SEMS equipment in connection with periodic technical inspections (PTI) of lorries

SEMS-udstyr i forbindelse med periodesyn på lastbiler

Report - Test of Heavy-Duty Trucks

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On behalf of Færdselsstyrelsen

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Content

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1. List of Abbreviation

CO	Carbon monoxide
CO_2	Carbon dioxide
EURO V and VI	EU emission standards for heavy-duty CI (diesel) engines
FC	Fuel consumption
NO_X	Nitrogen oxides
OBD	On-Board Diagnosis
PEMS	Portable Emission Measurement System
PM	Particle Mass
PN	Particle Number
RDE	Real Driving Emissions
STA	Swedish Transport Agency
PTI	Periodical Technical Inspection
WHTP	Worldwide harmonized Heavy vehicles Test Procedures
SCR	Selective Catalytic Reduction
EGR	Exhaust Gas Recirculation

2. Summary

On behalf of Færdselsstyrelsen, EXIS together with ECM and Applus Denmark have carried out a project named "SEMS equipment in connection with periodic technical inspections (PTI) of lorries"

The main question to which this work would provide answers was if SEMS equipment could be a useful tool for PTI on heavy-duty vehicles. This study clearly show that the answer is "Yes". The study also shows that the use of NOx Index is a powerful measure to use in this case and it´s highly effective in finding vehicles with problems (high emitters) as well as manipulated vehicles. For example, cheating with urea supply is very easily detected.

In this study, 26 Heavy duty trucks have been tested with respect to NOx emission and the function of exhaust gas aftertreatment system. All tests, except one, have been performed at the Applus Denmark PTI station in Kolding (Nord). Prior to the test campaign in Kolding, one test was carried out in Gothenburg, Sweden.

The tests at Applus in Kolding in this study and prior tests at Bilprovningen in Gothenburg both show that it is possible to integrate this test procedure and tools in the regular PTI process. It took roughly about 10-20 minutes per vehicle to carry out the test, including mounting of the test equipment, driving the test route and de-mounting the test equipment. The time for test may be improved for the future with some fine tuning of the exhaust probe, heavy duty cabling and new algorithms for detecting when the aftertreatment system is warm enough for performing the test. These things could be the scope for further investigations.

The main concept for the tests in this study has been based on doing an arbitrary and short test route (~4km) in connection to the PTI station and in combination with measuring the NOx Index using a PEMS-system named EZ-PEMS from ECM. The big advantage of this concept is that it can be implemented at any PTI station with low investment cost and that it is fast and accurate. With this concept it does not matter so much what the test route looks like in terms of speed and elevations and therefore supports the idea behind measuring RDE in an efficient way. Prior to all tests, the vehicles were driven so they reached a fully warmed-up aftertreatment system.

Earlier studies have clearly showed that it is possible to assess a vehicles' emission performance by just investigate the emission index, EI. Index means that the exhaust component is related to the CO_2 level. This study confirms that it works in this way for HD-trucks and resulted in suggesting the following limits during PTI:

- NOx Index < 1,0 for EURO VI
- NOx Index < 5,5 for EURO V

The assessment is that these levels are high enough to not reject fully functional vehicles without false positives and low enough to find defective vehicles. These levels can be adjusted and may need a higher number of vehicles to be tested to provide a better statistical basis before being finally determined.

With respect to the suggested limits, 4 of 20 EURO VI and 3 of 5 EURO V vehicles failed the test. When urea was turned off (manipulated) 2 of 2 EURO VI failed. By this manipulation, the EURO VI vehicles were no better than a 25-year-old EURO II Trucks with respect to NOx emissions. Likewise, it should be mentioned that some of the Euro VI vehicles had exceptionally low NOx levels, indicating the great potential of a well-functioning aftertreatment system and engine control strategy.

The actual tests performed will not state what the cause is for failing a test, but if data is continuous generated and compiled as in this study, then it will give an indication of why there is a problem. If the urea is turned off that is very easily detected since the NOx concentration levels and NOx Index are significantly increased. For trucks that may have an aftermarket tune or a malfunctional exhaust aftertreatment system but

with no check engine lamp active further technical inspection will be required by a workshop. Some of the failed trucks showed continuously higher NOx levels while some seemed to have it mainly during transients, which can be due to the design of the engine/aftertreatment or due to that an aftermarket tune is used on the vehicle.

3. Dansk Resumé

På vegne af Færdselsstyrelsen har EXIS sammen med ECM og Applus Danmark udført et projekt kaldet "SEMS-udstyr i forbindelse med periodiske syn af lastbiler"

Det vigtigste spørgsmål, som dette arbejde skulle give svar på, var, om SEMS-udstyr kunne være et nyttigt redskab ved periodiske syn af tunge køretøjer. Dette forsøg viste tydeligt, at svaret er "Ja". Forsøget viste også, at anvendelsen af NOx-indekset er et vigtigt målesystem i dette tilfælde, og at det er meget effektivt til at finde køretøjer med problemer (køretøjer, der udsender høje emissioner) såvel som manipulerede køretøjer. Det er for eksempel meget let at opdage, hvis der snydes med urea-forsyningen.

I dette forsøg er 26 tunge lastbiler blevet testet for NOx-emissioner, og for hvordan systemet til efterbehandling af udstødningsgas fungerer. Alle disse test på nær én er blevet udført hos Applus Danmarks PTI-station i Kolding (Nord). Før testkampagnen i Kolding var en test blevet udført i Gøteborg, Sverige.

Testene hos Applus i Kolding gennemført dette projekt og tidligere test hos Bilprovningen i Gøteborg viste begge, at det er muligt at integrere denne testprocedure og disse måleinstrumenter i den regelmæssige periodesyn. Det tog cirka 10-20 minutter for hvert køretøjer at gennemgå testen, herunder montering af testudstyr, kørsel af testruten og afmontering af testudstyret. Testtiden kan måske forbedres i fremtiden med lidt finjustering af udstødningssensoren, den tunge kabelføring og nye detektionsalgoritmer der viser hvornår efterbehandlingssystemet er varmt nok til at gennemgå testen. Disse ting kunne være et emne for yderligere undersøgelser.

Hovedkonceptet for testene i dette forsøg er baseret på at køre en vilkårlig og kort testrute (~4 km) i tilknytning til den periodiske synsstation og i kombination med måling af NOx-indekset ved hjælp et SEMS-systemet kaldet EZ-PEMS fra ECM. Den store fordel ved dette koncept er, at det kan indføres i enhver synshal med lave investeringsomkostninger, og at det er hurtigt og præcist. Med dette koncept gør det ikke så meget, hvordan testruten ser ud, hvad angår hastighed og stigninger, og det understøtter derfor effektivt idéen bag måling af emissioner under virkelige kørselsforhold. Før alle test havde køretøjerne kørt, således at deres efterbehandlingssystem var fuldt opvarmet.

