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World Forum for Harmonization of Vehicle Regulations

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Item 4.2.8 of the provisional agenda

1958 AGREEMENT

Consideration of draft amendments to existing Regulations

Proposal for Supplement 7 to the 05 series of amendments to Regulation No. 83
(Emissions of M_1 and N_1 vehicles)

Submitted by the Working Party on Pollution and Energy (GRPE) ∗/

The text reproduced below was adopted by GRPE at its fifty-fifth session. It is based on ECE/TRANS/WP.29/GRPE/2007/8/Rev.1, as amended by Annex III to the report. It is submitted to WP.29 and AC.1 for consideration (ECE/TRANS/WP.29/GRPE/55, para. 20).

∗/ In accordance with the programme of work of the Inland Transport Committee for 2006-2010 (ECE/TRANS/166/Add.1, programme activity 02.4), the World Forum will develop, harmonize and update Regulations in order to enhance performance of vehicles. The present document is submitted in conformity with that mandate.

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The list of Contents, the annexes, insert a new Annex 4a, to read:

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……"

Insert a new Annex 4a, to read:

"Annex 4a

TYPE I TEST
(Verifying exhaust emissions after a cold start)

1.   APPLICABILITY

This annex is not applicable for the time being, for the purpose of type approval according to this Regulation. It will be made applicable in the future.

2.   INTRODUCTION

This annex describes the procedure for the Type I test defined in paragraph 5.3.1. of this Regulation. When the reference fuel to be used is LPG or NG, the provisions of Annex 12 shall apply additionally.

3.   TEST CONDITIONS

3.1.   Ambient conditions

3.1.1.   During the test, the test cell temperature shall be between 293 K and 303 K (20 °C and 30 °C). The absolute humidity (H) of either the air in the test cell or the intake air of the engine shall be such that:

$$5.5 \leq H \leq 12.2 \qquad (g\ H_2O/kg\ dry\ air)$$

The absolute humidity (H) shall be measured.

The following temperatures shall be measured:

Test cell ambient air

Dilution and sampling system temperatures as required for emissions measurement systems defined in Appendices 2 to 5 of this annex.

The atmospheric pressure shall be measured.

3.2. Test vehicle

3.2.1. The vehicle shall be presented in good mechanical condition. It shall have been run-in and driven at least 3,000 km before the test.

3.2.2. The exhaust device shall not exhibit any leak likely to reduce the quantity of gas collected, which quantity shall be that emerging from the engine.

3.2.3. The tightness of the intake system may be checked to ensure that carburation is not affected by an accidental intake of air.

3.2.4. The settings of the engine and of the vehicle's controls shall be those prescribed by the manufacturer. This requirement also applies, in particular, to the settings for idling (rotation speed and carbon monoxide content of the exhaust gases), for the cold start device and for the exhaust gas cleaning system.

3.2.5. The vehicle to be tested, or an equivalent vehicle, shall be fitted, if necessary, with a device to permit the measurement of the characteristic parameters necessary for chassis dynamometer setting, in conformity with paragraph 5. of this annex.

3.2.6. The technical service responsible for the tests may verify that the vehicle's performance conforms to that stated by the manufacturer, that it can be used for normal driving and, more particularly, that it is capable of starting when cold and when hot.

3.3. Test fuel

3.3.1. The appropriate reference fuel as defined in Annex 10 to this Regulation shall be used for testing.

3.3.2. Vehicles that are fuelled either with petrol or with LPG or NG shall be tested according to Annex 12 with the appropriate reference fuel(s) as defined in Annex 10a.

3.4. Vehicle installation

3.4.1. The vehicle shall be approximately horizontal during the test so as to avoid any abnormal distribution of the fuel.

3.4.2. A current of air of variable speed shall be blown over the vehicle. The blower speed shall be such that, within the operating range of 10 km/h to at least 50 km/h, the linear velocity of the air at the blower outlet is within ±5 km/h of the corresponding roller speed. The final selection of the blower shall have the following characteristics:
(a) Area: at least 0.2 m^2;
(b) Height of the lower edge above ground: approximately 0.2 m;
(c) Distance from the front of the vehicle: approximately 0.3 m.

As an alternative the blower speed shall be fixed at an air speed of at least 6 m/s (21.6 km/h).

For special vehicles (e.g. vans, off-road), the height of the cooling fan can also be modified at the request of the manufacturer.

TEST EQUIPMENT

4.1.   Chassis dynamometer

The chassis dynamometer requirements are given in Appendix 1.

4.2.   Exhaust dilution system

The exhaust dilution system requirements are given in Appendix 2.

4.3.   Gaseous emissions sampling and analysis

The gaseous emissions sampling and analysis equipment requirements are given in Appendix 3.

