Submitted by the IWG on PMP

Informal document **GRPE-82-29-Rev.1**
82nd GRPE, 11-15 January 2021
Agenda item 7.

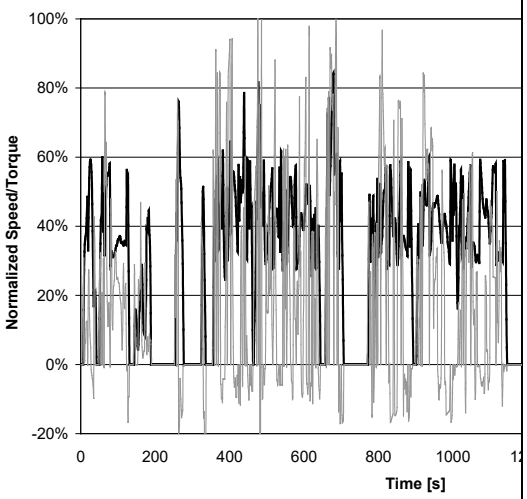
Particle Measurement procedure for HD Engines

Remark: This working document is based on the PN measurement procedure laid down in UNECE Regulation 49 but should be considered exclusively a technical working document. The purpose of this document is only to discuss within the PMP group the changes/additions needed to modify the PN cut-off size from 23 to approximately 10 nm and to include raw exhaust sampling

TEST PROCEDURE	CHANGES FOR SPN10	CHANGES FOR DIRECT RAW EXHAUST SAMPLING
7.1. Principles of emissions measurement		
~~To measure the specific emissions, the engine shall be operated over the test cycles defined in paragraphs 7.2.1. and 7.2.2. The measurement of specific emissions requires the determination of the mass of components in the exhaust and the corresponding engine cycle work. The components are determined by the sampling methods described in paragraphs 7.1.1. and 7.1.2.~~		To measure the specific emissions, the engine shall be operated over the test cycles defined in paragraphs 7.2.1. and 7.2.2. The measurement of specific emissions requires the quantification of the mass or number of components of designated emissions species in the exhaust and the corresponding engine cycle work. The components are determined by the sampling methods described in paragraphs 7.1.1. and 7.1.2.
7.1.1. Continuous sampling		
~~In continuous sampling, the component's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) exhaust flow rate at the emission sampling location to determine the component's mass flow rate. The component's~~		In continuous sampling, the component's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) exhaust flow rate at the emission sampling location to determine the component's mass or number flow rate. The

~~emission is continuously summed over the test cycle. This sum is the total mass of the emitted component.~~		component's emission is continuously summed over the test cycle. This sum is the total mass or number of the emitted component.
7.1.2. Batch sampling		
~~In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous components in a bag and collecting particulate matter (PM) on a filter. The batch sampled concentrations are multiplied by the total exhaust mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted component. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.~~		In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous components in a bag and collecting particulate matter (PM) on a filter. The batch sampled concentrations are multiplied by the total exhaust mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass (or number) or mass (or number) flow of the emitted component. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.
7.1.3. Measurement procedures		
~~This annex applies two measurement procedures that are functionally equivalent. Both procedures may be used for both the WHTC and the WHSC test cycle:~~ ~~(a) The gaseous components are sampled continuously in the raw exhaust gas, and the particulates are determined using a partial flow dilution system;~~ ~~(b) The gaseous components and the particulates are determined using a full flow dilution system (CVS system).~~ ~~Any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted.~~		This annex applies two measurement procedures that are functionally equivalent. Both procedures may be used for both the WHTC and the WHSC test cycle: (a) The gaseous components are sampled continuously in the raw exhaust gas, and the particulates are determined using a partial flow dilution system; (b) The gaseous components and the particulates are determined using a full flow dilution system (CVS system). Any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted. Particle Number (PN) can be determined by a suitable measurement system employing fixed ratio dilution as the initial dilution stage, or with proportional flow dilution by a

		partial-flow dilution system or a full-flow dilution system as the initial dilution stage.
7.2. Test cycles		
7.2.1. Transient test cycle WHTC		
~~The transient test cycle WHTC is listed in Appendix 1 as a second by second sequence of normalized speed and torque values. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine-mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those references speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.~~ ~~For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work shall be within prescribed limits of the reference cycle work.~~ ~~For the gaseous pollutants, continuous sampling (raw or dilute exhaust gas) or batch sampling (dilute exhaust gas) may be used. The particulate sample shall be diluted with a conditioned diluent (such as ambient air), and collected on a single suitable filter. The WHTC is shown schematically in Figure 3.~~		The transient test cycle WHTC is listed in Appendix 1 as a second-by-second sequence of normalized speed and torque values. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine-mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those references speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test. For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work shall be within prescribed limits of the reference cycle work. For the gaseous pollutants, continuous sampling (raw or dilute exhaust gas) or batch sampling (dilute exhaust gas) may be used. The particulate sample shall be diluted with a conditioned diluent (such as ambient air), and collected on a single suitable filter. Particle Number (PN) can be determined by a suitable measurement system employing fixed ratio dilution as the initial dilution stage, or with proportional flow dilution by a partial-flow dilution system or a full-flow dilution system as the initial dilution stage. The WHTC is shown schematically in Figure 3.

Figure 3 **WHTC test cycle**  		
7.2.2. Ramped steady state test cycle WHSC		
~~The ramped steady state test cycle WHSC consists of a number of normalized speed and load modes which shall be converted to the reference values for the individual engine under test based on the engine mapping curve. The engine shall be operated for the prescribed time in each mode, whereby engine speed and load shall be changed linearly within 20 ± 1 seconds. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.~~		The ramped steady state test cycle WHSC consists of a number of normalized speed and load modes which shall be converted to the reference values for the individual engine under test based on the engine-mapping curve. The engine shall be operated for the prescribed time in each mode, whereby engine speed and load shall be changed linearly within 20 ± 1 seconds. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

~~The concentration of each gaseous pollutant, exhaust flow and power output shall be determined over the test cycle. The gaseous pollutants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with a conditioned diluent (such as ambient air). One sample over the complete test procedure shall be taken, and collected on a single suitable filter.~~ ~~For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle.~~ ~~The WHSC is shown in Table 1. Except for mode 1, the start of each mode is defined as the beginning of the ramp from the previous mode.~~		The concentration of each gaseous pollutant, exhaust flow and power output shall be determined over the test cycle. The gaseous pollutants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with a conditioned diluent (such as ambient air). One sample over the complete test procedure shall be taken, and collected on a single suitable filter. Particle Number (PN) can be determined by a suitable measurement system employing fixed ratio dilution as the initial dilution stage, or with proportional flow dilution by a partial-flow dilution system or a full-flow dilution system as the initial dilution stage. For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. The WHSC is shown in Table 1. Except for mode 1, the start of each mode is defined as the beginning of the ramp from the previous mode.

Table 1 **WHSC test cycle**					
Mode	*Normalized speed (per cent)*	*Normalized torque (per cent)*	*Mode length incl. 20 s ra*		
1	0	0	2		
2	55	100			
3	55	25	2		
4	55	70			
5	35	100			
6	25	25	2		
7	45	70			
8	45	25	1		
9	55	50	1		
10	75	100			
11	35	50	2		
12	35	25	2		
13	0	0	2		
Sum			1,8		
…..					
7.5. Pre-test procedures					
7.5.1. Installation of the measurement equipment					
The instrumentation and sample probes shall be installed as required. The tailpipe shall be connected to the full flow dilution system, if used.					
7.5.2. Preparation of measurement equipment for sampling					

The following steps shall be taken before emission sampling begins: (a) Leak checks shall be performed within 8 hours prior to emission sampling according to paragraph 9.3.4.; (b) For batch sampling, clean storage media shall be connected, such as evacuated bags; (c) All measurement instruments shall be started according to the instrument manufacturer's instructions and good engineering judgment; (d) Dilution systems, sample pumps, cooling fans, and the data-collection system shall be started; (e) The sample flow rates shall be adjusted to desired levels, using bypass flow, if desired; (f) Heat exchangers in the sampling system shall be pre-heated or pre-cooled to within their operating temperature ranges for a test; (g) Heated or cooled components such as sample lines, filters, coolers, and pumps shall be allowed to stabilize at their operating temperatures; (h) Exhaust dilution system flow shall be switched on at least 10 minutes before a test sequence; (i) Any electronic integrating devices shall be zeroed or re-zeroed, before the start of any test interval.		
7.5.3. Checking the gas analyzers		
Gas analyzer ranges shall be selected. Emission analyzers with automatic or manual range switching are permitted. During the test cycle, the range of the emission analyzers shall not be switched. At the same time the gains of an analyzer's analogue		

operational amplifier(s) may not be switched during the test cycle. Zero and span response shall be determined for all analyzers using internationally-traceable gases that meet the specifications of paragraph 9.3.3. FID analyzers shall be spanned on a carbon number basis of one (C1).		
7.5.4. Preparation of the particulate sampling filter		
At least one hour before the test, the filter shall be placed in a petri dish, which is protected against dust contamination and allows air exchange, and placed in a weighing chamber for stabilization. At the end of the stabilization period, the filter shall be weighed and the tare weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber.		
7.5.5. Adjustment of the dilution system		
The total diluted exhaust gas flow of a full flow dilution system or the diluted exhaust gas flow through a partial flow dilution system shall be set to eliminate water condensation in the system, and to obtain a filter face temperature between 315 K (42 °C) and 325 K (52 °C).		
7.5.6. Starting the particulate sampling system		
The particulate sampling system shall be started and operated on by-pass. The particulate background level of the diluent may be determined by sampling the diluent prior to the entrance of the exhaust gas into the dilution tunnel. The measurement may be done prior to or after the test. If the measurement is done both at the beginning and at the end of the cycle, the values may be averaged. If a different sampling system is used for background measurement, the measurement shall be done in parallel to the test run.		

