vehicles during driving.

2.4. Instruments

Different mobile instruments have been developed to measure emissions during real driving. In the following are the different instruments briefly explained.

2.4.1. PEMS

A Portable Emission Measurement System (PEMS) is a relatively small measurement system that is used for mobile emission measurements for Light-Duty, Heavy-Duty as well as Non-Road Mobile machinery. With the Commission Regulation 582/2011 coming in force, it became mandatory for truck manufactures to demonstrate the in-service conformity for their new type approved vehicles. The testing shall be repeated at least every two years over the useful life period which is 700.000km or 7 years for a heavy-duty vehicle of the category N3.

AVL is, among others, a manufacturer of PEMS equipment. The setup of different systems is similar. The instrument for passenger cars is either mounted on the tow hook or in the trunk. For heavy duty vehicles it is usually installed in the truck box or in a purpose build trailer. An exhaust flow meter (EFM) is fit after the original exhaust pipe to measure the exhaust mass flow and be able to define mass emissions. Sampling points are installed after the EFM and transport exhaust gases through heated lines to the PEMS instrument.

To calculate the emission factors in g/kWh it is necessary to read out data from the vehicle to be able to calculate the work. An OBD reader, reads out the needed signals from the vehicle through the OBDII connection. In addition to the PEMS equipment and EFM there are also ambient sensors for temperature, humidity and pressure installed as well as a GPS antenna. Batteries or generators are usually used to provide sufficient power to the equipment. Figure 4 shows a PEMS equipment installed on a passenger car and Figure 5 shows the whole setup for a heavy-duty vehicle.

Figure 4 AVL PEMS equipment installed on the tow hook of a passenger car. Typical setup during a Real-Driving Emission (RDE) test

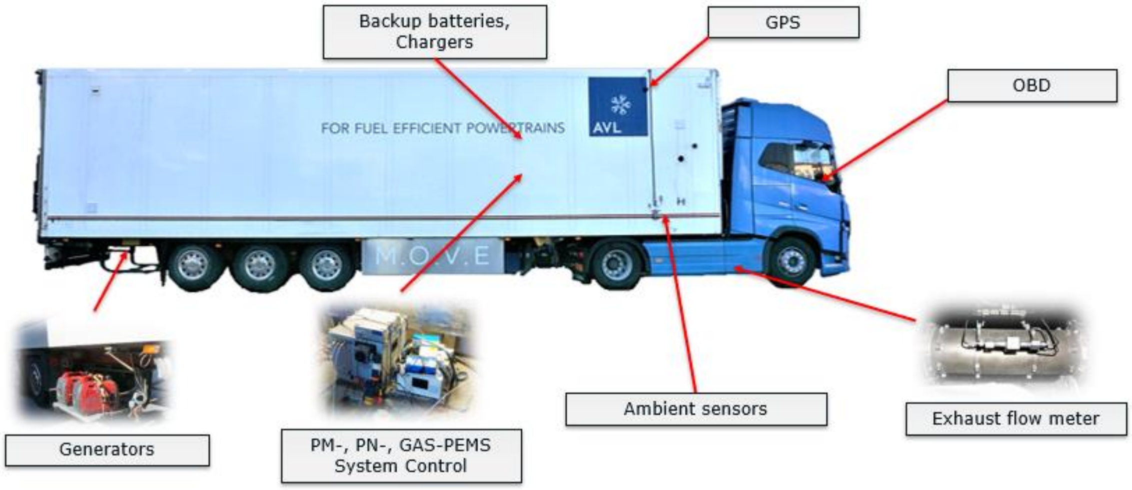

Figure 5 Overview of the PEMS equipment installation on a heavy-duty vehicle for an In-Service Conformity test. Showing the different components and their placement on the vehicle

The benefit of PEMS over traditionally used test bed testing is that emissions are measured on-road. Besides that, there is the cost effectiveness and the relative fast installation.

Although relatively fast compared to test bed testing, it still requires modifications to exhaust system and installation of equipment on the vehicle. The idea of mobile NO_x screening would be without any direct interaction with the vehicle. This makes PEMS not suitable for these activities. In this study, the PEMS is used to define the current state of the tested vehicle, in regards of emission levels and to see if the vehicle complies with the limits allowed for In-Service Conformity.

2.4.2. Portable NO_x Analyzer

There are several manufactures for portable NO_x analyzer. The analyzers can be in different forms for example as a handheld instrument or portable with a handle or carrying case., as stationary instrument. Depending on the configuration they are powered by their internal batteries or need and external power supply. Figure 6 gives an overview of different analyzers.

Figure 6 Overview of different type of portable NO_x analyzer [10] [11] [12][13]

Despite form factor, all studied analyzers use an electrochemical sensor for measuring NO_x. The produced signal is directly proportional to the concentration (% or ppm).

The typical measurement range for a portable NO_x analyzer is around 0-1000ppm for NO and 0-500ppm for NO_2. The accuracy is ±5ppm or ±5% depending on the level of concentration [11]. For the intended use this principle provides enough accuracy.

Most of the studied instruments are modular, which gives the user ability to outfit the instrument with analyzers for the desired emission components. For instruments in the higher price range, it is also common for the user to be able to choose sampling lines with internal heating and probe clamps, suitable for vehicle tailpipe measurements. Prices vary from around 3000 € for handheld variants analyzers to approximately 8000 € for the analyzers equipped with heated lines and more features.