Tidligere studier har klart vist, at det er muligt at vurdere et køretøjs emissionspræsentation ved blot at undersøge emissionsindekset (EI). Indekset betyder, at udstødningskomponenten er relateret til CO_2-niveauet. Dette forsøg bekræfter, at det derfor fungerer på tunge lastbiler og resulterede i et forslag til følgende grænser ved det periodiske syn:

- NOx-indeks < 1,0 for EURO VI
- NOx-indeks < 5,5 for EURO V

Vurderingen er, at disse niveauer er tilstrækkelig høje, til at fuldt funktionsdygtige køretøjer uden falske positive ikke afvises, og tilstrækkeligt lave til at finde defekte køretøjer. Disse niveauer kan justeres og har muligvis brug for et højere antal af testede køretøjer for at skaffe et bedre statistisk grundlag inden den endelige afgørelse.

Med hensyn til de foreslåede grænser dumpede 4 ud af 20 EURO VI- og 3 ud af 5 EURO V-køretøjer i testen. Når det emissionsbegrænsende system var slået fra (manipuleret), dumpede 2 ud af 2 EURO VI-køretøjer. Ved denne manipulering var EURO VI-køretøjer ikke bedre end en 25 år gammel EURO II-lastbil, hvad angår NOx-emissioner. Det bør ligeledes nævnes, at nogle af Euro VI-køretøjerne havde exceptionelt lave NOx-niveauer, hvilket indikerer det store potentiale ved et velfungerende efterbehandlingssystem og en motorstyringsstrategi.

De aktuelle test siger ikke noget om, hvorfor lastbilen ikke består en test men hvis der genereres og indsamles data som i dette forsøg, kan det danne datagrundlaget for yderligere undersøgelser. . Hvis det emissionsbegrænsende system er slået fra, kan det meget let opdages, da niveauerne af NOx-koncentrationen og NOx-indekset øges væsentligt. For lastbiler, som måske har en eftermarkedstuning eller et dårligt fungerende efterbehandlingssystemet i udstødningen, men uden at lampen for tjek af motoren er aktiv, kræves der yderligere teknisk eftersyn på et værksted. Nogle af de lastbiler der viste konstant højere NOx-niveauer, mens andre virkede til at have det hovedsagelig under transienter, hvilket kan skyldes designet af motoren/efterbehandlingen, eller at der bruges en eftermarkedstuning på køretøjet.

4. Definitions

Emission Index
By measuring in wet condition and vol-% it is possible to calculate an index. For NOx emissions, a convenient unit is mg NOx/gCO_2 for the EI.

Emission factor
This means absolute values, for example, mg NOx per km or per kWh.

Limit values based on Emission Index
To be able to suggest limit values for the emission index it is necessary to have a rough idea about the vehicles' fuel consumption (and that gives indirect the CO_2). Heavy-duty engines often have a specific fuel consumption in the interval 190 – 230 g/kWh in a representative test cycle. Currently, NOx limits are based on measurements from engines in a test bench in an emission laboratory. For EURO VI, a conformity factor of 1,5 is used when tests are performed on the road (RDE tests). For EURO V, there are no similar guidelines. The suggestion for PTI tests for the purpose of screening vehicles as in this case, is to use a conformity factor of 2 and a fuel consumption in the 210-230 g/kWh range.

This gives the following suggested PTI limit values:

- NOx Index < 1,0 for EURO VI
- NOx Index < 5,5 for EURO V

The assessment is that these levels are high enough to not reject fully functional vehicles and low enough to find defect vehicles.

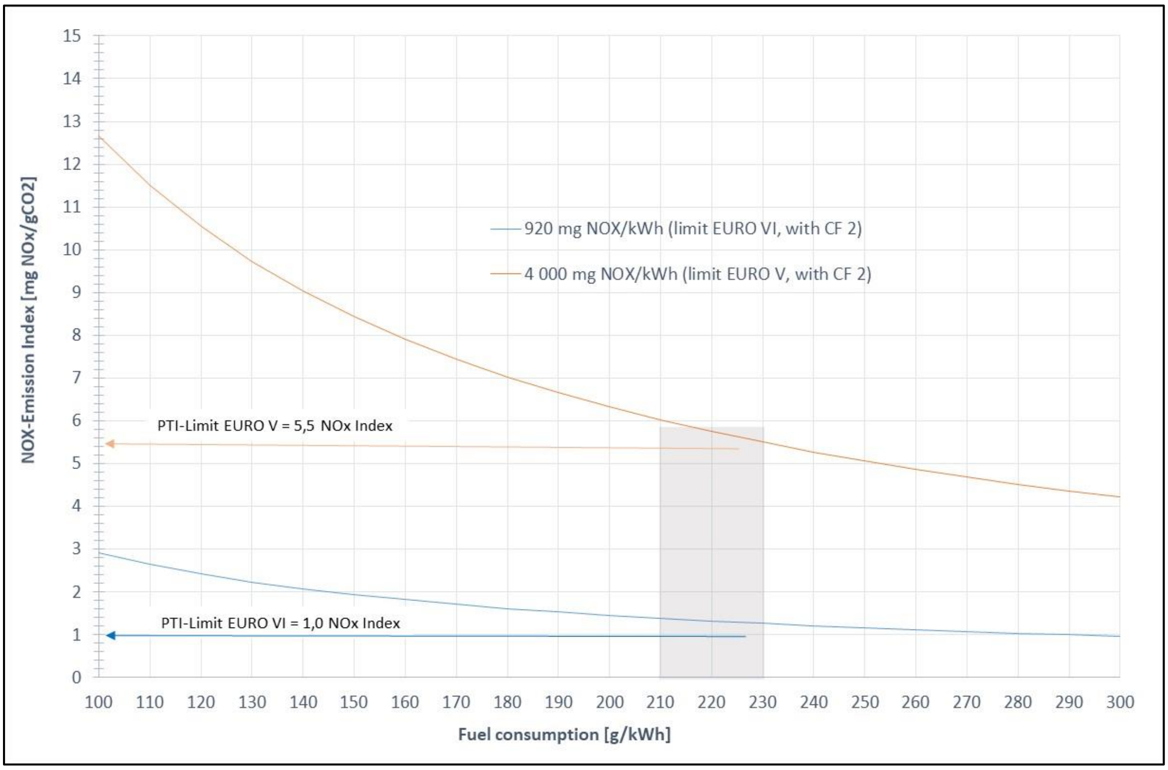

Figure 1. Suggested PTI-limits for HD-trucks. The marked area represents typical fuel consumption for HD-engines.

In the **Figure 1** above, the method of using NOx Index is showed. Since we roughly know the interval for specific fuel consumption for compressed ignition engines in heavy duty applications, we also know "were we are" on the x-axis. In cases where data on fuel consumption is known (via the manufacturer or any other reliable source), the estimate could be made with even higher precision. Likewise, information about the actual fuel consumption during the on-board test would also make the assessment of EI more precise but it is felt that this is not necessary considering the margin used for the limit. The measured index is on the y-axis and its measured with high precision. (The index is calculated from the sensor values for CO_2 and NO_X measured under "wet condition", i.e. with no drying of the exhaust for either emission component). So, if a EURO VI vehicle shows higher NOx Index values than about 1,0, and a Euro V over 5,5, these vehicles are most likely over the approved limit values. By using the index, it is easy to find out if a vehicle is of EURO V or VI class or if it is manipulated.

Important to note is that index will not give values in g/km or g/kWh, but it gives a good picture of the emission level.

The proposed limit values are based on current knowledge and experience. By collecting data through a larger number of tests, the proposed levels can be adjusted. A large statistical database with tests at different locations and under different ambient temperatures is desirable to fulfil such an objective.