7.6. WHTC cycle run		
7.6.1. Engine cool-down		
A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-treatment system cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.		
7.6.2. Cold start test		
The cold-start test shall be started when the temperatures of the engine's lubricant, coolant, and after-treatment systems are all between 293 and 303 K (20 and 30 °C). The engine shall be started using one of the following methods: (a) The engine shall be started as recommended in the owner's manual using a production starter motor and adequately charged battery or a suitable power supply; or (b) The engine shall be started by using the dynamometer. The engine shall be motored within □25 per cent of its typical in-use cranking speed. Cranking shall be stopped within 1 second after the engine is running. If the engine does not start after 15 seconds of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owner's manual or the service-repair manual describes the longer cranking time as normal.		
7.6.3. Hot soak period		

Immediately upon completion of the cold start test, the engine shall be conditioned for the hot start test using a 10 ± 1 minute hot soak period.		
7.6.4. Hot start test		
The engine shall be started at the end of the hot soak period as defined in paragraph 7.6.3. using the starting methods given in paragraph 7.6.2.		
7.6.5. Test sequence		
The test sequence of both cold start and hot start test shall commence at the start of the engine. After the engine is running, cycle control shall be initiated so that engine operation matches the first set point of the cycle. The WHTC shall be performed according to the reference cycle as set out in paragraph 7.4. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. The set points shall be calculated by linear interpolation between the 1 Hz set points of the reference cycle. Actual engine speed and torque shall be recorded at least once every second during the test cycle (1 Hz), and the signals may be electronically filtered.		
7.6.6. Collection of emission relevant data		
~~At the start of the test sequence, the measuring equipment shall be started, simultaneously:~~ ~~(a) Start collecting or analyzing diluent, if a full flow dilution system is used;~~ ~~(b) Start collecting or analyzing raw or diluted exhaust gas, depending on the method used;~~ ~~(c) Start measuring the amount of diluted exhaust gas and the required temperatures and pressures;~~		At the start of the test sequence, the measuring equipment shall be started, simultaneously: (a) Start collecting or analyzing diluent, if a full flow dilution system is used; (b) Start collecting or analyzing raw or diluted exhaust gas, depending on the method used; (c) Start measuring the amount of diluted exhaust gas and the required temperatures and pressures;

~~(d) Start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;~~ ~~(e) Start recording the feedback data of speed and torque of the dynamometer.~~ ~~If raw exhaust measurement is used, the emission concentrations ((NM)HC, CO and NOx) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.~~ ~~If a full flow dilution system is used, HC and NOx shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 seconds, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO2, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the diluent shall be determined prior to the point where the exhaust enters into the dilution tunnel by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).~~		(d) Start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used; (e) Start recording the feedback data of speed and torque of the dynamometer. If raw exhaust measurement is used, the emission concentrations (PN, (NM)HC, CO and NOx) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation. If a full flow dilution system is used, PN, HC and NOx shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 seconds, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO2, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the diluent shall be determined prior to the point where the exhaust enters into the dilution tunnel by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).
7.6.7. Particulate sampling		
At the start of the test sequence, the particulate sampling system shall be switched from by-pass to collecting particulates.		

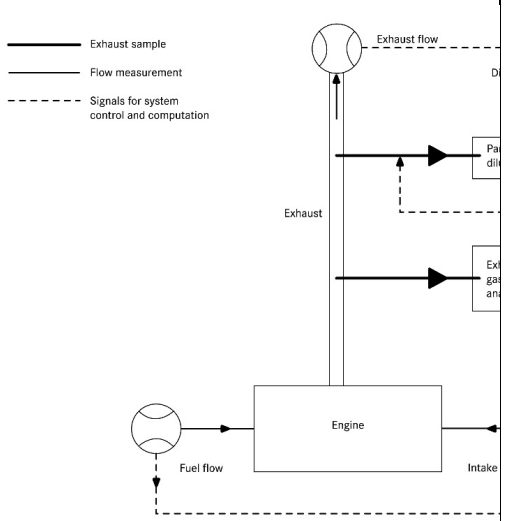
If a partial flow dilution system is used, the sample pump(s) shall be controlled, so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate as determined in accordance with paragraph 9.4.6.1. If a full flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within ±2.5 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ±2.5 per cent of its set value (except for the first 10 seconds of sampling). The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle within ±2.5 per cent because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower sample flow rate.		
7.6.8. Engine stalling and equipment malfunction		
If the engine stalls anywhere during the cold start test, the test shall be voided. The engine shall be preconditioned and restarted according to the requirements of paragraph 7.6.2., and the test repeated. If the engine stalls anywhere during the hot start test, the hot start test shall be voided. The engine shall be soaked according to paragraph 7.6.3., and the hot start test repeated. In this case, the cold start test need not be repeated. If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided and repeated in line with the above provisions.		

7.7. WHSC cycle run		
7.7.1. Preconditioning the dilution system and the engine		
The dilution system and the engine shall be started and warmed up in accordance with paragraph 7.4.1. After warm-up, the engine and sampling system shall be preconditioned by operating the engine at mode 9 (see paragraph 7.2.2., Table 1) for a minimum of 10 minutes while simultaneously operating the dilution system. Dummy particulate emissions samples may be collected. Those sample filters need not be stabilized or weighed, and may be discarded. Flow rates shall be set at the approximate flow rates selected for testing. The engine shall be shut off after preconditioning.		
7.7.2. Engine starting		
5 ± 1 minutes after completion of preconditioning at mode 9 as described in paragraph 7.7.1., the engine shall be started according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer in accordance with paragraph 7.6.2.		
7.7.3. Test sequence		
The test sequence shall commence after the engine is running and within one minute after engine operation is controlled to match the first mode of the cycle (idle). The WHSC shall be performed according to the order of test modes listed in Table 1 of paragraph 7.2.2.		
7.7.4. Collection of emission relevant data		
At the start of the test sequence, the measuring equipment shall be started, simultaneously:		

(a) Start collecting or analyzing diluent, if a full flow dilution system is used; (b) Start collecting or analyzing raw or diluted exhaust gas, depending on the method used; (c) Start measuring the amount of diluted exhaust gas and the required temperatures and pressures; (d) Start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used; (e) Start recording the feedback data of speed and torque of the dynamometer. If raw exhaust measurement is used, the emission concentrations ((NM)HC, CO and NOx) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation. If a full flow dilution system is used, HC and NOx shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 seconds, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO2, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the diluent shall be determined prior to the point where the exhaust enters into the dilution tunnel by integration or by collecting into the background bag. All other		

parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).		
7.7.5. Particulate sampling		
At the start of the test sequence, the particulate sampling system shall be switched from by-pass to collecting particulates. If a partial flow dilution system is used, the sample pump(s) shall be controlled, so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate as determined in accordance with paragraph 9.4.6.1. If a full flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within ±2.5 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ±2.5 per cent of its set value (except for the first 10 seconds of sampling). The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle within ±2.5 per cent because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower sample flow rate.		
7.7.6. Engine stalling and equipment malfunction		
If the engine stalls anywhere during the cycle, the test shall be voided. The engine shall be preconditioned according to paragraph 7.7.1. and restarted according to paragraph 7.7.2., and the test repeated.		

If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided and repeated in line with the above provisions.		
7.8. Post-test procedures		
…		
8.4. Partial flow dilution (PFS) and raw gaseous measurement		
The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly, or calculated using the methods of intake air and fuel flow measurement, tracer method or intake air and air/fuel ratio measurement. Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals. For particulates, the exhaust mass flow rate signals are used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with paragraph 9.4.6.1. The complete test set up is schematically shown in Figure 6.		