The studied instruments are easy to use and require little introduction. The interfaces are typically easy to read and have an illuminated display. The studied instruments are typically not weather, or water protected. Their focus is towards indoor usage but can be protected using optional protective cases.

3. Methods

The following section describes how the database analysis was conducted, which vehicles were tested and how the practical tests were conducted.

3.1. Database analysis

For the database analysis, 49 different PEMS tests were analyzed. The selected tests were performed according to the requirements for In-Service Conformity for heavy duty vehicles. Thus, the trip share of the test is defined in urban, rural and highway with a specific share per section. For the analysis of emissions during standstill, only tests with a minimum period of 2 min or longer were selected. This timeframe is considered as the minimum time to stop a vehicle and start the stationary NO_x measurements. Stops during highway driving are considered of particular interest since a roadside control would be most practical to perform in connection to highway parking lot. Nevertheless, stops during urban and rural were analyzed as well. However, the stops in the beginning of the test, where the exhaust aftertreatment has not reached its required temperature, were excluded.

Figure 7 shows an example of the time resolved results from one PEMS test in terms of engine speed [rpm], NO_x results [ppm], velocity [km/h] and exhaust temperature [°C]. The stops were then successively selected and analyzed. The length of the stop, the emission level and the moment when the emission starts to rise were noted.

The allowed emission limits, (see section 0), are regulated as specific emissions in mg/kWh. However, defining specific emissions during stationary NO_x measurements, would require acquiring engine data in order to calculate the performed work. During roadside measurements this is considered as impractical due to the complexity of operation and the limited timeframe available for the acquisition. This would then complicate measurements procedures and require additional time.

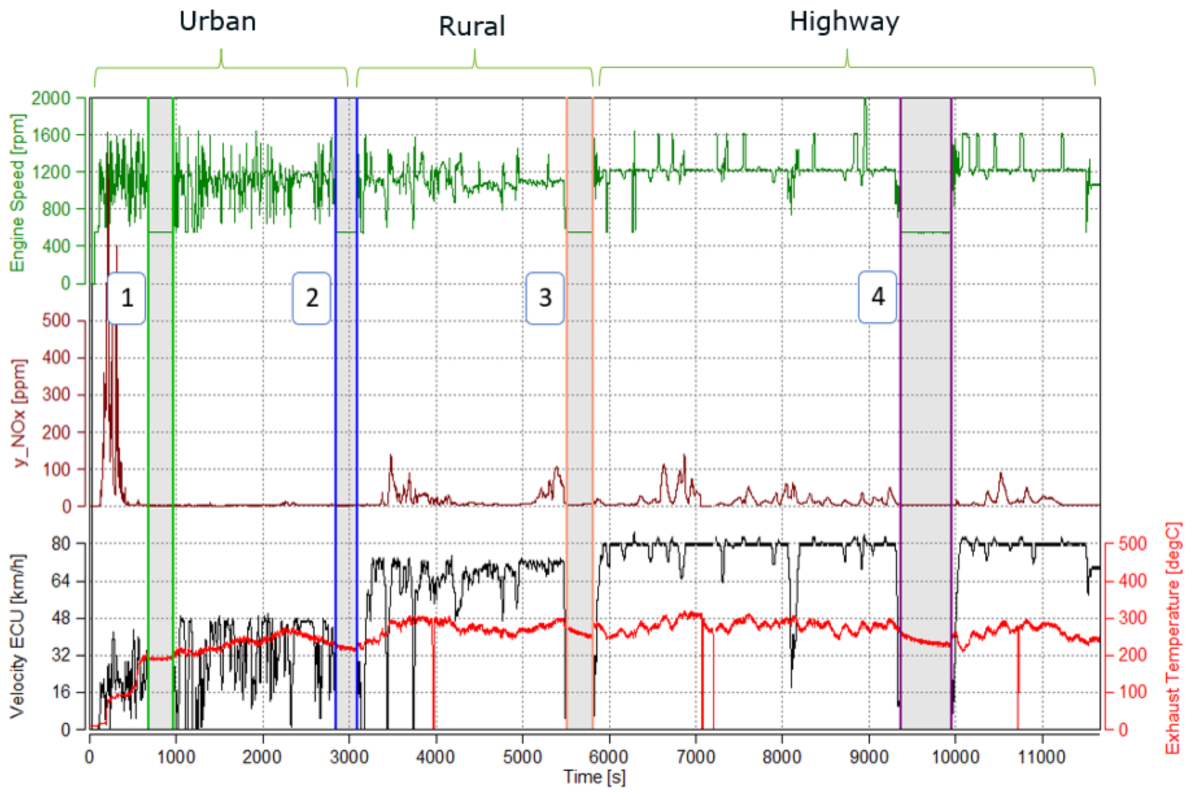

Figure 7 Example of an analyzed standstill period. The figure displays the emission results as well as exhaust temperature, vehicle velocity and engine speed. The results are from an In-Service Conformity test with a required share of urban, rural and highway.

3.2. Practical tests

The practical tests were conducted on two different vehicles with a mobile NO_x analyzer from the manufacturer MRU GmbH. In the following part the test vehicles as well as the instrument are described.