4.4.   Particulate Mass (PM) emissions equipment

The particulate mass sampling and measurement requirements are given in Appendix 4.

4.5.   Particle Number (PN) emissions equipment

The particle number sampling and measurement requirements are given in Appendix 5.

4.6.   General test cell equipment

The following temperatures shall be measured with an accuracy of ±1.5 K:
(a)   Test cell ambient air
(b)   Intake air to the engine
(c)   Dilution and sampling system temperatures as required for emissions measurement systems defined in Appendices 2 to 5 of this annex.

The atmospheric pressure shall be measurable to within ±0.1 kPa.

The absolute humidity (H) shall be measurable to within ±5 per cent.

5.   DETERMINATION OF VEHICLE ROAD LOAD

5.1.   Test procedure

          The procedure for measuring the vehicle road load is described in Appendix 7.

          This procedure is not required if the chassis dynamometer load is to be set according
          to the reference mass of the vehicle.

6.   EMISSIONS TEST PROCEDURE

6.1.   Test cycle

          The operating cycle, made up of a Part One (urban cycle) and Part Two (extra-urban
          cycle), is illustrated in Figure 1. During the complete test the elementary urban cycle
          is run four times followed, by Part Two.

6.1.1.   Elementary urban cycle

          Part One of the test cycle comprises 4 times the elementary urban cycle which is
          defined in Table 1, illustrated in Figure 2, and summarized below.

          Breakdown by phases:

	Time (s)	per cent	
Idling	60	30.8	35.4
Deceleration, clutch disengaged	9	4.6	
Gear-changing	8	4.1	
Accelerations	36	18.5	
Steady-speed periods	57	29.2	
Decelerations	25	12.8	
Total	195	100	

          Breakdown by use of gears

	Time (s)	per cent	
Idling	60	30.8	35.4
Deceleration, clutch disengaged	9	4.6	
Gear-changing	8	4.1	
First gear	24	12.3	
Second gear	53	27.2	
Third gear	41	21	
Total	195	100	

General information:

Average speed during test:	19 km/h
Effective running time:	195 s
Theoretical distance covered per cycle:	1.013 km
Equivalent distance for the four cycles:	4.052 km

6.1.2.   Extra-urban cycle

Part Two of the test cycle is the extra-urban cycle which is defined in Table 2, illustrated in Figure 3, and summarized below.

Breakdown by phases:

	Time (s)	per cent
Idling	20	5.0
Deceleration, clutch disengaged	20	5.0
Gear-shift	6	1.5
Accelerations	103	25.8
Steady-speed periods	209	52.2
Decelerations	42	10.5
Total	400	100

Breakdown by use of gears:

	Time (s)	per cent
Idling	20	5.0
Deceleration, clutch disengaged	20	5.0
Gear-shift	6	1.5
First gear	5	1.3
Second gear	9	2.2
Third gear	8	2
Fourth gear	99	24.8
Fifth gear	233	58.2
Total	400	100

General information:

Average speed during test:	62.6 km/h
Effective running time:	400 s
Theoretical distance covered per cycle:	6.955 km
Maximum speed:	120 km/h
Maximum acceleration:	0.833 m/s^2
Maximum deceleration:	-1.389 m/s^2

6.1.3.   Use of the gearbox

6.1.3.1.   If the maximum speed which can be attained in first gear is below 15 km/h, the second, third and fourth gears shall be used for the urban cycle (Part One) and the second, third, fourth and fifth gears for the extra-urban cycle (Part Two).   The second, third and fourth gears may also be used for the urban cycle (Part One) and the second, third, fourth and fifth gears for the extra-urban cycle (Part Two) when the manufacturer's instructions recommend starting in second gear on level ground, or when first gear is therein defined as a gear reserved for cross-country driving, crawling or towing.

Vehicles which do not attain the acceleration and maximum speed values required in the operating cycle shall be operated with the accelerator control fully depressed until they once again reach the required operating curve.   Deviations from the operating cycle shall be recorded in the test report.

Vehicles equipped with semi-automatic-shift gearboxes shall be tested by using the gears normally employed for driving, and the gear shift is used in accordance with the manufacturer's instructions.

6.1.3.2.   Vehicles equipped with automatic-shift gearboxes shall be tested with the highest gear ("Drive") engaged. The accelerator shall be used in such a way as to obtain the steadiest acceleration possible, enabling the various gears to be engaged in the normal order. Furthermore, the gear-change points shown in Tables 1 and 2 of this annex shall not apply; acceleration shall continue throughout the period represented by the straight line connecting the end of each period of idling with the beginning of the next following period of steady speed.   The tolerances given in paragraphs 6.1.3.4. and 6.1.3.5. below shall apply.