Figure 6 **Scheme of raw/partial flow measurement system**  		
8.4.1. Determination of exhaust gas mass flow		
8.4.1.1. Introduction		
~~For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, one of the methods described in paragraphs 8.4.1.3. to 8.4.1.7. may be used.~~		For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, one of the methods described in paragraphs 8.4.1.3. to 8.4.1.7. may be used. If necessary for calculations of exhaust emissions, the exhaust flow rate shall be corrected for any extracted flows. If applicable, the results of the

		full dilution tunnel shall be corrected for the extracted flow rate unless: Q(extracted) <0.5% of cycle mean exhaust flow rate In this case the correction is optional.
8.4.1.2. Response time		
For the purpose of emissions calculation, the response time of any of the methods described in paragraphs 8.4.1.3. to 8.4.1.7. shall be equal to or less than the analyzer response time of ≤ 10 seconds, as required in paragraph 9.3.5. For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, the response time shall be ≤ 0.3 second. For partial flow dilution systems with look ahead control based on a pre-recorded test run, the response time of the exhaust flow measurement system shall be ≤ 5 seconds with a rise time of ≤ 1 second. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for the exhaust gas flow and partial flow dilution system are indicated in paragraph 9.4.6.1.		
8.4.1.3. Direct measurement method		
Direct measurement of the instantaneous exhaust flow shall be done by systems, such as: (a) Pressure differential devices, like flow nozzle, (details see ISO 5167); (b) Ultrasonic flowmeter; (c) Vortex flowmeter. Precautions shall be taken to avoid measurement errors which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust		

system according to the instrument manufacturers' recommendations and to good engineering practice. Especially, engine performance and emissions shall not be affected by the installation of the device. The flowmeters shall meet the linearity requirements of paragraph 9.2.		
8.4.1.4. Air and fuel measurement method		
…		
8.4.1.5. Tracer measurement method		
…		
8.4.1.6. Airflow and air to fuel ratio measurement method		
…		
8.4.1.7. Carbon balance method		
…		
8.4.2. Determination of the gaseous components		
8.4.2.1. Introduction		
The gaseous components in the raw exhaust gas emitted by the engine submitted for testing shall be measured with the measurement and sampling systems described in paragraph 9.3. and Appendix 2 to this annex. The data evaluation is described in paragraph 8.4.2.2. Two calculation procedures are described in paragraphs 8.4.2.3. and 8.4.2.4., which are equivalent for the reference fuel of Annex 5. The procedure in paragraph 8.4.2.3. is more straightforward, since it uses tabulated u values for the ratio between component and exhaust gas density. The procedure in paragraph 8.4.2.4. is more accurate for fuel qualities that		

deviate from the specifications in Annex 5, but requires elementary analysis of the fuel composition.		
8.4.2.2. Data evaluation		
The emission relevant data shall be recorded and stored in accordance with paragraph 7.6.6. For calculation of the mass emission of the gaseous components, the traces of the recorded concentrations and the trace of the exhaust gas mass flow rate shall be time aligned by the transformation time as defined in paragraph 3.1. Therefore, the response time of the exhaust gas mass flow system and each gaseous emissions analyzer shall be determined according to paragraphs 8.4.1.2. and 9.3.5., respectively, and recorded.		
8.4.2.3. Calculation of mass emission based on tabulated values		
…		
8.4.2.4. Calculation of mass emission based on exact equations		
…		
8.4.3. Particulate determination		
8.4.3.1. Data evaluation		
The particulate mass shall be calculated according to equation 27 of paragraph 8.3. For the evaluation of the particulate concentration, the total sample mass (msep) through the filter over the test cycle shall be recorded. With the prior approval of the Type Approval Authority , the particulate mass may be corrected for the particulate level of the diluent, as determined in paragraph 7.5.6., in line with		

good engineering practice and the specific design features of the particulate measurement system used.		
….		
10. Particle number measurement test procedure		
10.1. Sampling		
~~Particle number emissions shall be measured by continuous sampling from either a partial flow dilution system, as described in Appendix 2 to this annex, paragraph A.2.2.1. and A.2.2.2. or a full flow dilution system as described in Appendix 2 to this annex, paragraph A.2.2.3. and A.2.2.4.~~		Particle number emissions shall be measured by continuous sampling from 1) the tailpipe using fixed dilution 2) a proportional partial flow dilution system, as described in Appendix 2 to this annex, paragraph A.2.2.1 and A.2.2.2 or 3) a full flow dilution system as described in Appendix 2 to this annex, paragraph A.2.2.3 and A.2.2.4.
10.1.1. Diluent filtration		
Diluent used for both the primary and, where applicable, secondary dilution of the exhaust in the dilution system shall be passed through filters meeting the High-Efficiency Particulate Air (HEPA) filter requirements defined in Appendix 2 to this annex, paragraphs A.2.2.2. or A.2.2.4. The diluent may optionally be charcoal scrubbed before being passed to the HEPA filter to reduce and stabilize the hydrocarbon concentrations in the diluent. It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal scrubber, if used.		

10.2. Compensating for particle number sample flow – full flow dilution systems		
To compensate for the mass flow extracted from the dilution system for particle number sampling the extracted mass flow (filtered) shall be returned to the dilution system. Alternatively, the total mass flow in the dilution system may be mathematically corrected for the particle number sample flow extracted. Where the total mass flow extracted from the dilution system for the sum of particle number sampling and particulate mass sampling is less than 0.5 per cent of the total dilute exhaust gas flow in the dilution tunnel (m_{ed}) this correction, or flow return, may be neglected.		
10.3. Compensating for particle number sample flow – partial flow dilution systems		
10.3.1.For partial flow dilution systems the mass flow extracted from the dilution system for particle number sampling shall be accounted for in controlling the proportionality of sampling. This shall be achieved either by feeding the particle number sample flow back into the dilution system upstream of the flow measuring device or by mathematical correction as outlined in paragraph 10.3.2. In the case of total sampling type partial flow dilution systems, the mass flow extracted for particle number sampling shall also be corrected for in the particulate mass calculation as outlined in paragraph 10.3.3.		
10.3.2.The instantaneous exhaust gas flow rate into the dilution system (q_{mp}), used for controlling the proportionality of sampling, shall be corrected according to one of the following methods:		
(a) In the case where the extracted particle number sample flow is discarded, equation 83 in paragraph 9.4.6.2. shall be replaced by the following:		

$q_{mp} = q_{mdew} - q_{mdw} + q_{ex}$ (92)		
Where:		
q_{mp} = sample flow of exhaust gas into partial flow dilution system, kg/s,		
q_{mdew} = diluted exhaust mass flow rate, kg/s,		
q_{mdw} = dilution air mass flow rate, kg/s,		
q_{ex} = particle number sample mass flow rate, kg/s.		
The q_{ex} signal sent to the partial flow system controller shall be accurate to within 0.1 per cent of q_{mdew} at all times and should be sent with frequency of at least 1 Hz.		
(b) In the case where the extracted particle number sample flow is fully or partially discarded, but an equivalent flow is fed back to the dilution system upstream of the flow measurement device, equation 83 in paragraph 9.4.6.2. shall be replaced by the following:		
$q_{mp} = q_{mdew} - q_{mdw} + q_{ex} - q_{sw}$ (93)		
Where:		
q_{mp} = sample flow of exhaust gas into partial flow dilution system, kg/s,		

q_{mdew} = diluted exhaust mass flow rate, kg/s,		
q_{mdw} = dilution air mass flow rate, kg/s,		
q_{ex} = particle number sample mass flow rate, kg/s,		
q_{sw} = mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction, kg/s.		
The difference between q_{ex} and q_{sw} sent to the partial flow system controller shall be accurate to within 0.1 per cent of q_{mdew} at all times. The signal (or signals) should be sent with frequency of at least 1 Hz.		
10.3.3.Correction of PM measurement		
When a particle number sample flow is extracted from a total sampling partial flow dilution system, the mass of particulates (m_{PM}) calculated in paragraph 8.4.3.2.1. or 8.4.3.2.2. shall be corrected as follows to account for the flow extracted. This correction is required even where filtered extracted flow is fed back into the partial flow dilution systems.		
$m_{PM,corr} = m_{PM} \times \frac{m_{sed}}{(m_{sed} - m_{ex})}$ (94)		
Where:		
$m_{PM,corr}$ = mass of particulates corrected for extraction of particle number sample flow, g/test,		

m_{PM} = mass of particulates determined according to paragraph 8.4.3.2.1. or 8.4.3.2.2., g/test,		
m_{sed} = total mass of diluted exhaust gas passing through the dilution tunnel, kg,		
m_{ex} = total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg.		
10.3.4.Proportionality of partial flow dilution sampling		
For particle number measurement, exhaust mass flow rate, determined according to any of the methods described in paragraphs 8.4.1.3. to 8.4.1.7., is used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with paragraph 9.4.6.1.		
10.4. Determination of particle numbers		
10.4.1.Time alignment		
~~For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedure in paragraph 8.4.2.2. The transformation time of the particle number sampling and measurement system shall be determined according to paragraph A.8.1.3.7. of Appendix 8 to this annex.~~		For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedure in paragraph 8.4.2.2. The transformation time of the particle number sampling and measurement system shall be determined according to paragraph A.8.1.3.7. of Appendix 8 to this annex. For direct tailpipe sampling with fixed initial dilution ratio the particle number signal shall be time aligned with the exhaust flow signal using the respective transformation times. The

		transformation time of the particle number sampling shall be determined according to paragraph A.8.1.3.7 of Appendix 8 to this annex.
10.4.2.Determination of particle numbers with a partial flow dilution system		
Where particle numbers are sampled using a partial flow dilution system according to the procedures set out in paragraph 8.4., the number of particles emitted over the test cycle shall be calculated by means of the following equation:		
$N = \frac{m_{edf}}{1.293} . k . \overline{c_s} . \overline{f_r} . 10^6$ (95)		
Where:		
N = number of particles emitted over the test cycle,		
m_{edf} = mass of equivalent diluted exhaust gas over the cycle, determined according to paragraph 8.4.3.2.2., kg/test,		
k = calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in the above equation,		
$\overline{c_s}$ = average concentration of particles from the diluted exhaust gas		

corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,		
$\overline{f_r}$ = mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.		
$\overline{c_s}$ shall be calculated from the following equation:		
$\overline{c_s} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n}$ (96)		
Where:		
$c_{s,i}$ = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected ~~for coincidence and~~ to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,		cs,i = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,
n = number of particle concentration measurements taken over the duration of the test.		
10.4.3.Determination of particle numbers with a full flow dilution system		
Where particle numbers are sampled using a full flow dilution system according to the procedures set out in paragraph 8.5., the number of particles emitted over the test cycle shall be calculated by means of the following equation:		

$N = \frac{m_{edf}}{1.293} \cdot k \cdot \overline{c_s} \cdot \overline{f_r} \cdot 10^6$ (97)		
Where:		
N = number of particles emitted over the test cycle,		
m_{ed} = total diluted exhaust gas flow over the cycle calculated according to any one of the methods described in paragraphs 8.5.1.2. to 8.5.1.4., kg/test,		
k = calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in the above equation,		
$\overline{c_s}$ = average corrected concentration of particles from the diluted exhaust gas corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,		
$\overline{f_r}$ = mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.		
$\overline{c_s}$ shall be calculated from the following equation:		

$\bar{c} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n}$ (98)		
Where:		

$c_{s,i}$ = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for ~~coincidence and~~ to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,		cs,i = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,
n = number of particle concentration measurements taken over the duration of the test.		

