Environmental Test Manual of the Danish Public Transport Authorities

Part 1 - Emission measurement

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ON BEHALF OF:

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1 Introduction

The Danish Public Transport Authorities focus on keeping emissions from buses as low as possible for health and environmental reasons and to protect passengers and the surroundings.

For the purpose of limiting the emission of soot particles (particle mass (PM) and particle number (PN)), NO_x gases (NO and NO_2) and noise from vehicles, the buses used by the bus operators running bus services on the routes of the Danish Public Transport Authorities are subject to routine testing. The routine testing forms part of the environmental testing of in-service buses.

The Environmental Test Manual of the Danish Public Transport Authorities is used to determine whether the buses tested are well-maintained and whether their emissions are reduced to the greatest extent possible. Also, the environmental test ensures that the bus operators comply with the guidelines of the relevant Transport Authority. The Environmental Test Manual consists of two parts:

Part 1: Measuring emissions from buses:
- Nitrogen and nitrogen oxide, NO_x (sum of NO and NO_2)
- Carbon dioxide, CO_2
- Soot particles, including particle mass (PM) and particle number (PN)

Part 2: Measuring noise from buses:
- Exterior vehicle noise
- Interior vehicle noise

This Environmental Test Manual is Part 1 and contains a description of the requirements for measuring emissions from buses in connection with environmental tests. Part 1 of the Environmental Test Manual applies to buses with original, unoriginal and retrofit emission reduction systems from the following emission classes:

Diesel-powered buses: EURO VI, EURO V, EEV, EURO VI
- Diesel-powered hybrid buses: EURO VI
- Gas-powered buses: EURO VI

Part 2 is a separate manual which contains a description of the requirements for measuring noise from buses.

The Environmental Test Manual has been prepared by FORCE Technology at the request of Movia.

2 Measuring emissions from buses

2.1 Measuring equipment requirements

The measuring equipment must be portable as the equipment is to be installed in the bus during the measurement. If possible, the 12V or 24V DC power supply of the bus will be used for the measuring equipment, but it is also permitted to use a separate power supply which is carried on the bus. As it is necessary to use a heated extractive system to conduct the measurement, it may take up to 60

minutes to mount and prepare the measuring equipment on the first bus. After that, it will be possible to reduce the time it takes to mount and prepare the equipment on the subsequent buses if it is moved directly onto the new bus and quickly reconnected to a power supply.

It is also possible to conduct the environmental test on a roller bench, in which case there is no requirement for the measuring equipment to be portable.

A complete measuring system must consist of an extractive system, a gas conditioning unit, a gas analyser and a particle counter.

Extractive system
The extractive system must consist of a heated sample line (120 – 190°C) with a probe. The latter must be fitted 10 – 20 cm inside the exhaust pipe. The extractive system must be heated, partly to avoid condensation of water vapour in the sample line and partly to avoid loss of particles in the extractive system. The sample line to the NO_x and particle counter must be made of conductive (anti-static) Teflon or stainless steel to minimize the loss of gases and particles in the system. The sample line to measure CO_2 may be made of PVC, Teflon or stainless steel. It is permitted to combine the measurement of all emission parameters through the same extractive system if the above materials are used.

Gas conditioning unit and gas analyser
The gas conditioning unit must consist of a Peltier cooler which cools down the exhaust gas and removes the moisture from the exhaust gas before it is led into the gas analyser. The gas analyser may be a combined NO_x and CO_2 analyser or two separate analysers for NO_x and CO_2 respectively. It is permitted to use gas analysers with a fully integrated gas conditioning unit. Method and range of measurements are described in sections 2.1.1 and 2.1.2.

Particle counter
The particle counter must measure heated gas (180 – 190 °C) to avoid condensation of water vapour and to reduce condensation of semi-volatile hydrocarbons in the instrument. The counter is to be installed directly on the heated extractive system to avoid "cold" transfer lines. Method and range of measurements are described in section REF _Ref478847787 \r \h 2.1.3. It is recommended that the exhaust gas volume is led out of the bus to maintain a safe indoor climate in the bus during the measurement.