5. Concept and preparation

The main concept for the tests in this study has been based on doing an arbitrary and short test route (~4km) in combination with measuring the NOx Index. The big advantage of this is that it can be implemented at any PTI station with low investment cost and that it is fast and accurate. With this concept it does not matter so much what the test route looks like in terms of speed and elevations and therefore supports the idea behind measuring RDE in an efficient way.

The concept has already been demonstrated on light duty vehicles in a Swedish project (reference 1) in co-operation with the Swedish road administration and together with a PTI-company. Extensive comparisons between testing on chassis dynamometer, PEMS and SEMS has previously been conducted within the framework of the Swedish in-use emission programme that was carried out on behalf of the Swedish Transport Authority. The work was carried out in co-operation between Ecotraffic, EXIS and TÜV Nord in Essen, Germany.

Prior to the test campaign in Kolding, a test for HD-trucks was carried out in Gothenburg. A Euro VI Vehicle (construction vehicle) with 4 axis and fully loaded with sand was used for the tests (named as Vehicle Nr 1 in the Appendix).

The average speed during the test was 42 km/h and the maximum speed was 84 km/h. After the engine was warmed up, i.e. after about 10 minutes driving, the exhaust gas aftertreatment system worked without any problem and showed very low NOx-values. The average NOx emission index measured was 0,3 mg NOx/gCO_2 which is well below the proposed limit. This index represents roughly a NOx-emission level of about 180 - 210 mg NOx/kWh (limit for Euro VI is 460 mg/kWh and for test on roads (PEMS) 690 mg/kWh. So, there was no doubt whether the exhaust gas aftertreatment system worked or not.

By introducing a failure function in a similar way as the companies that sell systems to turn off the urea flow do and then repeating the test, the emissions of NOx increased significantly. The index increased from 0,3 to about 12, i.e. by a factor of 40. Emission index of 12 represents an NOx-emission level of about 7 000 mg/kWh. This could also be compared to a 25-year-old vehicle with an emission level corresponding to a Euro II vehicle.

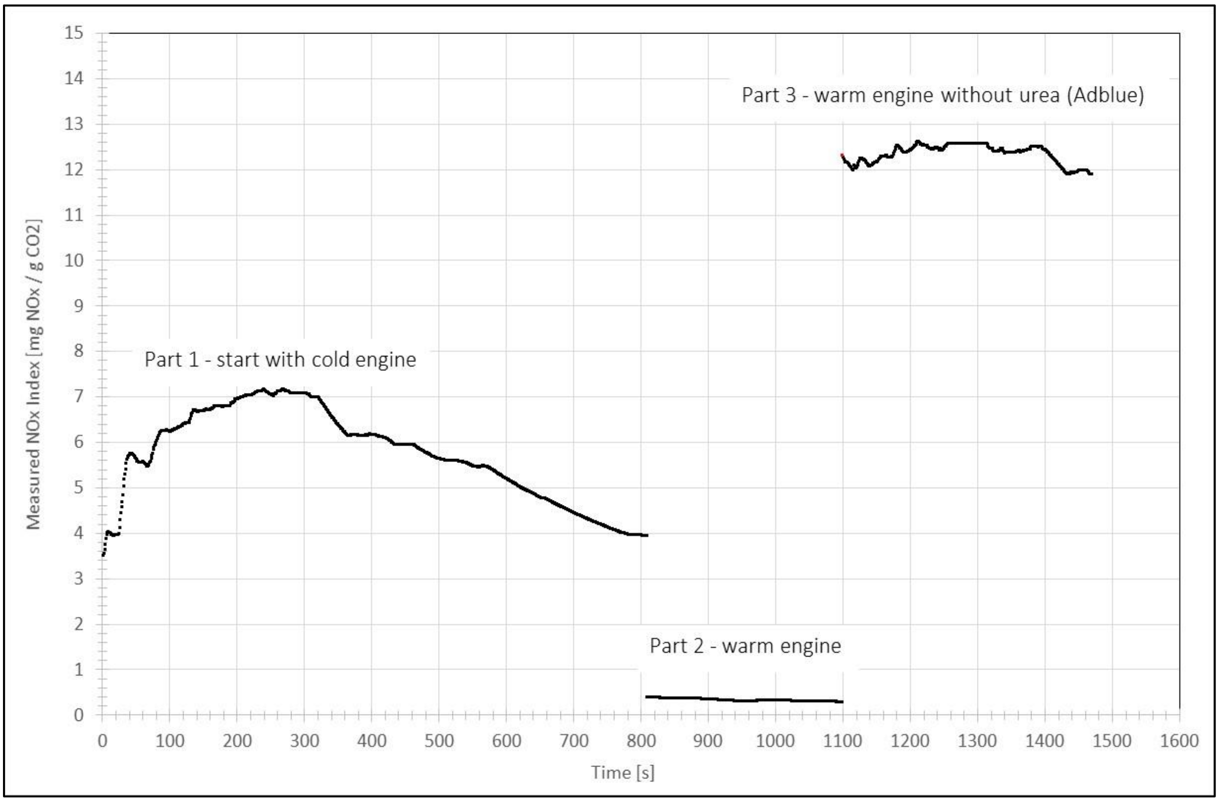

Figure 2. Vehicle no 1. Measured NOx Index (mg NOx/gCO$_2$) with warm engine gave a result of 0,3 mg NOx/gCO$_2$. Suggested PTI limit is 1,0. By turning off the urea system (AdBlue) it gave a significantly increased NOx emission and an index of a about 12.

Beside these tests, one test during idle was carried out. See Figure 3. The reason for this test was to find out how long time it takes from stopping a vehicle on the road until the NOx level starts to increase by cool-down of the emission aftertreatment system. The idea is to be able stop vehicles driving on the roads and directly during idling measure the NOx Index. If the index is low, the vehicle is OK and vice versa.

The three tests mentioned above clearly showed that this method would be suitable for the subsequent tests in Kolding. It was considered fast and showed it can find out if a vehicle is manipulated or has a non-functional exhaust gas aftertreatment system due to other reasons.