		Determination of particle numbers with raw exhaust sampling (Correct paragraph number has to be determined maybe 10.4.3b) The instantaneous particle number emissions [particles/s] shall be determined by multiplying the instantaneous concentration of the pollutant under consideration [particles/cm3] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time. If applicable, negative instantaneous emission values shall enter all subsequent data evaluations. All significant digits of intermediate results shall enter the calculation of the instantaneous emissions. The following equation shall apply: $N_i = c_{N,i}\ q_{mew,i} / \rho_e$ Where: N_i is the particle number flux [particles/s] $c_{N,i}$ is the measured particle number concentration normalized at 0°C [particles/m^3], corrected for any calibration factors $q_{mew,i}$ is the measured exhaust mass flow rate [kg/s] (8.4.1.3) ρ_e is the exhaust gas density at 0°C, 1013 mbar [kg/m^3] (Table 5)
10.4.4. Test result		
10.4.4.1. Calculation of the specific emissions		
For each individual WHSC, hot WHTC and cold WHTC the specific emissions in number of particles/kWh shall be calculated as follows:		

$e = \frac{N}{W_{act}}$ (99)		
Where:		
e = is the number of particles emitted per kWh,		
W_{act} = is the actual cycle work according to paragraph 7.8.6., in kWh.		
10.4.4.2. Exhaust after-treatment systems with periodic regeneration		
For engines equipped with periodically regenerating after-treatment systems, the general provisions of paragraph 6.6.2. apply. The WHTC hot start emissions shall be weighted according to equation 5 where $\bar{e}$ is the average number of particles/kWh without regeneration, and $\overline{e_r}$ is the average number of particles/kWh with regeneration. The calculation of the regeneration adjustment factors shall be done according to equations 6, 6a, 7 or 8, as appropriate.		
10.4.4.3. Weighted average WHTC test result		
For the WHTC, the final test result shall be a weighted average from cold start and hot start (including periodic regeneration where relevant) tests calculated using one of the following equations:		

(a) In the case of multiplicative regeneration adjustment, or engines without periodically regenerating after-treatment		
$e = k_r \left(\frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right)$ (100)		
(b) In the case of additive regeneration adjustment		
$e = k_r + \left(\frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right)$ (101)		
Where:		
N_{cold} = is the total number of particles emitted over the WHTC cold test cycle,		
N_{hot} = is the total number of particles emitted over the WHTC hot test cycle,		
$W_{act,cold}$ = is the actual cycle work over the WHTC cold test cycle according to paragraph 7.8.6., in kWh,		
$W_{act,\ hot}$ = is the actual cycle work over the WHTC hot test cycle according to paragraph 7.8.6., in kWh,		
k_r = is the regeneration adjustment, according to paragraph 6.6.2., or in the case of engines without periodically regenerating after-treatment $k_r = 1$		

10.4.4.4. Rounding of final results		
The final WHSC and weighted average WHTC test results shall be rounded in one step to three significant figures in accordance with ASTM E 29–06B. No rounding of intermediate values leading to the final brake specific emission result is permissible.		
10.5. Determination of particle number background		
10.5.1.At the engine manufacturer's request, dilution tunnel background particle number concentrations may be sampled, prior to or after the test, from a point downstream of the particle and hydrocarbon filters into the particle number measurement system, to determine the tunnel background particle concentrations.		
10.5.2.Subtraction of particle number tunnel background concentrations shall not be allowed for type approval, but may be used at the manufacturer's request, with the prior approval of the Type Approval Authority , for conformity of production testing, if it can be demonstrated that tunnel background contribution is significant, which can then be subtracted from the values measured in the diluted exhaust.		

Particle number emissions measurement equipment

A.8.1. Specification		
A.8.1.1. System overview		
A.8.1.1.1. ~~The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system as described in Appendix 2 to this annex, paragraph A.2.2.1. and A.2.2.2. or A.2.2.3. and A.2.2.4., a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing~~.		The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in the tailpipe or in a dilution system as described in Appendix 2 to this annex, paragraph A.2.2.1 and A.2.2.2 or A.2.2.3 and A.2.2.4, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing. For direct tailpipe sampling, optionally, a pre-diluter may be included between the sampling probe or point and the VPR.
A.8.1.1.2. It is recommended that a particle size pre-classifier (e.g. cyclone, impactor, etc.) be located prior to the inlet of the VPR. However, a sample probe acting as an appropriate size-classification device, such as that shown in Appendix 2 to this annex, Figure 14, is an acceptable alternative to the use of a particle size pre-classifier. In the case of partial flow dilution systems it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.		
A.8.1.2. General requirements		

A.8.1.2.1. ~~The particle sampling point shall be located within a dilution system.~~		A.8.1.2.1 Particle transfer system
~~The sampling probe tip or particle sampling point and particle transfer tube (PTT) together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance of the VPR. The PTS shall meet the following conditions:~~		The sampling probe tip or particle sampling point and particle transfer tube (PTT), and optionally a pre-diluter for direct tailpipe sampling, together comprise the particle transfer system (PTS). The PTS conducts the sample to the entrance of the VPR. A cold or hot pre-diluter may be located at the end of the particle sampling probe and in front of the PTT. A fixed dilution ratio >5:1 shall be applied to the cold or hot dilution stage. Cold dilution is defined as a dilution with (unheated) dilution air and/or diluter temperature ≥20°C. Indicators of whether temperatures (if applicable) and dilutions are at their correct operating ranges shall be provided. The pre-diluter shall incorporate good aerosol sampling practice as described for the VPR in A.8.1.2.3 and A.8.2.2.4. The penetration for each model of pre-diluter shall be determined as described in A.8.2.2.4. The final system penetration (pre-diluter and VPR) shall fulfil the requirements of A.8.1.3.3.6. The particle concentration reduction factors of each pre-diluter shall be determined as described in A.8.2.2.2. The complete system (pre-diluter and VPR) shall fulfil the requirements of A.8.1.3.3.4. The pre-diluter shall be calibrated or validated at the same time intervals as the VPR, as given in A.8.2.2.1. The PTS shall meet the following conditions:
In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in Appendix 2 to this annex, paragraph A.2.2.1.) the sampling probe shall be installed near the tunnel centre line, 10 to 20		

tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel. The sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.		
In the case of partial flow dilution systems of the total sampling type (as described in Appendix 2 to this annex, paragraph A.2.2.1.) the particle sampling point or sampling probe shall be located in the particulate transfer tube, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture. The dimensions of the particle sampling probe should be sized not to interfere with the operation of the partial flow dilution system.		

		In case of direct tailpipe sampling, the exhaust shall be sampled from the center of the exhaust stream. The PN sampling probe shall be fitted at least 0,5 m or three times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system but sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe. In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest PN emission. For exhaust emission calculation the total exhaust mass flow shall be used. The PN particle sampling point or sampling probe shall be located in close proximity to the gaseous emissions sampling probe (if used) or the proportional sampling system (if used), but sufficiently distant as to not cause interference.
Sample gas drawn through the PTS shall meet the following conditions:		
In the case of full flow dilution systems, it shall have a flow Reynolds number (Re) of < 1,700;		
In the case of partial flow dilution systems, it shall have a flow Reynolds number (Re) of < 1,700 in the PTT i.e. downstream of the sampling probe or point;		
		In the case of direct tailpipe sampling, it shall have a flow Reynolds number (Re) of < 1 700 in the PTT

~~It shall have a residence time in the PTS of ≤ 3 seconds~~.		When sampling from full flow or partial flow dilution systems or a pre-diluter, it shall have a residence time in the PTT of ≤ 3 seconds. When sampling directly from the tailpipe the residence time until the pre-diluter or the VPR shall be ≤ 1 seconds. The tubing shall be heated at ≥150°C if >10 cm, otherwise only insulated. Any unheated parts shall be <10 cm.
~~Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable~~.	SPN23: Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable. SPN10: Any other sampling configuration for the PTS for which equivalent particle penetration at 15 nm can be demonstrated will be considered acceptable.	
The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:		
It shall have an internal diameter of ≥ 4 mm;		
Sample Gas flow through the OT shall have a residence time of ≤ 0.8 second.		
~~Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable~~.	SPN23: Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable. SPN10: Any other sampling configuration for the OT for which equivalent particle penetration at 15 nm can be demonstrated will be considered acceptable.	
A.8.1.2.2. The VPR shall include devices for sample dilution and for volatile particle removal.		