2.1.1 Gas analysis, nitrogen and nitrogen oxide, NOx

2.1.1.1 Method and range of measurements

There are two different types of permitted measurement principles for measuring NO_x: The chemi-luminescence detectors (CLD) and non-dispersive infrared detectors (NDIR)

The CLD measurement principle: Using a dry and particle-free partial gas flow, the NO_x concentration is determined by a chemiluminescence detector (CLD) with a fully integrated converter that reduces NO_2 to NO. After the converter, the instrument measures the total concentration of nitrogen oxides in the form of NO_x = NO + NO_2. The analyser must comply with European Commission Regulation 582/2011 or section 9.3.1 of Annex 4B to UN/ECE Regulation No. 49.

The NDIR measurement principle: Using a dry and particle-free partial gas flow, the NO_x concentration is determined by a non-dispersive infrared detector (NDIR). The gas is led through a sample chamber where the gas is illuminated by infrared light which is absorbed by the NO and NO_2 molecules in the gas at specific wavelengths. The signal is picked up by a detector and converted into a concentration. The analyser must comply with European Commission Regulation 582/2011 or section 9.3.1 of Annex 4B to UN/ECE Regulation No. 49.

The gas analyser must have a measurement range of 0-1500 ppm NO_x (dry gas) and a measurement solution of at least 1 ppm. If you want to measure emissions in dilute exhaust gas, you can do so by determining the dilution ratio during or immediately before or after the measurement. The measurement range on the detector must, however, be adjusted so as to achieve the same degree of accuracy as without dilution (see section 2.6).

2.1.2 Gas analysis, carbon dioxide, CO_2

2.1.2.1 Method and range of measurements

Using a dry and particle-free partial gas flow, the CO_2 concentration is determined by a non-dispersive infrared detector (NDIR). The analyser must comply with European Commission Regulation 582/2011 or section 9.3.1 of Annex 4B to UN/ECE Regulation No. 49.

The gas analyser must have a measurement range of 0-18 vol% CO_2 (dry gas) and a measurement solution of at least 0.1 vol%. If you want to measure emissions in dilute exhaust gas, you can do so by determining the dilution ratio during or immediately before or after the measurement. The measurement range on the detector must, however, be adjusted so as to achieve the same degree of accuracy as without dilution (see section 2.6).

2.1.3 Soot particles

2.1.3.1 Method and range of measurements

The measurement must be conducted according to the Charge Diffusion Principle. The signal is picked up by a detector and converted into particle number and particle mass using a software algorithm in the instrument. The particle mass is calculated on the basis of an assumed particle density of 1 mg/cm^3.
Fejl! Henvisningskilde ikke fundet.~~Table 1~~ sets out the unit, particle size, measurement range and solution of the particle counter.

Table ~~1~~1: Particle counter requirements.

Parameter	Particle mass (PM)	Particle number (PN)
Unit	mg/m^3 (wet) at given reference CO_2	number/cm^3 (wet) at given reference CO_2
Particle size	23 nm – 2500 nm	23 nm – 2500 nm
Measurement range	0-50 mg/m^3	10^4-10^9 number/cm^3
Measurement solution	0,001 mg/m^3	at least 10^3 number/cm^3

2.2 Data collection requirements

The data values from the gas and particle measurements must be read by the data collection system once every second. It must be possible to determine the maximum values of the measurement by reading the measuring equipment or through automatic reading of the data collection programme.

The data collection system must be able to save data from the measuring process, and it must be possible to export data to a format which is readable by an ordinary PC (e.g. csv or similar format).