3.2.1. Test vehicles

The two tested vehicles were both Euro VI in vehicle category N3. For both vehicles, the exhaust aftertreatment systems were equipped with an SCR. An overview of the specifications can be seen in

Table 2 Overview of the two tested vehicles

	Vehicle 1	Vehicle 2
Model year	2017	2015
Emission standard	Euro VI	Euro VI
Vehicle category	N3 (Tractor)	N3 (Rigid)
After treatment system	EGR, DOC, DPF, SCR, ASC	
Engine	13L, 375kW	9.3L, 265kW
Fuel	Diesel (Market fuel)	Diesel (Market fuel)

3.2.2. Practical tests of mobile NO_x analyzer

To perform practical tests a mobile NO_x analyzer was acquired. As said in 1.1 the focus lays on the feasibility of performing stationary NO_x measurement and how those would be conducted than on the instrument used. For these tests, an MRU Vario Luxx analyzer was acquired. The particular instrument was chosen based on availability and configuration and was easily acquired though a local retail company. Table 3 shows the technical overview and Table 4 the measurement range as well as accuracy of CO, NO and NO_2.

A picture of the actual instrument is presented in Figure 8.

Table 3 General technical data of the acquired mobile NO_x analyzer

Typical properties	
System warming up time	Typically, 30min (according to manufacturer)
Power consumption	~ 105W, 86 - 265V, up to 600W during heat up
Typical gas flow	90l/h
Interface to external PC	Ethernet, Bluetooth, WLAN, RS232
Display	7" TFT colour display with touch pad, illuminated
Internal battery	Li-Ion, 48W, for standby
Protection class	IP20
Weight	7.5 kg, minimal configuration
Size	430 x 290 x 150 mm (W x H x D)

Table 4 Overview measurement range and accuracy of acquired mobile NO_x analyzer

Measurement components	Meas. range	Accuracy
CO	0 - 10.000 / 20.000ppm	± 10 ppm or 5% reading
NO	0 - 1.000 / 5.000ppm	± 5 ppm or 5% reading
NO_2	0 - 200 / 1.000ppm	± 5 ppm or 5% reading

As can be seen in Figure 9, the sampling probe was not prepared to measure at an exhaust pipe because there was no clip or mount to attach the probe to the exhaust endpipe. However, other sample probes that is more fit the purpose can be found. Therefore, the sampling probe was placed underneath the vehicle and reached far enough inside the exhaust pipe.