6.1.3.3.   Vehicles equipped with an overdrive that the driver can actuate shall be tested with the overdrive out of action for the urban cycle (Part One) and with the overdrive in action for the extra-urban cycle (Part Two).

6.1.3.4.   A tolerance of ±2 km/h shall be allowed between the indicated speed and the theoretical speed during acceleration, during steady speed, and during deceleration when the vehicle's brakes are used. If the vehicle decelerates more rapidly without the use of the brakes, only the provisions of paragraph 6.4.4.3. below shall apply. Speed tolerances greater than those prescribed shall be accepted during phase changes provided that the tolerances are never exceeded for more than 0.5 s on any one occasion.

6.1.3.5.   The time tolerances shall be ±1.0 s. The above tolerances shall apply equally at the beginning and at the end of each gear-changing period for the urban cycle (Part One) and for the operations Nos. 3, 5 and 7 of the extra-urban cycle (Part Two). It should be noted that the time of two seconds allowed includes the time for changing gear and, if necessary, a certain amount of latitude to catch up with the cycle.

6.2.   Test preparation

6.2.1.   Load and inertia setting

6.2.1.1.   Load determined with vehicle road test

The dynamometer shall be adjusted so that the total inertia of the rotating masses will simulate the inertia and other road load forces acting on the vehicle when driving on the road. The means by which this load is determined is described in paragraph 5. of this annex.

Dynamometer with fixed load curve: the load simulator shall be adjusted to absorb the power exerted on the driving wheels at a steady speed of 80 km/h and the absorbed power at 50 km/h shall be noted.

Dynamometer with adjustable load curve: the load simulator shall be adjusted in order to absorb the power exerted on the driving wheels at steady speeds of 120, 100, 80, 60 and 40 and 20 km/h.

6.2.1.2.   Load determined by vehicle reference mass

With the manufacturer's agreement the following method may be used.

The brake is adjusted so as to absorb the load exerted at the driving wheels at a constant speed of 80 km/h, in accordance with Table 3.

If the corresponding equivalent inertia is not available on the dynamometer, the larger value closest to the vehicle reference mass will be used.

In the case of vehicles other than passenger cars, with a reference mass of more than 1,700 kg or vehicles with permanent all-wheel drive, the power values given in Table 3 are multiplied by a factor 1.3.

6.2.1.3.   The method used and the values obtained (equivalent inertia - characteristic adjustment parameter) shall be recorded in the test report.

6.2.2.   Preliminary testing cycles

Preliminary testing cycles should be carried out if necessary to determine how best to actuate the accelerator and brake controls so as to achieve a cycle approximating to the theoretical cycle within the prescribed limits under which the cycle is carried out.

6.2.3.   Tyre pressures

The tyre pressures shall be the same as that specified by the manufacturer and used for the preliminary road test for brake adjustment. The tyre pressure may be

increased by up to 50 per cent from the manufacturer's recommended setting in the case of a two-roller dynamometer. The actual pressure used shall be recorded in the test report.

6.2.4.   Background particulate mass measurement

The particulate background level of the dilution air may be determined by passing filtered dilution air through the particulate filter. This shall be drawn from the same point as the particulate sample. One measurement may be performed prior to or after the test. Particulate mass measurements may be corrected by subtracting the background contribution from the dilution system. The permissible background contribution shall be ≤ 1mg/km (or equivalent mass on the filter). If the background exceeds this level, the default figure of 1 mg/km (or equivalent mass on the filter) shall be employed. Where subtraction of the background contribution gives a negative result, the particulate mass result shall be considered to be zero.

6.2.5.   Background particle number measurements

The subtraction of background particle numbers may be determined by sampling dilution air drawn from a point downstream of the particle and hydrocarbon filters into the particle number measurement system. Background correction of particle number measurements shall not be allowed for type approval, but may be used at the manufacturer's request for conformity of production and in service conformity where there are indications that tunnel contribution is significant.

6.2.6.   Particulate mass filter selection

A single particulate filter without back-up shall be employed for both urban and extra-urban phases of the cycle combined.

Twin particulate filters, one for the urban, one for the extra-urban phase, may be used without back-up filters, only where the pressure-drop increase across the sample filter between the beginning and the end of the emissions test is otherwise expected to exceed 25 kPa.

6.2.7.   Particulate mass filter preparation

6.2.7.1.   Particulate mass sampling filters shall be conditioned (as regards temperature and humidity) in an open dish that has been protected against dust ingress for at least 2 and for not more than 80 hours before the test in an air-conditioned chamber. After this conditioning, the uncontaminated filters will be weighed and stored until they are used. If the filters are not used within one hour of their removal from the weighing chamber they shall be re-weighed.