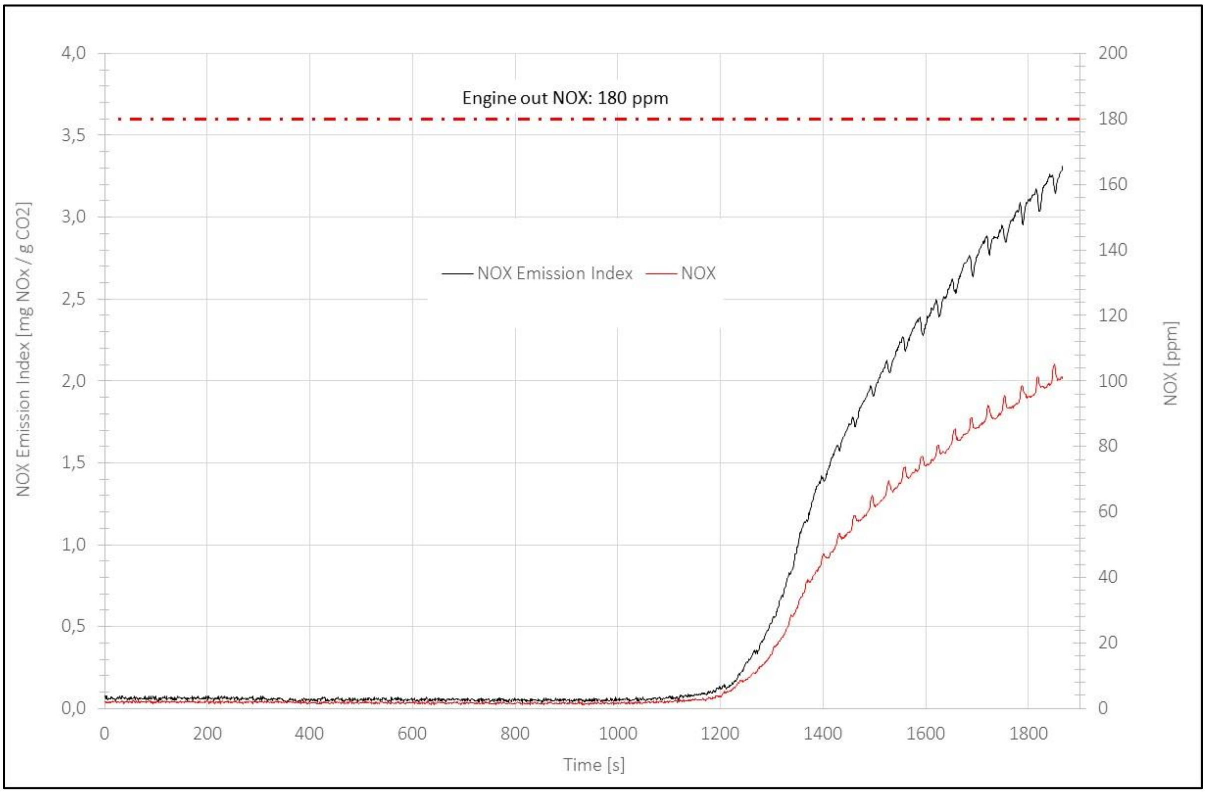

Figure 3. Vehicle no 1. Idling after the test drive. The exhaust gas after treatment system worked about 20 minutes and after about 26 minutes the NOx Emission Index reached over limit (1,0). During this test also the NOx-level up-streams the catalyst was measured.

6. Test in Kolding

Test equipment

During all tests, a SEMS-system named EZ-PEMS from ECM was used. A truck-specific type of sampling probe was used It´s of big importance that the probe is fast and easy to mount in order to have an efficient PTI test procedure. Further adoptions and developments of the solution used may be carried out in the future. See photos in Appendix.

EZ-PEMS is a small and rugged device specifically designed with rapid real-time PTI and vehicle screening tests in mind. EZ-PEMS takes just a few minutes to install and it´s sensor technology is very robust and accurate. It incorporates the unique NOx Index method, but also continuously measures NOx and O_2 and subsequently CO_2. With add-ons for OBDII communication it will also give data from the vehicle. The user interface can be through a RED/GREEN light or a more comprehensive display unit. With a connection to a data acquisition server, various reports and statistics of all tests conducted can be generated.

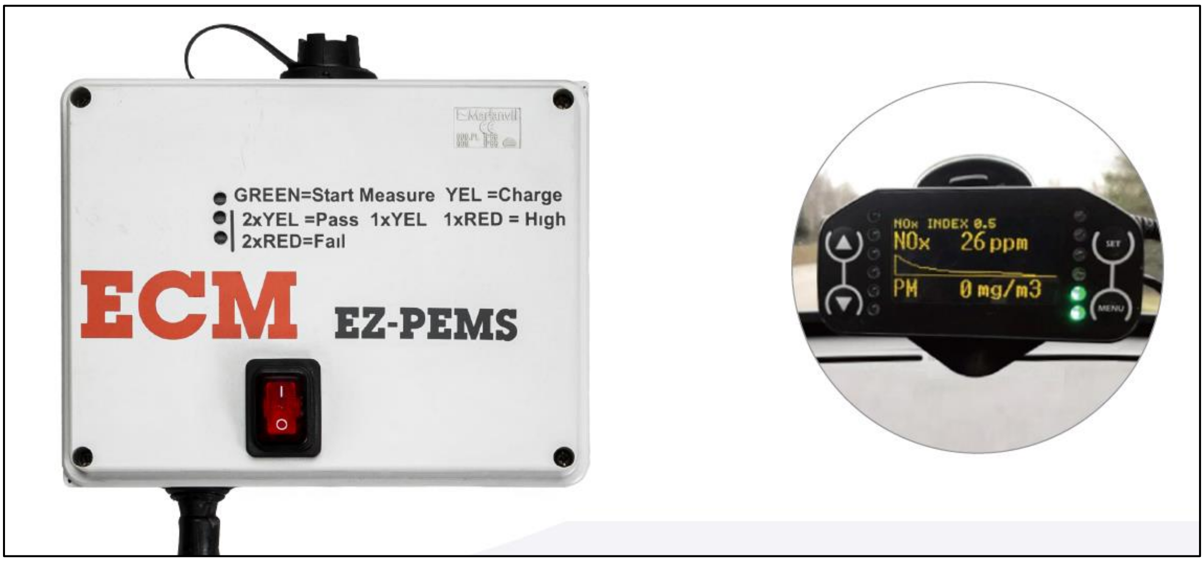

Figure 4. The EZ-PEMS system. To the left the main unit to which the senor is connected. To the right is the display where real time data can be viewed and buttons to control start and stop of the tests. After stop of a test the data is uploaded to the cloud and reports are automatic generated.

By connecting to the OBD connector, data from the vehicle computer will be available. Data that enables to calculate absolute emission values (masses per kilometre). Depending on the purpose of the test there might be some potential caveats with this procedure. By connecting to OBD the "vehicle" and the manufacturer might know that a device is connected. Theoretically, then "the vehicle" may suspect that a test is going on and can adapt its engine and aftertreatment system accordingly.

By not connecting to OBD it is possible to perform completely anonymous tests. The vehicle, or the manufacturer, cannot know that a test is going on. The disadvantage by not connecting is that it will not be possible to calculate absolute levels of emissions or fuel consumption in an inexpensive and easy way. However, as discussed in this study, it is possible to assess a vehicles emission performance by just investigating the emission index.

In this study, the OBD was only connected on two of the vehicles and therefore, all other tests were carried out with no risk that the vehicles might know that test are ongoing.

Figure 5. After the test are stopped the data can be downloaded from the cloud server. It is also possible to follow in real-time.

Figure 6. Different type of report can be generated and exported.