A.8.1.2.3. ~~All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects~~.	All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be made of electrically conductive materials, shall be electrically grounded to prevent electrostatic effects and designed to minimize deposition of the particles.	
A.8.1.2.4. The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in cross-paragraph, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Gradual changes in the cross-section are permissible.		
A.8.1.3. Specific requirements		
A.8.1.3.1. The particle sample shall not pass through a pump before passing through the PNC.		
A.8.1.3.2. A sample pre-classifier is recommended.		
A.8.1.3.3. The sample preconditioning unit shall:		
A.8.1.3.3.1. ~~Be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC and a gas temperature below 35 °C at the inlet to the PNC;~~	Be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC below a maximum allowed inlet temperature specified by the PNC manufacturer;	
A.8.1.3.3.2. ~~Include an initial heated dilution stage which outputs a sample at a temperature of ≥ 150 °C and ≤ 400 °C, and dilutes by a factor of at least 10~~;	SPN23 Include an initial heated dilution stage which outputs a sample at a temperature of ≥ 150 °C and ≤ 350 °C ±10 °C, and dilutes by a factor of at least 10. SPN10	

	Include an initial heated dilution stage which outputs a sample at a temperature of ≥ 150 °C and ≤ 350 °C ±10 °C, and dilutes by a factor of at least 10. Include a catalytically active part at a fixed (±10°C) wall temperature greater than or equal to that of the initial dilution stage.	
A.8.1.3.3.3. Control heated stages to constant nominal operating temperatures, within the range specified in paragraph A.8.1.3.3.2., to a tolerance of ±10 °C. Provide an indication of whether or not heated stages are at their correct operating temperatures;		
A.8.1.3.3.4. ~~Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in paragraph A.8.2.2.2. below, for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole~~;	SPN23: Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in paragraph A.8.2.2.2. below, for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole; SPN10: Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in paragraph A.8.2.2.2. below, for particles of 15 nm, 30 nm and 50 nm electrical mobility diameters, that is no more than 100 per cent, 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;	
A.8.1.3.3.5. ~~Also achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet~~	SPN23: Also achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥	

Commented [BG1]: Note that there is no requirement to have an ET or CS at 350C, as in the original version of the regulation.

~~concentration of ≥ 10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane.~~	10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane. SPN10: Achieve more than 99.9 per cent vaporization of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with count median diameter > 50 nm and mass > 1 mg/m3 , by means of heating and reduction of partial pressures of the tetracontane.	
	A.8.1.3.3.6. Achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;	
A.8.1.3.4. The PNC shall:		
A.8.1.3.4.1. Operate under full flow operating conditions;		
A.8.1.3.4.2. Have a counting accuracy of ± 10 per cent across the range 1 cm^{-3} to the upper threshold of the single particle count mode of the PNC against a traceable standard. At concentrations below 100 cm^{-3} measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;		
A.8.1.3.4.3. Have a readability of at least 0.1 particle cm^{-3} at concentrations below 100 cm^{-3};		
A.8.1.3.4.4. Have a linear response to particle concentrations over the full measurement range in single particle count mode;		
A.8.1.3.4.5. Have a data reporting frequency equal to or greater than 0.5 Hz;		
A.8.1.3.4.6. Have a t_{90} response time over the measured concentration range of less than 5 s;		
A.8.1.3.4.7. ~~Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an~~	SPN23:	

~~internal calibration factor as determined in paragraph A.8.2.1.3., but shall not make use of any other algorithm to correct for or define the counting efficiency;~~	Incorporate an internal calibration factor from the linearity calibration against a traceable reference, as determined in paragraph A.8.2.1.3, shall be applied to determine PNC counting efficiency. The counting efficiency shall be reported including the calibration factor. SPN10: Incorporate an internal calibration factor from the linearity calibration against a traceable reference, as determined in paragraph A.8.2.1.3, shall be applied to determine PNC counting efficiency. The counting efficiency shall be reported including the calibration factor. The PNC calibration material shall be 4cSt polyalphaolefin (Emery oil) or soot-like particles (e.g. flame generated soot or graphite particles).	
A.8.1.3.4.8. ~~Have counting efficiencies at particle sizes of 23 nm (±1 nm) and 41 nm (±1 nm) electrical mobility diameter of 50 per cent (±12 per cent) and > 90 per cent respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means;~~	SPN23: Have counting efficiencies at particle sizes of 23 nm (±1 nm) and 41 nm (±1 nm) electrical mobility diameter of 50 per cent (±12 per cent) and > 90 per cent respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means; SPN10: Have counting efficiencies at nominal particle sizes of 10 nm and 15 nm electrical mobility diameter of 65 per cent (±15 per cent) and > 90 per cent respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means;	

A.8.1.3.4.9. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.		
A.8.1.3.5. ~~Where they are not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at inlet to the PNC shall be measured and reported for the purposes of correcting particle concentration measurements to standard conditions.~~	Where not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at the PNC inlet shall be measured for the purposes of correcting particle number concentration measurements to standard conditions. The standard conditions are 101.325 kPa pressure and 0°C temperature.	
A.8.1.3.6. The sum of the residence time of the PTS, VPR and OT plus the t_{90} response time of the PNC shall be no greater than 20 s.		
A.8.1.3.7. The transformation time of the entire particle number sampling system (PTS, VPR, OT and PNC) shall be determined by aerosol switching directly at the inlet of the PTS. The aerosol switching shall be done in less than 0.1 s. The aerosol used for the test shall cause a concentration change of at least 60 per cent full scale (FS).		
The concentration trace shall be recorded. For time alignment of the particle number concentration and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).		
A.8.1.4. Recommended system description		
The following paragraph contains the recommended practice for measurement of particle number. However, any system meeting the performance specifications in paragraphs A.8.1.2. and A.8.1.3. is acceptable.		
Figures 19 and 20 are schematic drawings of the recommended particle sampling system configures for partial and full flow dilution systems respectively.		Figures 19, 20, and 21 are schematic drawings of the recommended particle sampling system configures for partial, full flow dilution and tailpipe systems respectively.

Figure 19
Schematic of recommended particle sampling system – Partial flow sampling

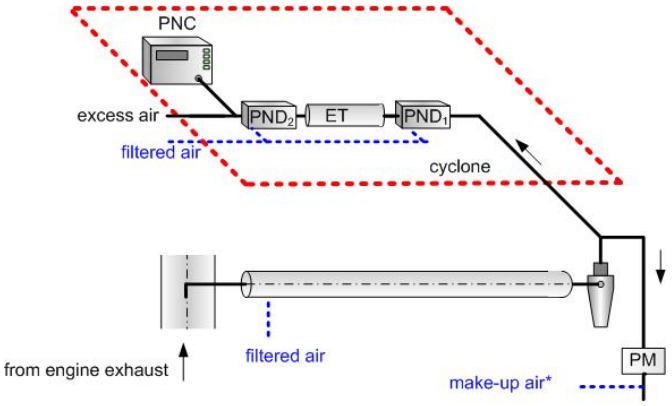


Figure 20
Schematic of recommended particle sampling system – Full flow sampling

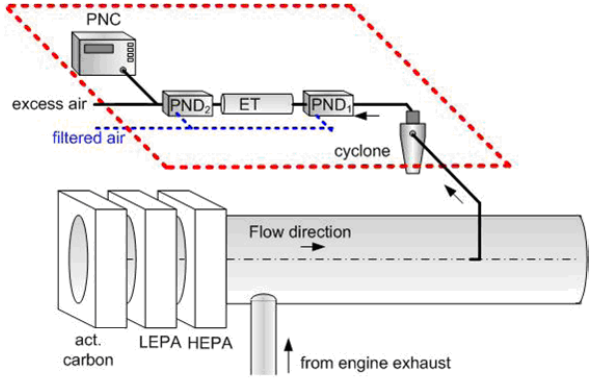
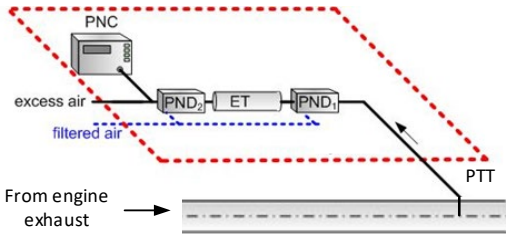
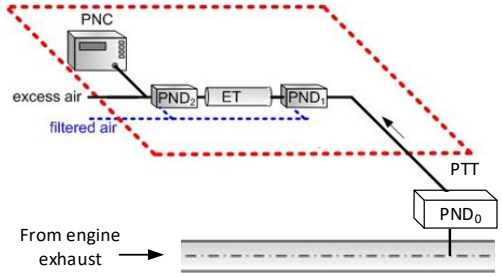


Figure 21
Schematic of recommended particle sampling system – Tailpipe sampling (i) without pre-diluter; (ii) with pre-diluter.