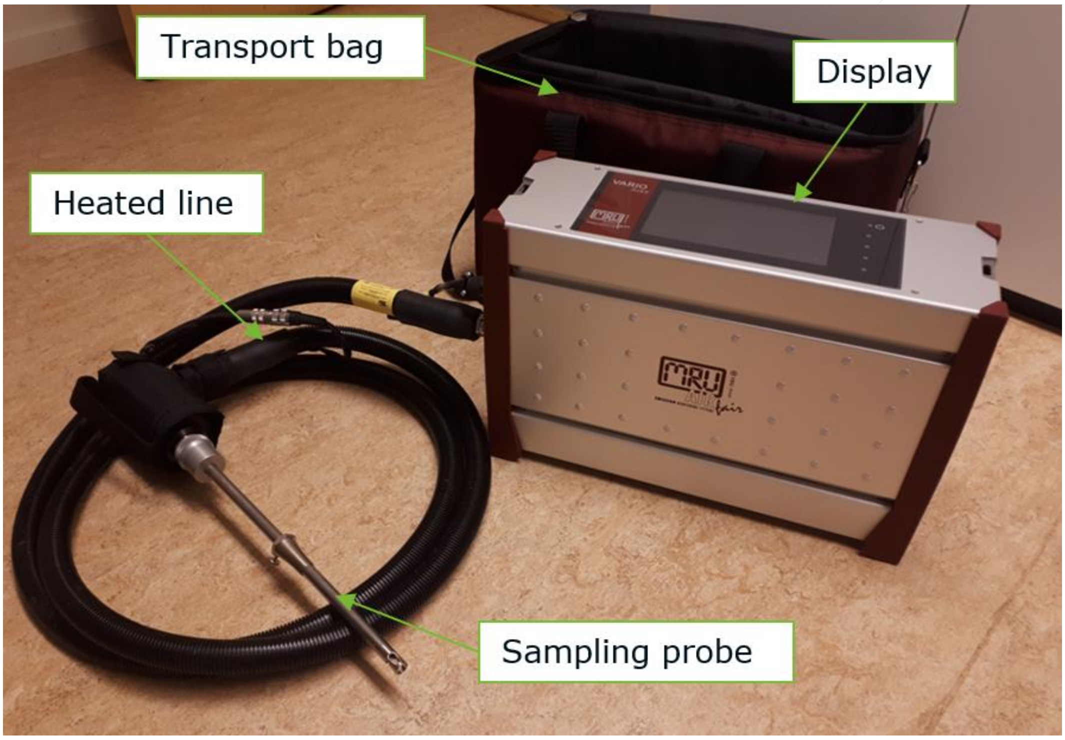

Figure 8 MRU Vario Luxx mobile NO_x anlayzer used for practical testing

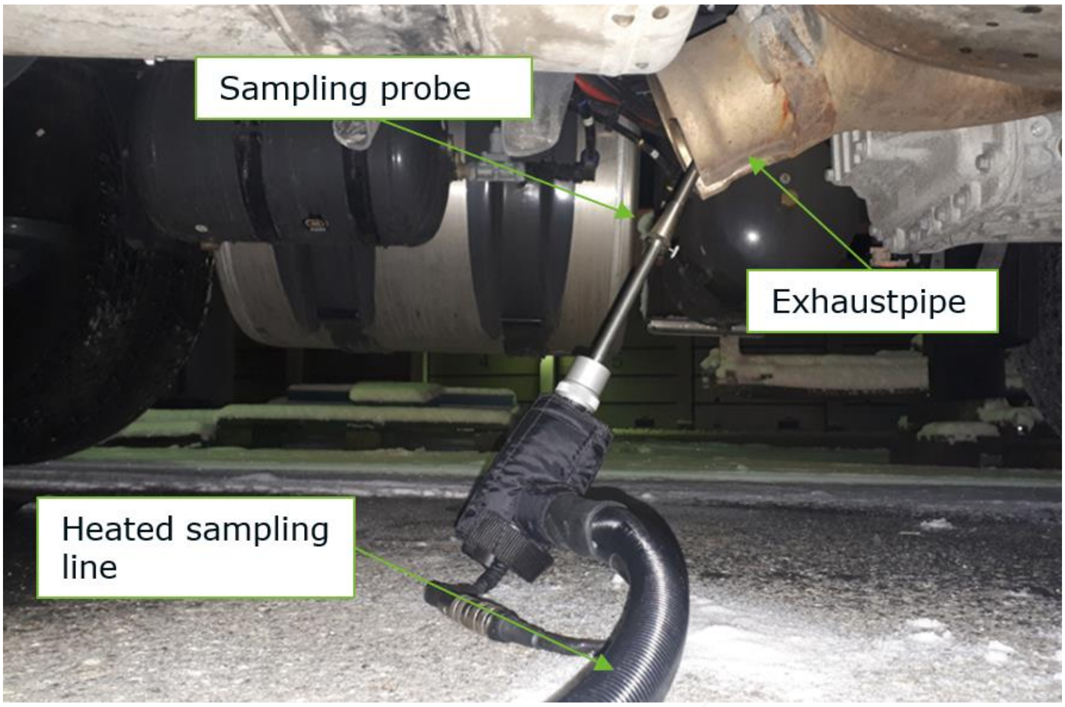

Figure 9 Mobile NOx analyzer probe while testing vehicle 1

4. Results

This section contains the results from the database analysis as well as practical test. Furthermore, are the practicability and availability of the mobile NO_x analyzers highlighted.

4.1. Practicability and Availability

NO_x instruments are cost effective, easy to handle and commonly available from a number of manufactures. As a measurement method, it has the benefit of not requiring extensive training or education to use it. In addition, for better measurements and precision, It should be considered to use an instrument with a heated probe and sampling line in order to avoid condensation and inaccurate measurements due to moisture build up in the sampling line. A flexible probe with a clamp should be useful to fit most exhaust configurations.

Some of the studied instrument featured an interface for reading the results in a tablet or smartphone with the use of a Bluetooth function. This should be useful since some exhaust layouts require instrument installation underneath the vehicle.

It is believed that the method has limited use as a tool for roadside measurements due to the restrains and boundaries set up by the investigated trucks aftertreatment systems, engine management strategies, etc., combined with the relative long measurement time needed.

The instrument could however be implemented as a tool for inspection services, such as PTI, for in depth analysis of suspicious vehicles, fleet monitoring, etc. In these situations, there is more time allowed for the measurements, and proper heating of the engine and aftertreatment system. can be assured by driving prior testing is conducted.

4.2. Results database analysis

The database has been analyzed as described in section 3.1. In the following are the NO_x emission results from three different vehicles graphically displayed. All results from other vehicles and tests are summarized in Table 5.

Figure 10 shows a stop after around 2 hours and 30 minutes of driving. The total length of the stop is almost 10min. The NO_x emissions stay constantly on a low level of 5-10ppm and the exhaust temperature decreases only slightly.