2.3 Requirements for measurement services provider and technicians

2.3.1 Requirements for measurement services provider

The measurements must be conducted by an independent emissions measurement services provider approved by the Danish Public Transport Authorities for the purpose. The independent emissions measurement services provider may not have any personal or financial interests in the outcome of the measurements. For example, bus operators previously employed by the Transport Authority and the repair shops normally used by bus operators will not be deemed to be independent.

2.3.2 Requirements for measurement technicians

It must be documented that the measurements are conducted by properly qualified staff having knowledge of general measurement technology, calibration, quality assurance and reproducibility of measurements.

2.4 Maintenance and calibration

2.4.1 Gas analyses

The analyser used to measure NO_x and CO^2 must be fitted out so as to make it possible to check the equipment at the point of measurement using test gas. The analyser must be maintained as recommended by the manufacturer.

2.4.2 Particle counters

The counter used to measure particles (particle mass (PM) and particle number (PN)) must be designed to allow for zero point calibration of the equipment using e.g. a HEPA filter. The counter must be maintained as recommended by the manufacturer.

2.4.3 Collecting data during emissions measurements

The data collection system must collect data while the measuring instruments are being calibrated. The data collection system must be maintained as recommended by the manufacturer.

2.5 Test preparations

Before the test, it is necessary to make sure that the bus has no defects that prevent the bus from working normally. There may be no visible defects in the engine or a substantial waste of coolant or oil.

Before commencing the test, you must check that the bus has no warning lights in the dashboard (e.g. back pressure sensor, additives, etc.). The sensor that makes sure that the doors are closed is, however, exempt if the sensor is activated because a heating coil for the emissions measuring device is stuck in the door.

The test must be conducted with the bus at normal operating temperature, which means that the water and oil temperature must be in normal service range (verified through the dashboard of the bus). This is done to ensure that the emission reduction equipment of the bus has the right operating environment. In practice, most buses will ready for testing after having run 15 – 20 minutes on the highway/motorway. The first acceleration test is conducted no later than after a 30-minute drive on the highway/motorway whether or not the bus is considered to have a normal operating temperature. The environmental test will not conducted at outdoor temperatures below -10ºC. This applies in particular to NO_x measurements, see section 2.5.1.

It must be stated in the measuring table whether the engine maintained its normal operating temperature during the test. This is done to avoid questions of doubt as to the compliance with limit values.

2.5.1 Special conditions to be considered in NO_x measurements after a SCR catalytic converter

In some cases, the temperature above the SCR catalytic converter is not sufficiently high even though the bus dashboard shows that the bus is running at normal operating temperature. This means that the NO_X concentration will be disproportionately high and not drop until the SCR catalytic converter is sufficiently hot. For this reason, the measurement supervisor must always assess whether the temperature of the SCR catalytic converter on the bus is sufficiently high for the measurements to be conducted. If the measured NO_X concentration (M) is clearly dropping (e.g. M1>M2>M3) for the individual acceleration measurements, it is recommended that the bus continues running for a time in order to reach normal operating temperature. Then new acceleration measurements can be carried out. One or more of the first acceleration measurements can be treated as *outliers* (see section 2.6).

2.6 Test procedure

Before commencing the test, a certified test gas is led via the test probe through the entire sampling system. This is done to ensure that there are no leakages and that the gas analyser is measuring correctly.

If the bus has been running idle for a long time, it is necessary to clean the exhaust system before measuring accumulated soot particles. This is done by stepping on the gas a few times in neutral position right after each other. Then you wait for the emissions to stabilise again before initiating the test itself. If, during the test, there are doubts about whether the exhaust system is sufficiently ready for testing, it may be necessary to treat specific measurements as outliers.

Environmental tests must be conducted by measuring emissions from the exhaust during a full uninterrupted acceleration cycle on a straight even road. Previous experience in conducting environmental tests has shown a clear correlation between the maximum values from the test cycle and the condition of the bus equipment reducing the emission of soot particles and NO_x.