To check if addition of figure number affects other figures numbers

A.8.1.4.1. Sampling system description		
The particle sampling system shall consist of a sampling probe tip or particle sampling point in the dilution system, a particle transfer tube (PTT), a particle pre-classifier (PCF) and a volatile particle remover (VPR) upstream of the particle number concentration measurement (PNC) unit. The VPR shall include devices for sample dilution (particle number diluters: PND_1 and PND_2) and particle evaporation (Evaporation tube, ET). The sampling probe or sampling point for the test gas flow shall be so arranged within the dilution tract that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture. The sum of the residence time of the system plus the t_{90} response time of the PNC shall be no greater than 20 s.		
A.8.1.4.2. Particle transfer system		
~~The sampling probe tip or particle sampling point and Particle Transfer Tube (PTT) together comprise the Particle Transfer System (PTS). The PTS conducts the sample from the~~		The sampling probe tip or particle sampling point and particle transfer tube (PTT), and optionally a pre-diluter for direct tailpipe sampling, together comprise the particle

~~dilution tunnel to the entrance to the first particle number diluter. The PTS shall meet the following conditions:~~		transfer system (PTS). The PTS conducts the sample to the entrance of the VPR. A cold or hot pre-diluter may be located at the end of the particle sampling probe and in front of the PTT. A fixed dilution ratio >5:1 shall be applied to the cold or hot dilution stage. Cold dilution is defined as a dilution with (unheated) dilution air and/or diluter temperature ≥20°C. Indicators of whether temperatures (if applicable) and dilutions are at their correct operating ranges shall be provided. The PTS shall meet the following conditions:
In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in Appendix 2 to this annex, paragraph A.2.2.1.) the sampling probe shall be installed near the tunnel centre line, 10 to 20 tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel. The sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.		
In the case of partial flow dilution systems of the total sampling type (as described in Appendix 2 to this annex, paragraph A.2.2.1.) the particle sampling point shall be located in the particulate transfer tube, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture.		

		In case of direct tailpipe sampling, the exhaust shall be sampled from the center of the exhaust stream. The PN sampling probe shall be fitted at least 0,5 m or three times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system but sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe. In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest PN emission. For exhaust emission calculation the total exhaust mass flow shall be used. The PN particle sampling point or sampling probe shall be located in close proximity to the gaseous emissions sampling probe (if used) or the proportional sampling system (if used), but sufficiently distant as to not cause interference.
Sample gas drawn through the PTS shall meet the following conditions:		
It shall have a flow Reynolds number (Re) of < 1,700;		
~~It shall have a residence time in the PTS of ≤ 3 seconds~~.		When sampling from full flow or partial flow dilution systems or a pre-diluter, it shall have a residence time in the PTT of ≤ 3 seconds. When sampling directly from the tailpipe the residence time until the pre-diluter or the VPR shall be ≤ 1 seconds. The

		tubing shall be heated at ≥150°C if >10 cm, otherwise only insulated. Any unheated parts shall be <10 cm.
~~Any other sampling configuration for the PTS for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable.~~	SPN23: Any other sampling configuration for the PTS for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable. SPN10: Any other sampling configuration for the PTS for which equivalent particle penetration for particles of 15 nm electrical mobility diameter can be demonstrated will be considered acceptable	
The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:		
It shall have an internal diameter of ≥ 4 mm;		
Sample gas flow through the POT shall have a residence time of ≤ 0.8 second.		
~~Any other sampling configuration for the OT for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable~~.	SPN23: Any other sampling configuration for the OT for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable. SPN10: Any other sampling configuration for the OT for which equivalent particle penetration for particles of 15 nm electrical mobility diameter can be demonstrated will be considered acceptable.	

A.8.1.4.3. Particle pre-classifier		
The recommended particle pre-classifier shall be located upstream of the VPR. The pre-classifier 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling particle number emissions. The pre-classifier shall allow at least 99 per cent of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling particle number emissions. In the case of partial flow dilution systems, it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.		
A.8.1.4.4. Volatile particle remover (VPR)		
The VPR shall comprise one particle number diluter (PND_1), an evaporation tube and a second diluter (PND_2) in series. This dilution function is to reduce the number concentration of the sample entering the particle concentration measurement unit to less than the upper threshold of the single particle count mode of the PNC and to suppress nucleation within the sample. The VPR shall provide an indication of whether or not PND_1 and the evaporation tube are at their correct operating temperatures.		
~~The VPR shall achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor (f_r) for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and~~	SPN23: The VPR shall achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor (f_r) for particles of 30 nm and 50 nm electrical mobility diameters.	

~~no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole~~.	that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole. SPN10: The VPR shall achieve more than 99.9 per cent vaporization of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with count median diameter > 50 nm and mass > 1 mg/m^3, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor (f_r) for particles of 15 nm, 30 nm and 50 nm electrical mobility diameters, that is no more than 100 per cent, 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole.	
A.8.1.4.4.1. First particle number dilution device (PND_1)		
The first particle number dilution device shall be specifically designed to dilute particle number concentration and operate at a (wall) temperature of 150 °C to 400 °C. The wall temperature setpoint should be held at a constant nominal operating temperature, within this range, to a tolerance of ±10 °C and not exceed the wall temperature of the ET (paragraph A.8.1.4.4.2.). The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution factor of 10 to 200 times.		
A.8.1.4.4.2. Evaporation Tube (ET)		
The entire length of the ET shall be controlled to a wall temperature greater than or equal to that of the first particle number dilution device and the wall temperature held at a fixed nominal operating temperature between 300 °C and 400 °C, to a tolerance of ±10 °C.		
	A.8.1.4.4.3.	

	SPN23: The ET may be catalytically active. SPN10: The ET shall be catalytically active.	
A.8.1.4.4.4. Second particle number dilution device (PND_2)		
~~PND2 shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of maintaining a single dilution factor within a range of 10 to 30 times. The dilution factor of PND2 shall be selected in the range between 10 and 15 such that particle number concentration downstream of the second diluter is less than the upper threshold of the single particle count mode of the PNC and the gas temperature prior to entry to the PNC is < 35 °C.~~	PND_2 shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of maintaining a single dilution factor within a range of 10 to 30 times. The dilution factor of PND_2 shall be selected in the range between 10 and 15 such that particle number concentration downstream of the second diluter is less than the upper threshold of the single particle count mode of the PNC and the gas temperature prior to entry below a maximum allowed inlet temperature specified by the PNC manufacturer;	
A.8.1.4.5. Particle number counter (PNC)		
The PNC shall meet the requirements of paragraph A.8.1.3.4.		
A.8.2. Calibration/Validation of the particle sampling system[1]		
A.8.2.1. Calibration of the particle number counter		
A.8.2.1.1. ~~The Technical Service shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 12 month period prior to the emissions test~~.	The Technical Service shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 13-month period prior to the emissions test. Between calibrations either the counting efficiency of the PNC shall be	

[1] Example calibration/validation methods are available at NOT WORKING: www.unece.org/es/trans/main/wp29/wp29wgs/wp29grpe/pmpfcp

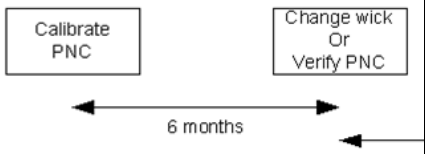
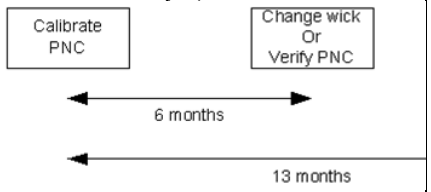
	monitored for deterioration or the PNC wick shall be routinely changed every 6 months if recommended by the instrument manufacturer. The responsible authority shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 13-month period prior to the emissions test. Between calibrations either the counting efficiency of the PNC shall be monitored for deterioration or the PNC wick shall be routinely changed every 6 months if recommended by the instrument manufacturer. See Figures 22 and 23. PNC counting efficiency may be monitored against a reference PNC or against at least two other measurement PNCs. If the PNC reports particle number concentrations within ±10 per cent of the arithmetic average of the concentrations from the reference PNC, or a group of two or more PNCs, the PNC shall subsequently be considered stable, otherwise maintenance of the PNC is required. Where the PNC is monitored against two or more other measurement PNCs, it is permitted to use a reference vehicle running sequentially in different test cells each with its own PNC.	
	Figure 22 **Nominal PNC annual sequence**  	

	Figure 23 **Extended PNC annual sequence (in the case that a full PNC calibration is delayed)**  	
A.8.2.1.2. The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.		
A.8.2.1.3. Calibration shall be traceable to a standard calibration method:		
(a) By comparison of the response of the PNC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles; or		
(b) By comparison of the response of the PNC under calibration with that of a second PNC which has been directly calibrated by the above method.		
~~In the electrometer case, calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 per cent of the standard concentration for each concentration used, with the~~	The calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. Five of these standard concentrations shall be as uniformly spaced as possible between the standard concentration of 2,000 particles per cm^3 or below and the maximum of the PNC's range in single particle count mode. The six standard concentrations points shall include a nominal zero concentration point produced by attaching HEPA filters of at least Class H13 of EN 1822:2008, or equivalent performance, to the inlet of each	

~~exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).~~	instrument. The gradient from a linear least squares regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (r) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and r^2, the linear regression shall be forced through the origin (zero concentration on both instruments). The calibration factor shall be between 0.9 and 1.1 or otherwise the PNC shall be rejected. Each concentration measured with the PNC under calibration, shall be within ±5 per cent of the measured reference concentration multiplied with the gradient, with the exception of the zero point, otherwise the PNC under calibration shall be rejected.	
~~In the reference PNC case, calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1,000 cm^{-3}, the remaining concentrations shall be linearly spaced between 1,000 cm^{-3} and the maximum of the PNC's range in single particle count mode. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 per cent of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or~~		