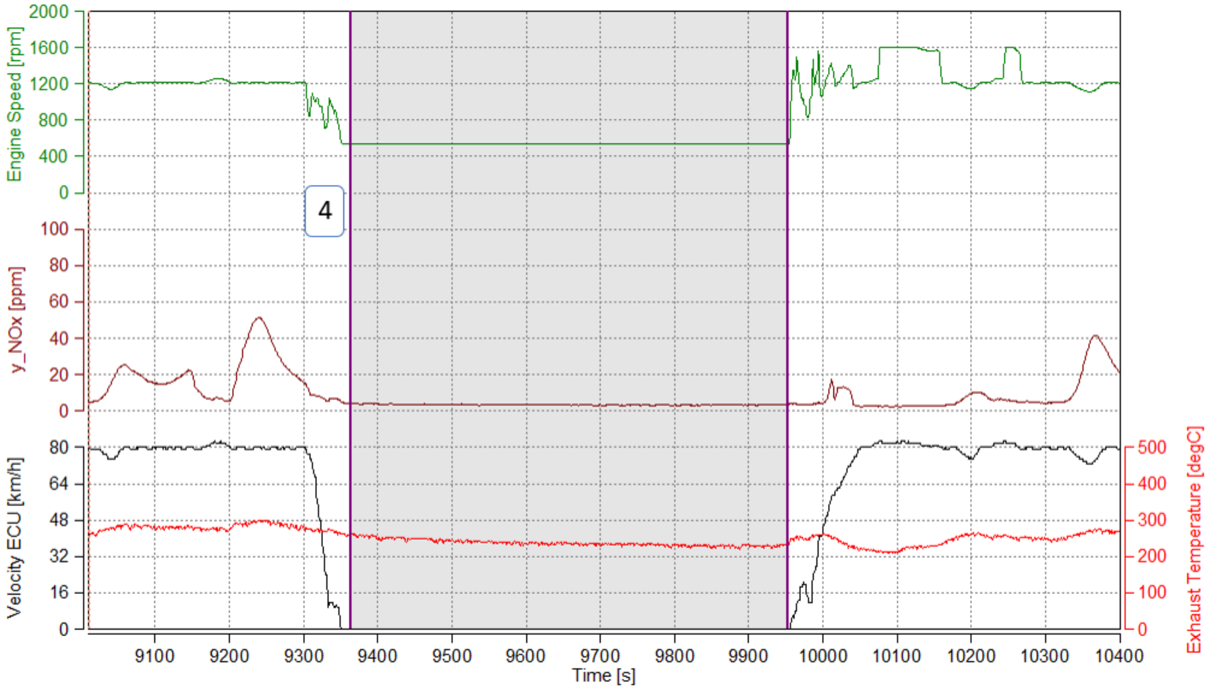

Figure 10 Example 1, closer look at standstill period, stable emission levels. Time on x-axis presented in seconds [s]

Figure 11 shows a 4 min stop after 1 hour and 24 min of driving. The NO_x emissions are at the begin of the stop stable at around 30ppm. After about 2 minutes the emissions start to increase slowly towards the end of the stop to 50ppm.

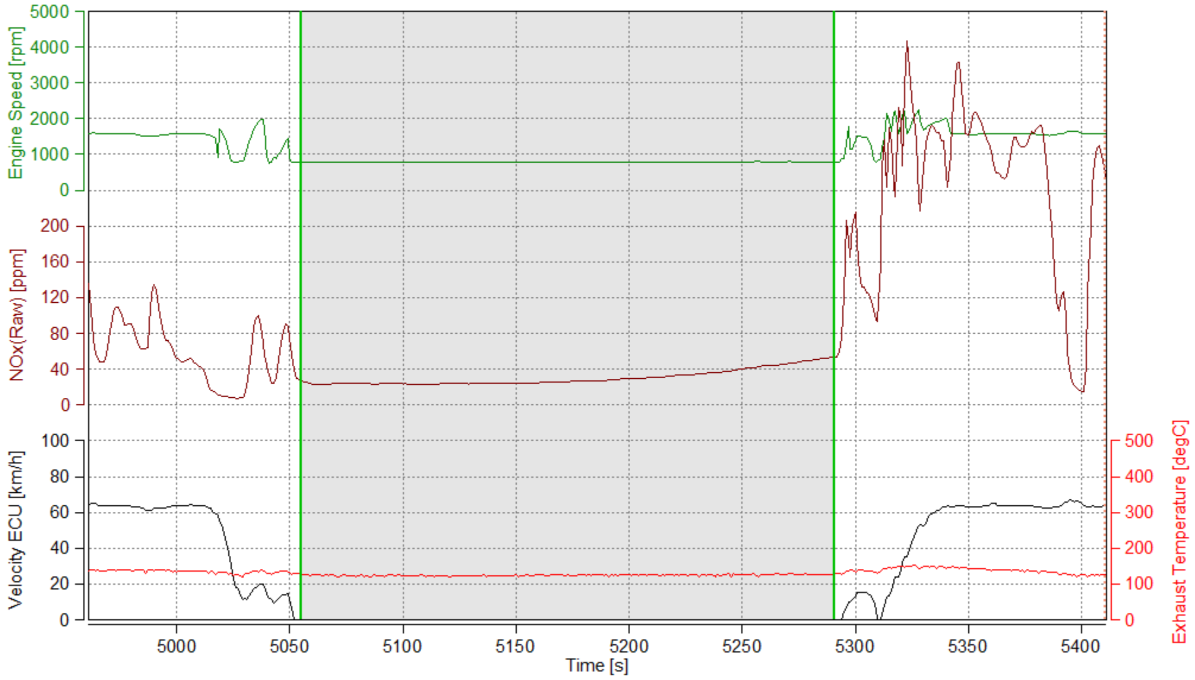

Figure 11 Example 2, standstill period with rising emissions after about 2min into the standstill. Time on x-axis presented in seconds [s]

Figure 12 shows example 3, a standstill period after around 1 hour and 30 minutes of driving. The total stop length is nearly 4 minutes. The data is from a vehicle where the urea injection was not functioning, therefore resulting in engine out NO_x emissions. Throughout the whole stop the NOx emissions stay on a quite constant level of ~250ppm.