The emissions measurement must be conducted on vehicles accelerating from standstill and up to 80-90 km/h (but the Danish Road Traffic Act must be observed). Then the speed is kept constant until the measurement supervisor signals that the test has finished. It is necessary to put the accelerator the whole way down and keep it down during the entire acceleration cycle. Throughout the cycle, data is collected on the different emissions (NO_x, CO_2, PM and PM) as described in section 2.2.

Three consecutive measurements of gasses and soot particles must be conducted. If there is any doubt whether one or more acceleration tests have not be conducted correctly or whether the operating temperature of the bus is not sufficiently high, one or more supplementary acceleration tests must be conducted (in addition to the three tests mentioned above). It is recommended not to conduct more than six acceleration tests. If it is assessed that a measurement is an outlier (e.g. an abnormally high concentration compared to the remaining measurements), such measurement will not be included in the calculations. Data should be reported from three environmental tests conducted correctly.

The determination of particles and NO_x needs not be made at the same time, but may be measured in separate acceleration cycles. For example, three acceleration cycles may be completed to measure NO_x and CO_2 followed by three acceleration cycles to measure PM, PN and CO_2. It is important to always measure CO_2 at the same time as both NO_x and particles in order to be able to compare and convert correctly to the CO_2 reference.

If a diluter system is used, the dilution ratio must be measured at the point of measurement. This is done by adding a known gas volume (e.g. NO gas) directly to the gas analyser and then through the entire sampling system. The dilution ratio is the ratio between the two measurements. Please note that it may prove necessary to adjust the dilution ratio for contributions from the atmospheric air if the dilution is done through air pressure from a compressor. This is relevant if CO_2 is used to determine the dilution ratio.

The test may also be conducted on a roller bench. Here you must ensure that the roller bench can have an impact on the bus corresponding to full acceleration on even road for about 25-30 seconds

from standstill up to 80-90 km/h. The test procedure itself is the same as when the test is conducted on a road.

The result of the CO_2 measurement will be used to convert the measured values of NO_X, PN and PM. Conversion using the following formula:

$$C_{ref} = \frac{CO2\ (reference)}{CO2\ (measured)} * C_{measured}$$

where
C (ref) = The measured NO_X or particle concentration converted into reference condition.
C (measured) = The measured NO_X or particle concentration.
CO_2 (measured) = The measured CO_2 concentration.
CO_2 (reference) = Reference-CO_2, (10 vol% CO_2).

2.6.1 Approval criteria

The following requirements must be met for the bus to be approved:

1. At least two out of the three measurements must be below the limit value.
2. The average of the three measurements must be below the limit value.
3. If you ignore a measurement (an outlier), then at least two out of the acceleration measurements used must be carried out immediately after one another.

If the measured emission values are deemed to be abnormally low/high due to defects, the Transport Authority may demand that the bus goes through yet another environmental test when the defects have been remedied.

2.7 Limit values

Buses of a given emission class must comply with the limit values specified in **Fejl! Henvisningskilde ikke fundet.**~~Table 2~~, **Fejl! Henvisningskilde ikke fundet.**~~Table 3~~ and **Fejl! Henvisningskilde ikke fundet.**~~Table 4~~ to be approved during an environmental test.

Table ~~2~~2: Limit values for NO_X. Diesel-powered buses including diesel-powered hybrid buses.

Emission class	NO_X [ppm] (ref)
EURO IV	1300
EURO V	1000
EEV	500
EURO VI	250
Other	Subject to agreement with the Transport Authority

'ref' refers to conversion to reference condition (10% CO_2)

Table ~~3~~3: Limit values for PM and PN. Diesel-powered buses including diesel-powered hybrid buses.

Emission class	PM [mg/m^3] (ref)	PN [numberl/cm^3] (ref)
EURO IV	20	$10*10^7$
EURO V	8	$4*10^7$

EEV	7	$3*10^7$
EURO VI	0.5	$0,2*10^7$
Other	Subject to agreement with the Transport Authority	

'ref' refers to conversion to reference condition (10% CO_2)

Table 44: Limit values for gas-powered busses.