~~greater than 0.97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).~~		
A.8.2.1.4. ~~Calibration shall also include a check, against the requirements in paragraph A.8.1.3.4.8., on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.~~	SPN23: Calibration shall also include a check, against the requirements in paragraph A.8.1.3.4.8., on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required. SPN10: Calibration shall also include a check, against the requirements in paragraph A.8.1.3.4.8., on the PNC's detection efficiency with particles of 10 nm electrical mobility diameter. A check of the counting efficiency with 15 nm particles is not required.	
	A.8.2.1.5. If the PNC applies some other working liquid besides n-butyl alcohol or isopropyl alcohol, the counting efficiency of the PNC shall be demonstrated with 4cSt polyalphaolefin and soot-like particles.	
A.8.2.2. Calibration/Validation of the volatile particle remover		
A.8.2.2.1. ~~Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating te mperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on diesel particulate filter equipped vehicles. The Technical Service shall ensure the existence of a calibration or validation certificate for the volatile particle remover within a 6-month period prior to the emissions test. If the volatile particle remover incorporates~~	Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on diesel particulate filter equipped vehicles. The Technical Service shall ensure the existence of a calibration or validation certificate for the volatile particle remover within a 6-month period prior to the emissions test. If the volatile particle remover incorporates	

~~temperature monitoring alarms a 12 month validation interval shall be permissible.~~	temperature monitoring alarms a 13 month validation interval shall be permissible.	
~~The VPR shall be characterised for particle concentration reduction factor with solid particles of 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors (f_r(d)) for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 per cent of the mean particle concentration reduction factor ($\overline{f_r}$) determined during the primary calibration of the VPR.~~	SPN23: The VPR shall be characterised for particle concentration reduction factor with solid particles of 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors (f_r(d)) for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 per cent of the mean particle concentration reduction factor ($\overline{f_r}$) determined during the primary calibration of the VPR. SPN10: The VPR shall be characterised for particle concentration reduction factor with solid particles of 15 nm, 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors (f_r(d)) for particles of 15 nm, 30 nm and 50 nm electrical mobility diameters shall be no more than 100 per cent, 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 per cent of the mean particle concentration reduction factor ($\overline{f_r}$) determined during the primary calibration of the VPR. f_r(d)	
A.8.2.2.2. ~~The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles cm^{-3} at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components~~.	SPN23: The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles cm^{-3} at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components. SPN10:	

	The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter of a minimum concentration of 5,000 particles per cm³ and a minimum concentration of 3,000 particles per cm³ of 15 nm electrical mobility diameter at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components.	
The particle concentration reduction factor at each particle size ($f_r(d_i)$) shall be calculated as follows:		
$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$ (117)		
Where:		
$N_{in}(d_i)$ = upstream particle number concentration for particles of diameter d_i		
$N_{out}(d_i)$ = downstream particle number concentration for particles of diameter d_i and		
~~d_i = particle electrical mobility diameter (30, 50 or 100 nm)~~	SPN23: d_i = particle electrical mobility diameter (30, 50 or 100 nm SPN10: d_i=particle electrical mobility diameter (15, 30, 50 or 100 nm)	
$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.		
The mean particle concentration reduction ($\overline{f_r}$) at a given dilution setting shall be calculated as follows:		
$$\overline{f_r} = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3}$$ (118)		

It is recommended that the VPR is calibrated and validated as a complete unit.		
A.8.2.2.3. ~~The Technical Service shall ensure the existence of a validation certificate for the VPR demonstrating effective volatile particle removal efficiency within a 6 month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12 month validation interval shall be permissible. The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration of ≥ 10,000 cm^{-3} when operated at its minimum dilution setting and manufacturers recommended operating temperature.~~	The volatile particle removal efficiency of a VPR needs to be proven only once for the instrument family. The instrument manufacturer must provide the maintenance or replacement interval that ensures that the removal efficiency of the VPR does not drop below the technical requirements. If such information is not provided, the volatile removal efficiency has to be checked yearly for each instrument. SPN23: The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration of ≥ 10,000 cm^{-3} when operated at its minimum dilution setting and manufacturers recommended operating temperature. SPN10: The VPR shall demonstrate greater than 99.9 per cent removal efficiency of Tetracontane (CH3(CH2)38CH3) particles with count median diameter > 50 nm and mass > 1 mg/m3 when operated at its minimum dilution setting and manufacturers recommended operating temperature.	
	A.8.2.2.4. The instrument manufacturer shall prove the solid particle penetration P_r (d_i) by testing one unit for each PN-system model. A PN-system model here covers all PN-systems with the same hardware, i.e. same geometry, conduit materials, flows and temperature profiles in the aerosol path. $P_r(d_i) = DF \cdot N_{out}(d_i)/N_{in}(d_i)$ Where $N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;	

	$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i; d_i is the particle electrical mobility diameter DF is the dilution factor between measurement positions of $N_{in}(d_i)$ and $N_{out}(d_i)$ determined either with trace gases, or flow measurements.	
A.8.2.3. Particle number system check procedures		
A.8.2.3.1. Prior to each test, the particle counter shall report a measured concentration of less than 0.5 particles cm^{-3} when a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, is attached to the inlet of the entire particle sampling system (VPR and PNC).		
A.8.2.3.2. ~~On a monthly basis, the flow into the particle counter shall report a measured value within 5 per cent of the particle counter nominal flow rate when checked with a calibrated flow meter.~~	On a monthly basis, the flow into the PNC shall have a measured value within 5 per cent of the PNC nominal flow rate when checked with a calibrated flow meter. Here the term 'nominal flow rate' refers to the flow rate stated in the most recent calibration for the PNC by the manufacturer.	
A.8.2.3.3. ~~Each day, following the application of a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of the particle counter, the particle counter shall report a concentration of ≤ 0.2 cm^{-3}. Upon removal of this filter, the particle counter shall show an increase in measured concentration to at least 100 particles cm^{-3} when challenged with ambient air and a return to ≤ 0.2 cm^{-3} on replacement of the HEPA filter.~~	Each day, a zero check on the PNC, using a filter of appropriate performance at the PNC inlet, shall report a concentration of ≤ 0.2 particles per cm^3. Upon removal of the filter, the PNC shall show an increase in measured concentration and a return to ≤ 0.2 particles per cm^3 on replacement of the filter. The PNC shall not report any errors.	
A.8.2.3.4. Prior to the start of each test it shall be confirmed that the measurement system indicates that the evaporation tube, where featured in the system, has reached its correct operating temperature.		

A.8.2.3.5. Prior to the start of each test it shall be confirmed that the measurement system indicates that the diluter PND_1 has reached its correct operating temperature.		

Definition

1. Introduction

This annex is based on the world-wide harmonized heavy duty certification (WHDC), global technical regulation (gtr) No. 4).

2. Reserved[1]

3. Definitions, symbols and abbreviations

3.1. Definitions

For the purpose of this Regulation,

3.1.1. "*Declared maximum power (P_{max})*" means the maximum power in ECE kW (net power) as declared by the manufacturer in his application for approval.

3.1.2. "*Delay time*" means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point. For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector.

3.1.3. "*Drift*" means the difference between the zero or span responses of the measurement instrument after and before an emissions test.

3.1.4. "*Full flow dilution method*" means the process of mixing the total exhaust flow with diluent prior to separating a fraction of the diluted exhaust stream for analysis.

3.1.5. "*High speed (n_{hi})*" means the highest engine speed where 70 per cent of the declared maximum power occurs.

3.1.6. "*Low speed (n_{lo})*" means the lowest engine speed where 55 per cent of the declared maximum power occurs.

3.1.7. "*Maximum power (P_{max})*" means the maximum power in kW as specified by the manufacturer.

3.1.8. "*Maximum torque speed*" means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer.

3.1.9. "*Normalized torque*" means engine torque in per cent normalized to the maximum available torque at an engine speed.

[1] The numbering of this annex is consistent with the numbering of gtr No. 4 on WHDC. However, some sections of the WHDC gtr are not needed in this annex.

3.1.10. "*Operator demand*" means an engine operator's input to control engine output. The operator may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal.

3.1.11. **"*Partial flow dilution method*" means the process of separating a part from the total exhaust flow, then mixing it with an appropriate amount of diluent prior to the particulate sampling filter.**

3.1.12. "*Ramped steady state test cycle*" means a test cycle with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined ramps between these modes (WHSC).

3.1.13. "*Rated speed*" means the maximum full load speed allowed by the governor as specified by the manufacturer in his sales and service literature, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer in his sales and service literature.

3.1.14. "*Response time*" means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 second. The system response time consists of the delay time to the system and of the rise time of the system.

3.1.15. "*Rise time*" means the difference in time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).

3.1.16. "*Span response*" means the mean response to a span gas during a 30 s time interval.

3.1.17. "*Specific emissions*" means the mass emissions expressed in g/kWh.

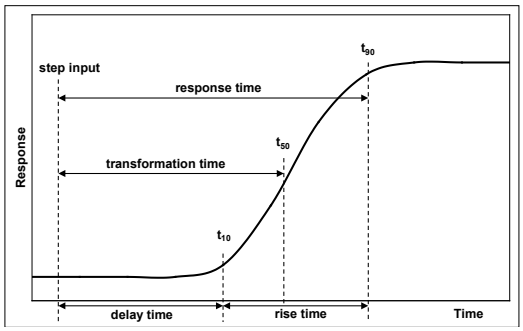
3.1.18. "*Test cycle*" means a sequence of test points each with a defined speed and torque to be followed by the engine under steady state (WHSC) or transient operating conditions (WHTC).

3.1.19. "*Transformation time*" means the difference in time between the change of the component to be measured at the reference point and a system response of 50 per cent of the final reading (t_{50}) with the sampling probe being defined as the reference point. The transformation time is used for the signal alignment of different measurement instruments.

3.1.20. "*Transient test cycle*" means a test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time (WHTC).