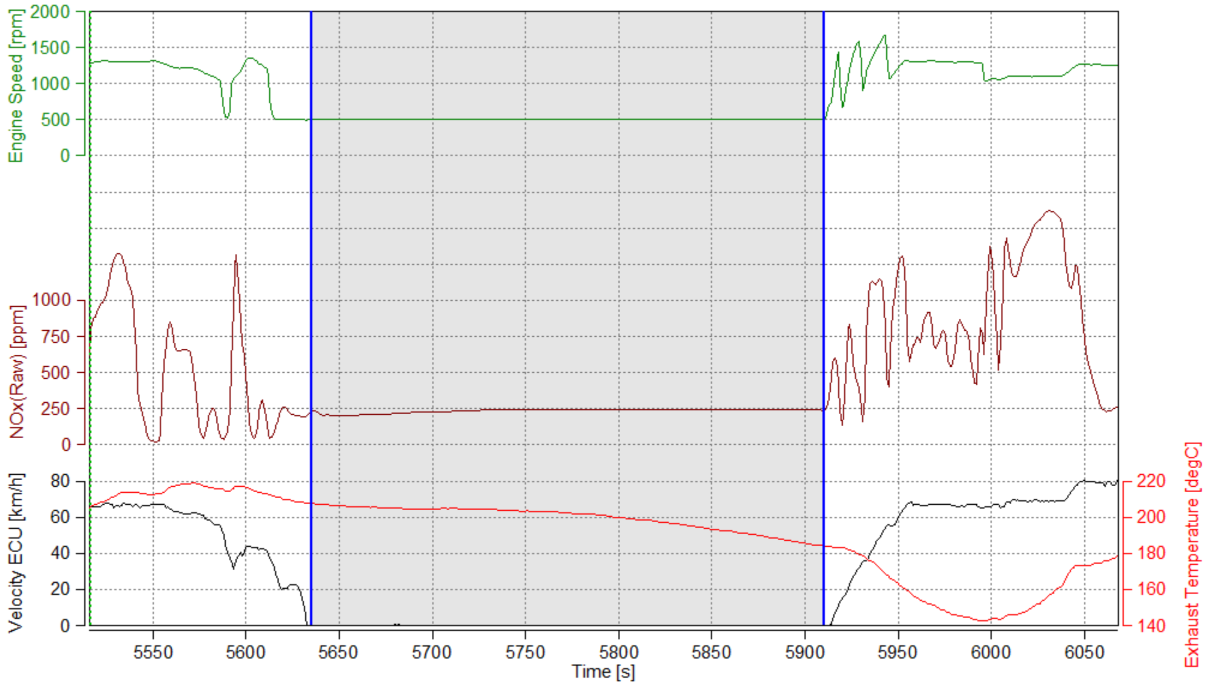

Figure 12 Example 3, standstill period of a vehicle with not functioning urea injection. NO_x emissions are constantly on an unusual high level. Time on x-axis presented in seconds [s]

The examples from Figure 10 to Figure 12 shows pretty constant emission results. However, there are test results with more fluctuating results. Figure 13 show the results from an around 10 minutes long stop where the emissions increase after approximately 5 minutes and starts alternating.

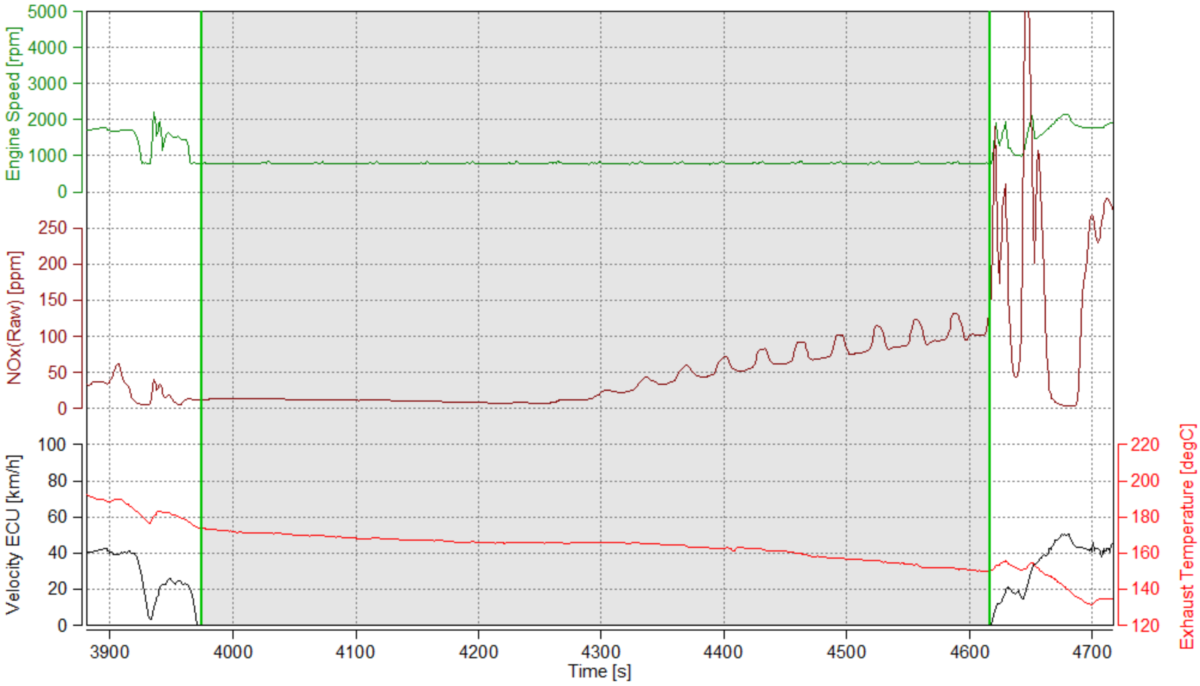

Figure 13 Example 4, increasing and varying emissions after around 5 minutes of standstill. Time on x-axis presented in seconds [s]

An extract from the table of the standstill analysis is shown in Table 5. From 12 out of 49 tests do the emissions increase during the standstill period. In only two cases do the emission increase to more than 100ppm. In one example to around 100ppm after 10 minutes and 30 seconds, in another example to 150ppm after 8 minutes 30 seconds.