Vehicles

A total number of 26 vehicles have been tested within the framework of this project. Below, a short summary of the test fleet is provided. The vehicle brands in the tests are Volvo, Iveco, Mercedes, Scania, and MAN. The table below presents the vehicles denoted as A-E (all "A" is from the same manufacturer etc.).

no	Brand	Load	Year	Type	Power (Hp)	Odometer (km)	Euro class
1	A	10000 kg	2020	Construction	540	10 000	6
2	B	No	2017	Distribution	280	112 725	6
3	B	No	2013	Semi-Truck	460	467 239	6
4	A	No	2020	Semi-Truck	500	294 695	6
5	A	No	2018	Semi-Truck	500	255 023	6
6	A	No	2018	Semi-Truck	500	208 901	6
7	B	No	2017	Distribution	280	112 764	6
8	B	No	2020	Semi-Truck	480	403 365	6
9	A	No	2018	Semi-Truck	500	184 497	6
10	C	No	2011	Semi-Truck	400	401 713	5
11	A	No	2019	Semi-Truck	500	385 652	6
12	D	8000 kg	2013	Tanker Truck	440	496 952	5
13	A	No	2019	Semi-Truck	500	115 852	6
14	D	No	2014	Garbage Truck	320	135 616	6
15	E	No	2020	Distribution	190	90	6
16	B	No	2016	Semi-Truck	460	467 248	6
17	E	No	2012	Semi-Truck	360	395 688	5
18	C	No	2020	Construction	300	2 364	6
19	A	No	2011	Semi-Truck	430	534 000	5
20	C	No	2020	Construction	300	2 514	6
21	E	No	2017	Semi-Truck	480	353	6
22	B	No	2015	Semi-Truck	460	340 356	6
23	A	No	2017	Distribution	340	282 680	6
24	A	No	2016	Container Truck	550	370 719	6
25	D	No	2013	Semi-Truck	440	602 865	5
26	A	No	2018	Semi-Truck	510	250 026	6

Table 1. Vehicles used in the tests.

Test Procedure

All tests were performed in Kolding except for vehicle no 1. The outside temperature varied between 8 and 17 deg C. Various test routes from 4 to 8 km was used.

- Prior to the test the exhaust gas probe was connected to the vehicles exhaust tailpipe and the display was placed on the windscreen inside the vehicle.
- All relevant data about the vehicle such as year model, emission class, odometer reading, win No. etc was recorded on a protocol.
- After start of the engine, the data acquisition system was started.
- Then driving the test route was initiated and simultaneous the NOx ppm and NOx Index could be followed on the display. When NOx ppm levels and NOx Index start to decrease, this indicates that the engine is warm and the engines aftertreatment system is working.
- With warm engine, a new test was started, NOx Index was reset, and a new file was recorded.
- If the average NOx Index are below the PTI-limit -> the vehicle passed the test
- In case of questionable results one more test was performed.

7. Results

Figure 7 below summarises the results from the test campaign. All vehicles were driven to reach warm engine temperature prior to start of data acquisition. One of the questions before this project was if it would be possible to find manipulated vehicles during PTI testing. The results clearly show that this is possible. Vehicle 1 and 7 were manipulated so the urea (AdBlue) flow was stopped. This resulted in a significant increase of the NOx Index. The vehicles are described in Table 1.

With respect to the suggested limits, 4 of 20 EURO VI and 3 of 5 EURO V vehicles failed the test. When urea was turned off (manipulated) then 2 of 2 EURO VI failed. By this manipulation, the EURO VI vehicles were no better than a 25-year-old EURO II Trucks with respect to NOx emissions. Likewise, it should be mentioned that some of the Euro VI vehicles had exceptionally low NOx levels, indicating the great potential of a well-functioning aftertreatment system and engine control strategy.

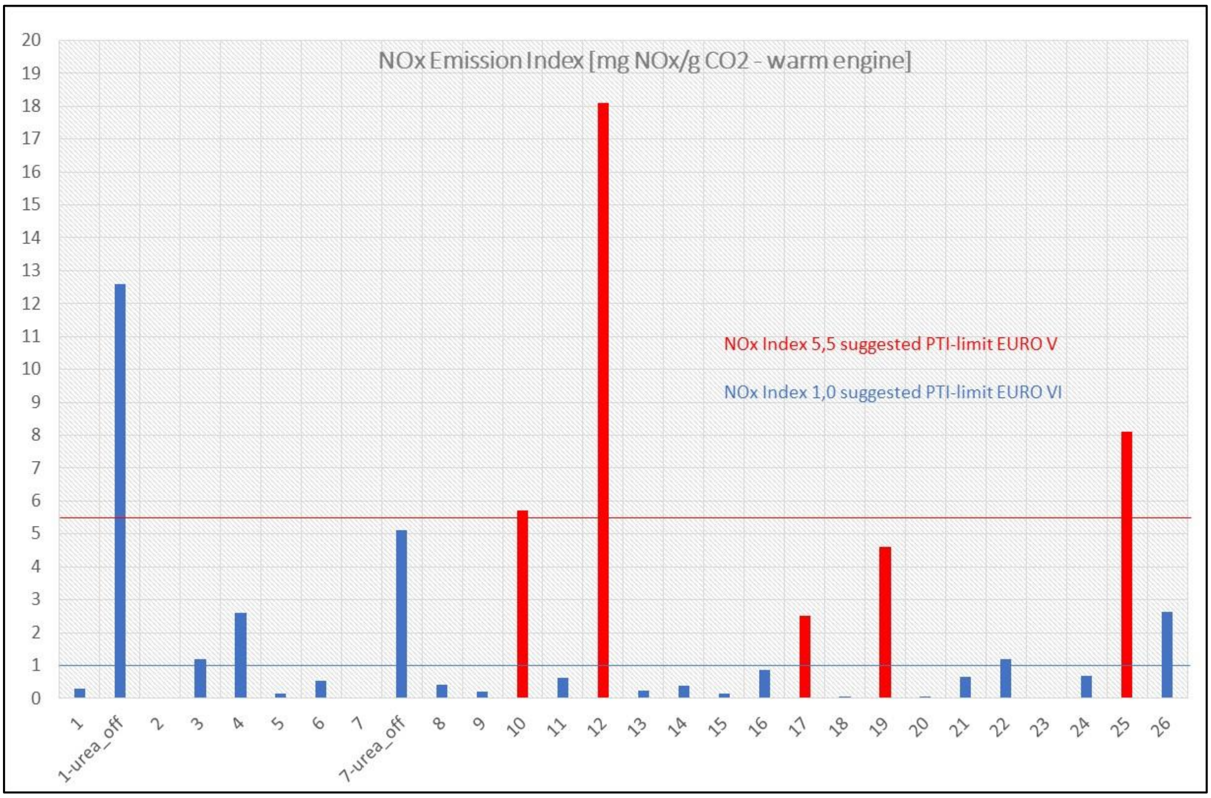

Figure 7. Summary of the test campaign. Red = EURO V and blue = EURO VI. The fleet are described in table 1 above.

Generally speaking, for relatively new vehicles with low odometer reading that shows a high NOx Index it may be due to the following:

- an aftermarket tune of the vehicle or other tampering
- an un-optimized design from the manufacturer for this kind of RDE tests
- a malfunctional system that has not been detected by the onboard diagnostics

EURO VI vehicles with manipulated urea systems gives relatively high NOx Index, which means that an index just over the suggested limit of 1 most likely do not mean the system has been manipulated. As an example, vehicle 3, 4 and 22 in the **Figure 7** above most likely haven´t a turned off urea flow, but are still not passing the limit. This also applies to vehicle no. 26 as turning off the urea flow would have a greater effect on the index.

During PTI it may not be obvious or in focus on why a vehicle shows higher NOx emission than expected for the model year and odometer reading. In order to find out if why further investigations in a workshop would be needed.