3.1.21. "*Zero response*" means the mean response to a zero gas during a 30 s time interval.

Figure 1
Definitions of system response



3.2. General symbols

Symbol	*Unit*	*Term*
a_1	-	Slope of the regression
a_0	-	y intercept of the regression
A/F_{st}	-	Stoichiometric air to fuel ratio
C	ppm/Vol per cent	Concentration
c_d	ppm/Vol per cent	Concentration on dry basis
c_w	ppm/Vol per cent	Concentration on wet basis
c_b	ppm/Vol per cent	Background concentration
C_d	-	Discharge coefficient of SSV
c_{gas}	ppm/Vol per cent	Concentration on the gaseous components
$\overline{c}_s$	**particles per cubic centimetre**	**Average concentration of particles from the diluted exhaust gas corrected to standard conditions (273.2 K and 101.33 kPa) particles per cubic centimetre**
$c_{s,i}$	**particles per cubic centimetre**	**A discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected ~~for coincidence and~~ to standard conditions (273.2 K and 101.33 kPa)**
D	m	Diameter
d_i		**Particle electrical mobility diameter (15, 30, 50 or 100 nm)**
d_V	m	Throat diameter of venturi
D_0	m^3/s	PDP calibration intercept
D	-	Dilution factor
Δt	s	Time interval

Symbol	*Unit*	*Term*
E		The number of particles emitted per kWh
e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	g/kWh	Specific emission of particulates
e_r	g/kWh	Specific emission during regeneration
e_w	g/kWh	Weighted specific emission
E_{CO2}	per cent	CO_2 quench of NO_x analyzer
E_E	per cent	Ethane efficiency
E_{H2O}	per cent	Water quench of NO_x analyzer
E_M	per cent	Methane efficiency
E_{NOx}	per cent	Efficiency of NO_x converter
F	Hz	Data sampling rate
f_a	-	Laboratory atmospheric factor
F_s	-	Stoichiometric factor
$\overline{f_r}$	-	Mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test
H_a	g/kg	Absolute humidity of the intake air
H_d	g/kg	Absolute humidity of the diluent
I	-	Subscript denoting an instantaneous measurement (e.g. 1 Hz)
K	-	Calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in the above equation
k_c	-	Carbon specific factor
$k_{f,d}$	m^3/kg fuel	Combustion additional volume of dry exhaust
$k_{f,w}$	m^3/kg fuel	Combustion additional volume of wet exhaust
$k_{h,D}$	-	Humidity correction factor for NO_x for CI engines
$k_{h,G}$	-	Humidity correction factor for NO_x for PI engines
k_r		The regeneration adjustment, according to paragraph 6.6.2., or in the case of engines without periodically regenerating after-treatment $k_r = 1$

Symbol	*Unit*	*Term*
$k_{r,d}$	-	Downward regeneration adjustment factor
$k_{r,u}$	-	Upward regeneration adjustment factor
$k_{w,a}$	-	Dry to wet correction factor for the intake air
$k_{w,d}$	-	Dry to wet correction factor for the diluent
$k_{w,e}$	-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$	-	Dry to wet correction factor for the raw exhaust gas
K_V	-	CFV calibration function
λ	-	Excess air ratio
m_b	mg	Particulate sample mass of the diluent collected
m_d	kg	Mass of the diluent sample passed through the particulate sampling filters
m_{ed}	kg	Total diluted exhaust mass over the cycle
m_{edf}	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_{ew}	kg	Total exhaust mass over the cycle
m_{ex}	kg	Total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling
m_f	mg	Particulate sampling filter mass
m_{gas}	g	Mass of gaseous emissions over the test cycle
m_p	mg	Particulate sample mass collected
m_{PM}	g	Mass of particulate emissions over the test cycle
$m_{PM,corr}$	g/test	Mass of particulates corrected for extraction of particle number sample flow
m_{se}	kg	Exhaust sample mass over the test cycle
m_{sed}	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	kg	Mass of diluted exhaust gas passing the particulate collection filters
m_{ssd}	kg	Mass of secondary diluent
M	Nm	Torque
M_a	g/mol	Molar mass of the intake air
M_d	g/mol	Molar mass of the diluent
M_e	g/mol	Molar mass of the exhaust

Symbol	*Unit*	*Term*
M_f	Nm	Torque absorbed by auxiliaries/equipment to be fitted
M_{gas}	g/mol	Molar mass of gaseous components
M_r	Nm	Torque absorbed by auxiliaries/equipment to be removed
N	-	Number of particles emitted over the test cycle
n	-	Number of measurements
n_r	-	Number of measurements with regeneration
n	min^{-1}	Engine rotational speed
n_{hi}	min^{-1}	High engine speed
n_{lo}	min^{-1}	Low engine speed
n_{pref}	min^{-1}	Preferred engine speed
n_p	r/s	PDP pump speed
N_{cold}	-	The total number of particles emitted over the WHTC cold test cycle
N_{hot}	-	The total number of particles emitted over the WHTC hot test cycle
N_{in}		Upstream particle number concentration
N_{out}		Downstream particle number concentration
p_a	kPa	Saturation vapour pressure of engine intake air
p_b	kPa	Total atmospheric pressure
p_d	kPa	Saturation vapour pressure of the diluent
p_p	kPa	Absolute pressure
p_r	kPa	Water vapour pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
P	kW	Power
P_f	kW	Power absorbed by auxiliaries/equipment to be fitted
P_r	kW	Power absorbed by auxiliaries/equipment to be removed
q_{ex}	kg/s	Particle number sample mass flow rate
q_{mad}	kg/s	Intake air mass flow rate on dry basis
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	kg/s	Carbon mass flow rate into the engine

Symbol	*Unit*	*Term*
q_{mCp}	kg/s	Carbon mass flow rate in the partial flow dilution system
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	kg/s	Diluent mass flow rate on wet basis
q_{medf}	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	kg/s	Fuel mass flow rate
q_{mp}	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_{sw}	kg/s	Mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction
q_{vCVS}	m³/s	CVS volume rate
q_{vs}	dm³/min	System flow rate of exhaust analyzer system
q_{vt}	cm³/min	Tracer gas flow rate
r^2	-	Coefficient of determination
r_d	-	Dilution ratio
r_D	-	Diameter ratio of SSV
r_h	-	Hydrocarbon response factor of the FID
r_m	-	Methanol response factor of the FID
r_p	-	Pressure ratio of SSV
r_s	-	Average sample ratio
s		Standard deviation
ρ	kg/m³	Density
ρ_e	kg/m³	Exhaust gas density
σ	-	Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
t	s	Time
t_{10}	s	Time between step input and 10 per cent of final reading
t_{50}	s	Time between step input and 50 per cent of final reading

Symbol	*Unit*	*Term*
t_{90}	s	Time between step input and 90 per cent of final reading
u	-	Ratio between the densities (or molar masses) of the gas components and the exhaust gas divided by 1,000
V_0	m^3/r	PDP gas volume pumped per revolution
V_s	dm^3	System volume of exhaust analyzer bench
W_{act}	kWh	Actual cycle work of the test cycle
$W_{act,cold}$	kWh	The actual cycle work over the WHTC cold test cycle according to paragraph 7.8.6.
$W_{act,\ hot}$	kWh	The actual cycle work over the WHTC hot test cycle according to paragraph 7.8.6.
W_{ref}	kWh	Reference cycle work of the test cycle
X_0	m^3/r	PDP calibration function

3.3. Symbols and abbreviations for the fuel composition

w_{ALF}	Hydrogen content of fuel, per cent mass
w_{BET}	Carbon content of fuel, per cent mass
w_{GAM}	Sulphur content of fuel, per cent mass
w_{DEL}	Nitrogen content of fuel, per cent mass
w_{EPS}	Oxygen content of fuel, per cent mass
α	Molar hydrogen ratio (H/C)
γ	Molar sulphur ratio (S/C)
δ	Molar nitrogen ratio (N/C)
ε	Molar oxygen ratio (O/C)

referring to a fuel $CH_\alpha O_\varepsilon N_\delta S_\gamma$

3.4. Symbols and abbreviations for the chemical components

C1	Carbon 1 equivalent hydrocarbon
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
CO	Carbon monoxide
CO_2	Carbon dioxide
DOP	Di-octylphtalate
HC	Hydrocarbons

H_2O	Water
NMHC	Non-methane hydrocarbons
NO_x	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
PM	Particulate matter

3.5. Abbreviations

CFV	Critical flow venturi
CLD	Chemiluminescent detector
CVS	Constant volume sampling
$deNO_x$	NO_x after-treatment system
EGR	Exhaust gas recirculation
ET	Evaporation tube
FID	Flame ionization detector
FTIR	Fourier transform infrared analyser
GC	Gas chromatograph
HCLD	Heated chemiluminescent detector
HFID	Heated flame ionization detector
LDS	Laser diode spectrometer
LPG	Liquefied petroleum gas
NDIR	Non-dispersive infrared (analyzer)
NG	Natural gas
NMC	Non-methane cutter
OT	Outlet tube
PDP	Positive displacement pump
Per cent FS	Per cent of full scale
PCF	Particle pre-classifier
PFS	Partial flow system
PNC	Particle number counter
PND	Particle number diluter
PTS	Particle transfer system
PTT	Particle transfer tube
SSV	Subsonic venturi
VGT	Variable geometry turbine

VPR	Volatile particle remover
WHSC	World harmonised steady state cycle
WHTC	World harmonised transient cycle