Table 5 Extract of database analysis. The orange marked cells highlight the tests with a rise of NO_x emissions during the standstill period.

Test #	Vehicle Cat.	Year	Displacement [l]	Engine rating [kW]	Euro class	1st Stop [min]	2nd Stop [min]	3rd stop [min]	4th stop [min]	Emission rise [Y/N]	At time? [min]
1	N3	2017	12,8	345	EU VI	4,9	4	5	8,85	N	-
2	N3	2017	12,8	345	EU VI	4,5	4	4,9	10	N	-
3	N3	2017	12,8	345	EU VI	4,8	4	5,1	10	N	-
4	N3	2017	12,8	345	EU VI	4	3,85	4,9	9,8	N	-
5	N3	2017	12,8	345	EU VI	4	5	10		N	-
6	N3	2017	12,8	345	EU VI	3,9	4,9	6,3		N	-
7	N3	2017	12,8	345	EU VI	4,1	4,9	10		N	-
8	N3	2017	12,8	345	EU VI	4,3	5,4	10,3		N	-
9	N3	2017	12,8	345	EU VI	4,2	5,1	10,4		N	-
10	N3	2017	12,8	345	EU VI	3,8	5,4	10,3		N	-
11	N3	2017	12,8	345	EU VI	4	5	9,7		N	-
12	N3	2017	12,8	345	EU VI	4,2	5,3	10,3		N	-
13	N3	2014	6,7	208	EU VI	3,4				N	-
14	N3	2018	7,7	210	EU VI	5				N	-
15	N2	2016	3,0	125	EU VI	10,6				Y	5,2
16	N2	2016	3,0	125	EU VI	2,9				N	-
17	N3	2014	12,4	353	EU VI	8,25	5,8	6,1		Y	10 seconds (2nd stop) after 68 seconds (3rd stop)
18	N3	2014	12,4	353	EU VI	6,2	6,5	4,7		Y	78 second (2nd stop) 55 seconds (3rd stop)
19	N3	2014	16,4	537	EU VI	7,5				Y	234 seconds
20	N3	2014	7,7	188	EU VI	3,3				N	-
21	N3	2016	7,7	175	EU VI	1,8				N	-
22	N2	2017	4,6	110	EU VI	4				N	-
23	N2	2017	4,6	110	EU VI	4,6				N	-
24	N2	2017	4,6	110	EU VI	4,1				N	-
25	N2	2017	4,6	110	EU VI	5				Y	149seconds
26	N2	2017	4,6	110	EU VI	8,6				Y	336
27	N2	2017	4,6	110	EU VI	5,4				Y	152
28	N2	2016	5,1	177	EU VI	15,3				N	
29	N2	2016	5,1	177	EU VI	5,8				N	-
30	N2	2016	5,1	177	EU VI	3,2				N	-
31	N2	2016	5,1	177	EU VI	4,6	4			N	-
32	N2	2016	5,1	177	EU VI	3,5	3,9			N	-
33	N3	2016	7,7	175	EU VI	4,5	6,9	3,6		N	-
34	N3	2016	7,7	175	EU VI	6,9	3,8	3,7		N	-
35	N3	2016	7,7	175	EU VI	6,4	2,2	3,1		N	-
36	N3	2017	12,7	331	EU VI	2,4				N	-
37	N3	2014	16,1	552	EU VI	18,8				Y	9,5
38	N3	2014	16,1	552	EU VI	20				Y	13,8
39	N3	2014	16,1	552	EU VI	25,6				Y	15,4
40	N2	2014	4,5	157	EU VI	3,9				N	
41	N2	2014	4,5	157	EU VI	2,9				N	
42	N2	2014	4,5	157	EU VI	4,3				N	
43	N3	2014	6,9	185	EU VI	3,5				N	
44						3,8				Y	2,2
45						3,8				Y	just after the stop
46						3,8				N	
47						4,1				N	
48	N2	2014	7,7	175	EU VI	5				N	
49	N2	2014	7,7	175	EU VI	5				N	

4.2.1. Results practical tests

For the practical tests, a series of measurements on different scenarios were carried out. The reasons for the tests was mainly to see the practicability and handling of the instrument. However, project scope did not include the build of an extensive emission measurement database conducted with portable NO_x analyzer.

Figure 14 shows the results from 15 minutes idling after a dynamic drive for about 30minutes. Both vehicles were tested in a non-manipulated state. It can be seen that the emission for both vehicles stay low until around 15 minutes. The emissions from Vehicle 2 start to raise and reach 130ppm at 15 minutes of testing time. As said in section 3.1, the results are vehicle and engine specific and the results cannot be interpreted as general. Therefore, the results from the practical test do only apply to those specific vehicles. However, with a high enough number of tests it is possible to calculate statistical probabilities.