According to EU emission standards for heavy-duty vehicles, the engines shall comply with the emission limit values for useful life periods of

- 500 000 km or 7 years for EURO V
- 700 000 km or 7 years for EURO VI

With regards to the vehicles that did not pass the tests in this study, the following comments can be made:

Nr 3: A EURO VI, 2013 vehicle that is close to the suggested limit and shows constant higher than normal NOx levels. This is a 7-year-old vehicle with an odometer reading just below 500 000 km. Since this vehicle is a little older than 7 year and not a high emitter, it might be that it is normally aged and with a gradual deterioration of the exhaust gas aftertreatment system.

Nr 4. A EURO VI, 2020 vehicle that constantly shows higher than normal NOx levels and it´s way above the limit for the NOx Index. This is a relatively new vehicle with an odometer reading just below 300 000 km. The test of the vehicle was repeated four times and despite driving for 40 minutes it would not reach the limit. See also Figure 10 below. The high NOx emission may not be explained by aging since the vehicle isn´t that old. Either there is something wrong with this vehicle or it may be tampered with. To be able to determine this, a careful examination of the vehicle will be required.

Nr 10. A EURO V, 2011 vehicle that is close to the suggested limit. It shows high NOx levels when the engine has moderate load and reasonable NOx levels when the engine has light load. This vehicle is soon 10 years old and with an odometer reading of about 400 000 km. The most likely explanation for the high NOx emission may be that the vehicle is normally aged and with a gradual deterioration of the emission control system.

Nr 12. A EURO V, 2013 vehicle that is way beyond the suggested limit. It shows extremely high NOx levels all the time and spikes can be up to 2 200 ppm. It´s so bad that it´s difficult to elaborate on the true cause. It should be noted that this EURO V vehicle does not use SCR, but only EGR in order to control the NOx emissions. It might be that a vehicle with this emission control strategy is not able to meet the supposed emission levels when tested under these RDE conditions.

Nr 22. A EURO VI, 2015 vehicle with an odometer reading of about 340 000 km. It is close to the limit and it shows higher than normal NOx levels especially during hard accelerations, which stands out a bit compared to other vehicles tested. The reason for this can be due to an aging aftertreatment system, an aftertreatment system that is just not able to meet the supposed emission levels when tested under these RDE conditions or it could even be a vehicle that has an aftermarket tune where it´s original optimization during acceleration has be modified.

Nr 25. A EURO V, 2013 vehicle that is well above the suggested limit and shows constant relatively high NOx levels. This vehicle is over 7-year-old and with an odometer reading of more than 600 000 km. This means that it already has passed the "comply limit "of 7 years and the 500 000 km. The explanation for the high NOx emission may be that the vehicle is normally aged and with a gradual deterioration of the emission control system or it could be a vehicle that has an aftermarket tune.

Nr 26. A EURO VI, 2018 vehicle that is way above the limit just as the vehicle Nr 4. Vehicle Nr 4 and Nr 26 are of the same make. Both are relatively new, 2018 respective 2020 and both with an odometer reading under 300 000 km. Either there is something wrong with this vehicle or it may be tampered with. To be able to determine this, a careful examination of the vehicle will be required.

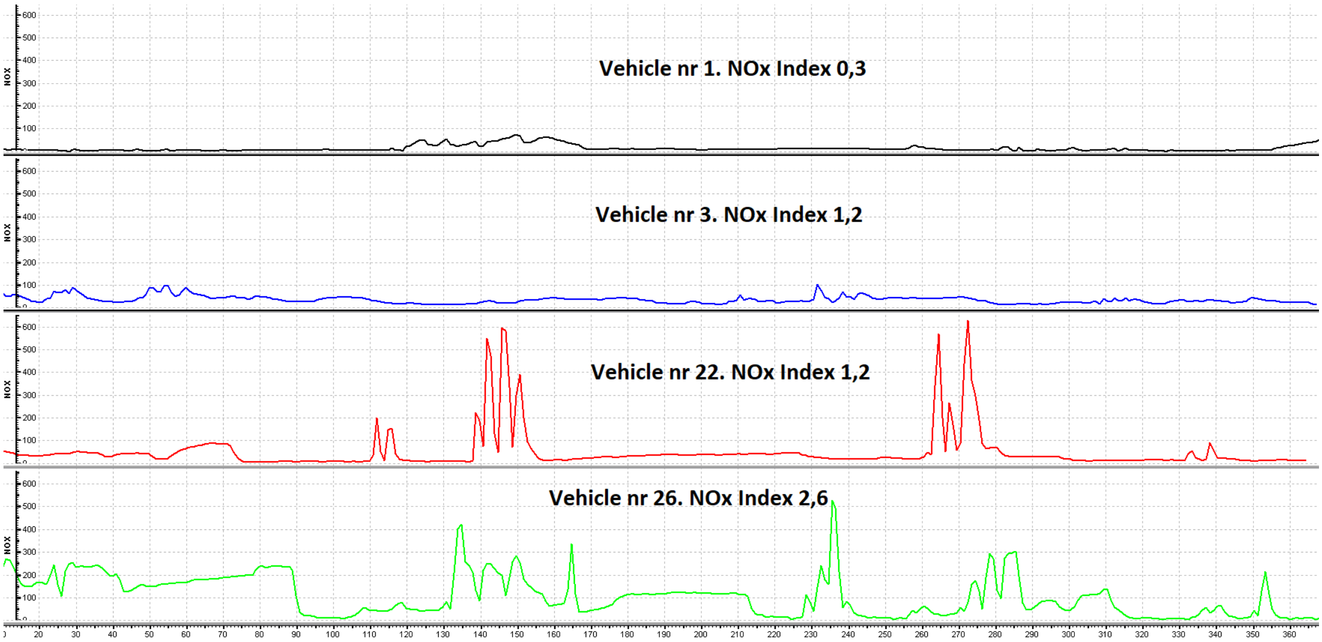

Figure 8. Comparison of the NOx trace from vehicle no 1, 3, 22 and 26. Where only Nr 1 is a vehicle that passed the test

In **Figure 8** above the NOx traces from four different Euro VI vehicles are plotted. Nr 1 is a fairly new and fully functional vehicle with only some NOx emissions during high load and acceleration. Typically, there is just a few ppm NOx and at maximum around 70ppm NOx. Nr 3, does not pass the test since the NOx levels are slightly higher than they are supposed to during the whole test. Nr 22, does not pass the test since it has NOx levels higher than normal during most of the test but also significant spikes in the range of 500-600 ppm during acceleration. Nr 26 does not pass the test and have a relatively high NOx Index since it has higher than normal NOx during the whole test.

In **Figure 9** below a typical example of a vehicle which pass the test is shown. In this case, the engine was sufficiently warmed-up after about 6 minutes, thereafter, the emission test was started, and the NOx Index was well under the suggested limit of 1,0 and therefore this vehicle passed the test.

One interesting detail about this test was that after about 650 sec it came up a message on the dashboard “Urea tank empty – only possible to drive another 9 more hours”. With no urea the index started to increase.