Emission class	PM [mg/m^3] (ref)	PN [numberl/cm^3] (ref)	NO_X [ppm] (ref)
Euro VI, CNG	1.0	$0.6 * 10^7$	300
Other	Subject to agreement with the Transport Authority		

'ref' refers to conversion to reference condition (10% CO_2)

Reference is made to Trafikselskabet Movia's Environmental Test Manual, 4th edition, July 2008, when buses of older emission classes (e.g. Euro II and Euro III) are being tested.

2.8 Comparative test of measuring equipment

To ensure that the measurements are reproducible (i.e. that it is possible to achieve uniform results regardless of which emissions measurement services provider is conducting the measurement), it is necessary to conduct a comparative test every third year and on an as-needed basis. The Transport Authority will give notice of the test and the emissions measurement services providers will meet at a specified place bringing the measuring equipment. The relevant Transport Authority will place 1-3 buses at disposal for the test. The table must be used as documentation to show that the instruments measure according to each other. The results of each of the different emissions measurement services providers must fall within a range of 20% in order for them to meet the common measurement standard. If the measurements deviate by more than 20% from the mean value, it is necessary to initiate an investigation into the cause of the larger deviation and to take subsequent corrective action.

2.9 Quality assurance

The emissions measurement services provider must be able to document the result (and the raw data) of the field calibration if required by the Transport Authority.

The results of the three acceleration measurements can be considered valid on satisfaction of the requirements for the operating temperature of the vehicle 3 (section 2.5) and points 1 - 3 (section 2.6).

The environmental test report must be accompanied by a comment if a bus fails and falls below the limit value in 2 out of 3 test measurements, but the total threshold is above the limit value. It must be made clear that the measurement is considered valid, and it must appear what has been done to ensure that the measurements are carried out while the bus is running at normal operating temperature.

3 Reporting and documentation

Measurement results must be recorded in a document which, together with measurement tables etc., are stored in an electronic database to which the Transport Authority has access.

The electronic version of the measurements, including raw data, must contain a time and date code which is generated automatically by the computer/data collection system. The documentation of each measurement must include: Measured concentrations (NO_x, CO_2, PM and PN), point of measurement, make and type of bus, emission class, bus number, information on emission reduction equipment on the bus and the name of the measurement technician/authority having conducted the measurements. File naming and data layout in the file (e.g. the order of the individual columns with data) must be agreed separately with the Transport Authority.

The relevant emissions measurement services providers must also ensure that the following information is saved:

- Results from continuous calibration/adjustment of the measuring equipment.
- Information on defects in and repair of the measuring equipment of relevance to the performance of accurate measurements
- Results of ring calibration.

The results of the environmental test measurements are the property of the Transport Authority and may not be published or used by operators or the measurement body in another context without permission from the Transport Authority.

3.1 Questions of doubt

In case of reasoned disagreement between the bus operator and the emissions measurement services provider, the Transport Authority is the supreme authority. The Transport Authority may demand documentation for calibration interval and calibration records from the company conducting the tests.

Annex A - Test Report

Date, start time (yyyy-mm-dd tt:mm):	
Date, end time (yyyy-mm-dd tt:mm):	
Point of measurement:	
Make of bus:	
Type:	
Bus number:	
Registration number:	
Euro standard:	
Operator:	
Infrastructure:	
Test method (Environmental Test Manual, version):	
Environmental test ordered by:	
Executed by:	

Test results

	Test 1	Test 2	Test 3	Mean	Limit value	Passed/ not passed
NO_X (ppm ref)						
PM (mg/m^3 ref)						
PN ($10^3/cm^3$ ref)						
CO_2 (vol. %)						

Note

Conclusion

Passed/not passed