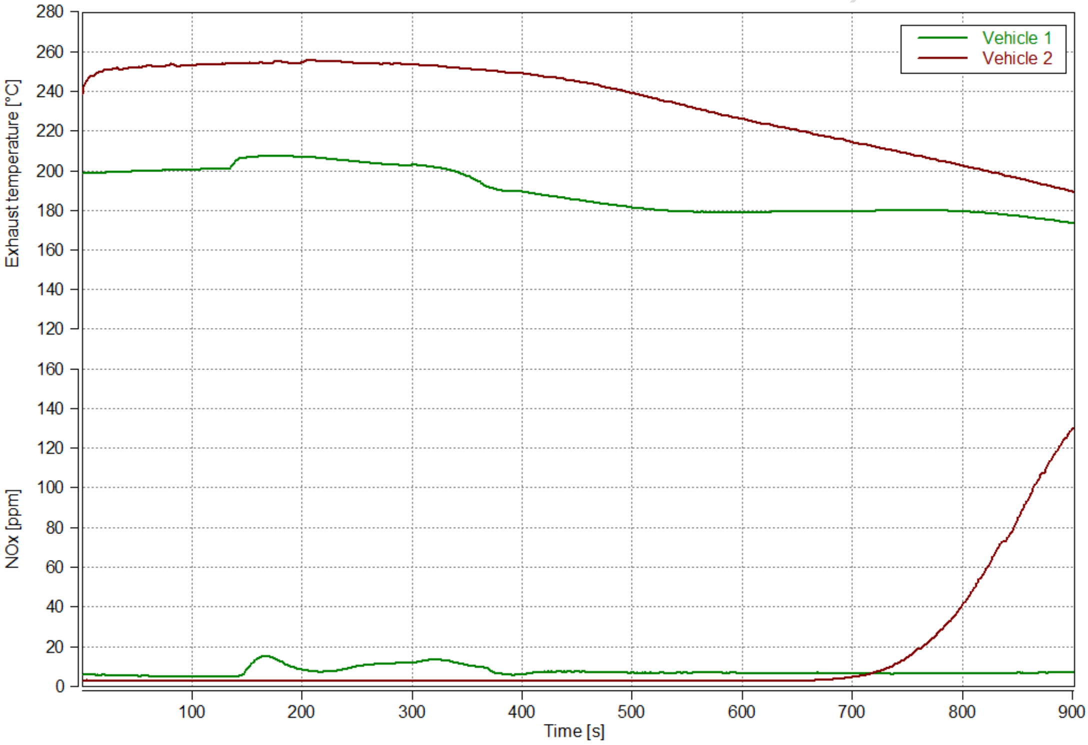

Figure 14 NOx emissions of Vehicle 1 and 2 during idling after a long driving. Constant low emissions of vehicle 1. Increasing emissions of vehicle 2 after 700s. Time on x-axis presented in seconds [s]

5. Conclusion and Discussion

The study presented covered an evaluation of the feasibility of using portable NOx analyzer for stationary measurements to identify high NOx emission from a possible stationary NOx measurement plume chasing method for detecting heavy-duty high NO_x emitters. For that, an extended research was performed to understand the needs for the method and to know the state-of-art.

The database analysis has shown that engine behavior during idling differs. There are different strategies for emission control between different manufacturers and vehicles.

Generally, the emissions during standstill, stayed on a constant level for most of the tests and did not raise significantly. Out of 49 analyzed tests, 12 tests showed an increase of emissions, however, the emissions did not reach the level of engine out emissions. In 6 out of 49 tests, the emissions started to raise before 5 min but to no more than a NO_x concentration of 45 ppm. Data from manipulated vehicles, as well as engine out NO_x emissions data, show at least 4 times higher values.

From this perspective, stationary NO_x measurements can under defined circumstances be used to identify unusual high emissions during standstill periods. Nevertheless, it is significant to know how the vehicle was driven prior to the stationary measurements. The exhaust temperature itself is not enough as a single indication to determine if the SCR has reached its working temperature. Different manufactures and vehicles use different types of SCR with different required working temperatures. To ensure that the SCR is functioning during the stationary measurement, the control point must be chosen carefully. Ideally, a parking lot on a highway or a parking by an exit should be selected where there is no other exit for at least 15min prior to the control point. A control point in an urban or rural section are not considerate as suitable.

Furthermore, the focus during stationary measurements should not be on single emission values. Instead the behavior and trend of the NO_x emissions should be analyzed. Therefore, an instrument that records and logs the measurements is most suitable. To be able analyze the data, background knowledge of in general internal combustion engines as well as exhaust emissions would be required.

Instruments for stationary NO_x measurements can be considered as practical for the intended use. However, they require a significant start up time, and it is not possible to perform a spontaneous measurement. In that case it is needed to have the instrument in a standby state before stopping a vehicle.

As mentioned in section 2.3.3, there are different type of AdBlue emulators, some that switch the SCR on during for example low vehicle speed or low engine speed. This fact makes it not possible to use a mobile NO_x analyzer during stationary measurements as a single indication for whether a vehicle is possibly tampered or has a nonfunctioning SCR. Instead, a combination of plume chasing, and stationary measurements would be recommended. If for example the measurements from the plume chasing indicate that the vehicle is a high emitter, but the stationary measurements indicate the opposite, then this discrepancy would awake the interest for further investigation.

Færdselsstyrelsen

AVL

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