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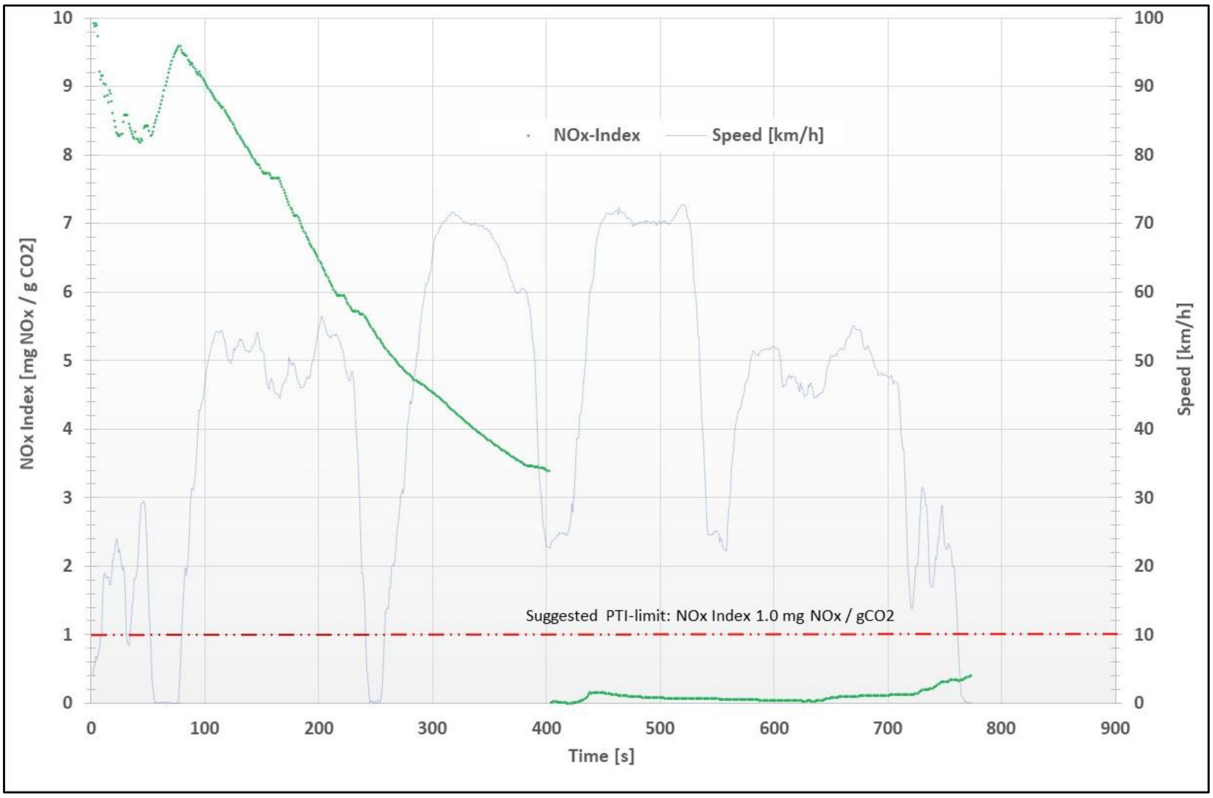

Figure 9. Vehicle no 14 (example of a vehicle who passed the test). The first 400 sec is the warm-up drive and thereafter the test with warm engine.

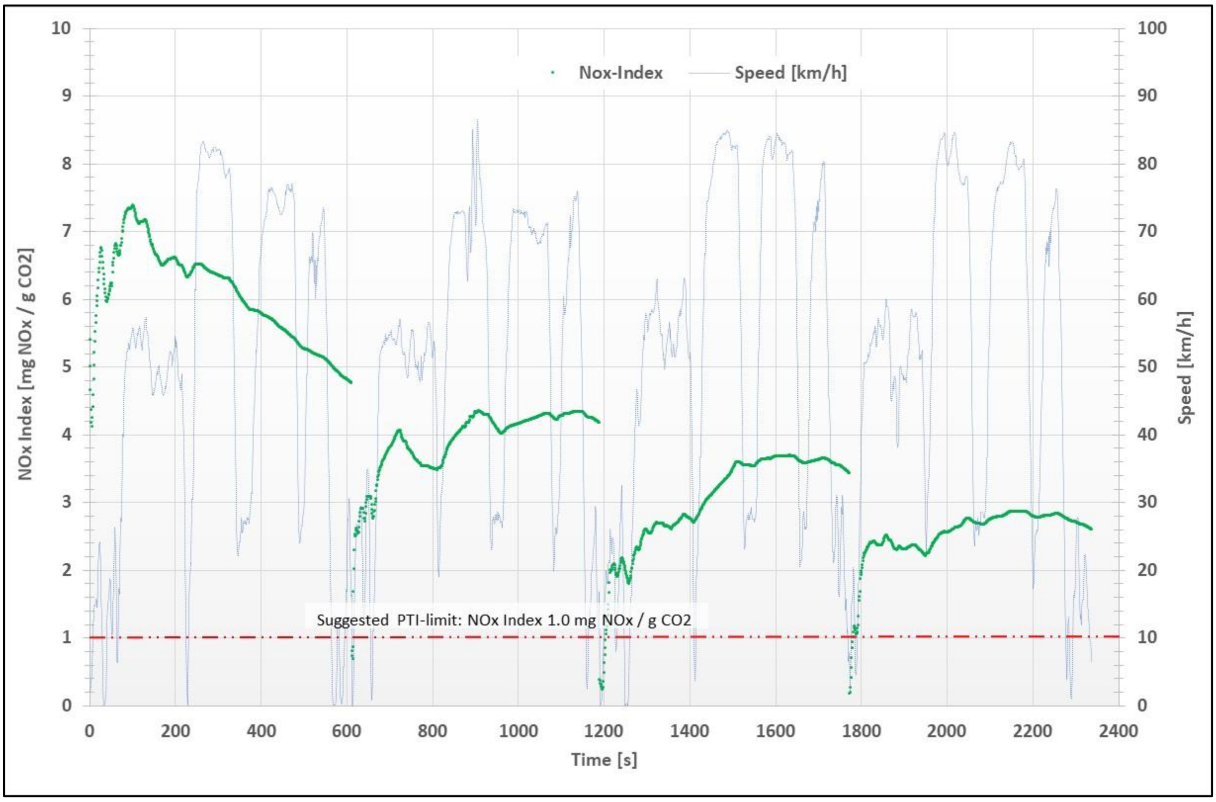

Figure 10. Vehicle no 4 (example of a vehicle who failed the test). The test was repeated 4 times and the driving time was almost 40 minutes, but it was not possible to reach under the suggested PTI limit line.

One question prior to this study was how long after start of idling the exhaust gas aftertreatment system will be active. The tests performed indicates that the interval before this happens will be between 10-20 minutes. After that the system cools down and the urea (AdBlue) flow is turned off. In Figure 11 below, one example from a vehicle with an active time of about 10 minutes is shown. Of course, this is only an indication and rough values as the cool-down time also correlates to how warm the engine and aftertreatment system is before the test and how the specific vehicle is designed etc. A short drive with empty load or a long and tough driving with full load may give different results. But 10 – 20 minutes is as assessment of a rough interval.

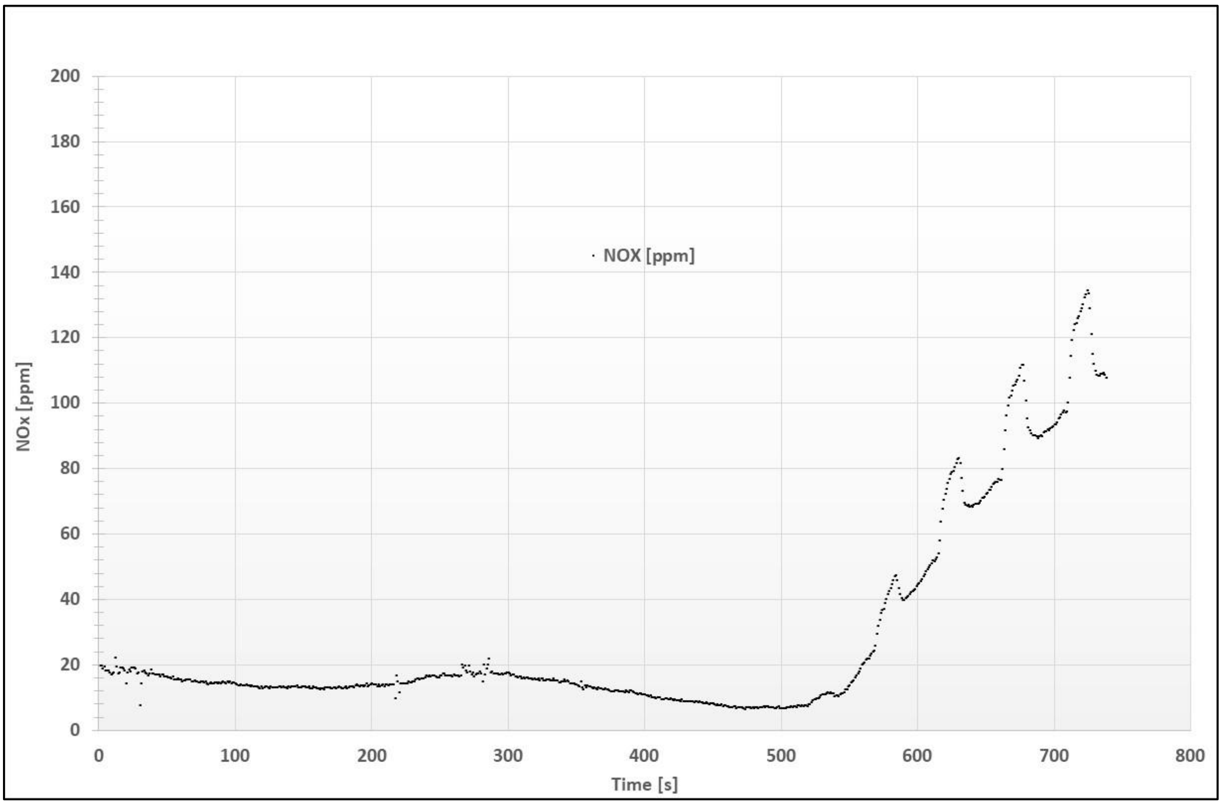

Figure 11. Vehicle no 3. Idling after test.

8. Conclusions and discussion

The main question, which this work was supposed to provide answers to was if SEMS equipment could be a useful tool during PTI. This study, together with earlier works (see references), clearly show that the answer is "Yes", both for light-duty and heavy-duty vehicles. These studies also show that Emission Index for NOx is a powerful unit to use for these types of tests.

The suggested PTI-limits for EURO V and VI are based on a conformity factor of 2 from the limit values, which applies to tests in a test cell, and a fuel consumption of roughly 210-230 g/kWh for this type of RDE test. The assessment is that these levels are high enough as limits for PTI and screening tests in order to not reject fully functional vehicles without false positives and low enough to find defective vehicles.

The tests at Applus in Kolding in the present study and prior tests at Bilprovningen in Gothenburg clearly show that it is possible to integrate this test procedure in the regular PTI process. It took roughly about 10-20 minutes per vehicle to carry out the test, including mounting of the test equipment, driving the test route and de-mounting the test equipment. The time for test may be improved for the future with some fine tuning of the process and components used for performing the tests. This could include refinements of the exhaust probe, heavy duty cabling and new algorithms for detecting when the aftertreatment system is warm enough for performing the test. These things could be the scope for further investigations.

Some vehicles will meet the limit values even with a relatively cold engine at start of the test, but for some of the vehicles a warm-up drive prior to test will be necessary. This study indicates that about 4 km is long enough for most of the vehicles. However, this procedure should be investigated further on a higher number of vehicles and with different outdoor temperatures.

To summarize the suggested test procedure will be as follow:

1. Mount the test equipment
2. Drive a test round (about 4 km for heavy duty vehicles)
3. If the average NOx Index is below the PTI-limit -> the vehicle passed the test
4. If the average NOx Index is above the PTI-limit -> Repeat point 2 above. If under limit - > the vehicle passed the test. If above limit -> the vehicle has not passed the test.

- The test will be performed on normal roads in direct connection to the PTI-station.
- By not using a defined test cycle it will be much more difficult to cheat with the tests.
- During cold ambient temperatures and when the vehicle has been unused for a long time it may be allowed to drive an additional route prior to test in order to warming up of the engine and its after-treatment system. Normally, HD-trucks arrive unloaded to the PTI station, which indicates that a longer time and driving distance for warm up on the roads than with a loaden vehicle might be necessary.

The method described above has proven to be highly effective in finding vehicles with problems (high emitters) as well as manipulated vehicles. The actual test will not state what the cause is for failing a test, but if data is continuous generated and compiled as in this study, then it will give an indication of why there is a problem. If the urea supply is turned off that is very easily detected since the NOx levels and NOx Index are significantly higher than they should be. For trucks that may have an aftermarket tune or a malfunctional exhaust after-treatment system but still with no check engine lamp active further technical inspection will be required by a workshop. Some of the failed trucks showed continuously higher NOx levels while some seemed to have it mainly during transients, which can be due to the design of the engine/aftertreatment system or due to that an aftermarket tune is used on the vehicle. This study (and in combination with earlier, see reference 1) it is obvious that the emission test can be easily incorporated into the regular PTI (periodical technical inspection) operations.

9. References

1. Swedish In-Service Testing Programme on Emissions from Passenger Cars and Light-Duty Trucks. Extra program 2019 (Simplified PEMS – MiniPEMS) - Concept study, Felix Köhler, TÜV NORD and Lars Eriksson, Ecotraffic
2. Swedish In-Service testing program on emissions from passenger cars and light duty trucks, 2015-2017. A report for IEA and the Swedish Transport Agency, Felix Köhler, TÜV NORD and Lars Eriksson, Ecotraffic
3. Measuring real emissions with simplified PEMS, 23rd Transport and Air Pollution Conference, Thessaloniki 2019, P Per Öhlund, Swedish Transport Agency and Lars Eriksson, Ecotraffic

10. Appendix

Photos from the tests

Figure 12. Test set-up inside the cabin

Figure 13. Test probe mounted in exhaust pipe

Figure 14. Special probe for exhaust outlets of the type as is shown to the right

Figure 15. Example of test probe mounting