6.2.7.2.   The one hour limit may be replaced by an eight-hour limit if one or both of the following conditions are met:

6.2.7.2.1.　A stabilized filter is placed and kept in a sealed filter holder assembly with the ends plugged, or;

6.2.7.2.2.　A stabilized filter is placed in a sealed filter holder assembly which is then immediately placed in a sample line through which there is no flow.

6.2.7.3.　The particulate sampling system shall be started and prepared for sampling.

6.2.8.　Particle number measurement preparation

6.2.8.1.　The particle specific dilution system and measurement equipment shall be started and readied for sampling.

6.2.8.2.　Prior to the test(s) the correct function of the particle counter and volatile particle remover elements of the particle sampling system shall be confirmed according to Appendix 5, paragraphs 2.3.1. and 2.3.3.:

The particle counter response shall be tested at near zero prior to each test and, on a daily basis, at high particle concentrations using ambient air.

When the inlet is equipped with a HEPA filter, it shall be demonstrated that the entire particle sampling system is free from any leaks.

6.2.9.　Checking the gas analysers

The emissions analysers for the gases shall be set at zero and spanned. The sample bags shall be evacuated.

6.3.　Conditioning procedure

6.3.1.　For the purpose of measuring particulates, at most 36 hours and at least 6 hours before testing, the Part Two cycle described in paragraph 6.1. of this annex shall be used for vehicle pre-conditioning. Three consecutive cycles shall be driven. The dynamometer setting shall be indicated as in paragraph 6.2.1. above.

At the request of the manufacturer, vehicles fitted with indirect injection positive-ignition engines may be preconditioned with one Part One and two Part Two driving cycles.

In a test facility in which there may be possible contamination of a low particulate emitting vehicle test with residue from a previous test on a high particulate emitting vehicle, it is recommended, for the purpose of sampling equipment pre-conditioning, that a 120 km/h steady state drive cycle of 20 minutes duration followed by three consecutive Part Two cycles be driven by a low particulate emitting vehicle.

After this preconditioning, and before testing, vehicles shall be kept in a room in which the temperature remains relatively constant between 293 and 303 K (20 °C and 30 °C). This conditioning shall be carried out for at least six hours and continue until the engine oil temperature and coolant, if any, are within ±2 K of the temperature of the room.

If the manufacturer so requests, the test shall be carried out not later than 30 hours after the vehicle has been run at its normal temperature.

6.3.3.   For positive-ignition engined vehicles fuelled with LPG or NG or so equipped that they can be fuelled with either petrol or LPG or NG, between the tests on the first gaseous reference fuel and the second gaseous reference fuel, the vehicle shall be preconditioned before the test on the second reference fuel. This preconditioning is done on the second reference fuel by driving a preconditioning cycle consisting of one Part One (urban part) and two times Part Two (extra-urban part) of the test cycle described in Appendix 1 to this annex. On the manufacturer's request and with the agreement of the technical service this preconditioning may be extended. The dynamometer setting shall be the one indicated in paragraph 6.2. of this annex.

6.4.   Test procedure

6.4.1.   Starting-up the engine

6.4.1.1.   The engine shall be started up by means of the devices provided for this purpose according to the manufacturer's instructions, as incorporated in the drivers' handbook of production vehicles.

6.4.1.2.   The first cycle starts on the initiation of the engine start-up procedure.

6.4.1.3.   In cases where LPG or NG is used as a fuel it is permissible that the engine is started on petrol and switched to LPG or NG after a predetermined period of time which cannot be changed by the driver.

6.4.2.   Idling

6.4.2.1.   Manual-shift or semi-automatic gearbox, see Tables 1 and 2.

6.4.2.2.   Automatic-shift gearbox

After initial engagement the selector shall not be operated at any time during the test except in the case specified in paragraph 6.4.3.3. below or if the selector can actuate the overdrive, if any.

6.4.3.   Accelerations

6.4.3.1.   Accelerations shall be so performed that the rate of acceleration is as constant as possible throughout the operation.

6.4.3.2.   If an acceleration cannot be carried out in the prescribed time, the extra time required shall be deducted from the time allowed for changing gear, if possible, but otherwise from the subsequent steady-speed period.

6.4.3.3.   Automatic-shift gearboxes

If acceleration cannot be carried out in the prescribed time, the gear selector shall operate in accordance with requirements for manual-shift gearboxes.

6.4.4.   Decelerations

6.4.4.1.   All decelerations of the elementary urban cycle (Part One) shall be effected by removing the foot completely from the accelerator with the clutch remaining engaged. The clutch shall be disengaged, without use of the gear lever, at the higher of the following speeds: 10 km/h or the speed corresponding to the engine idle speed.

All decelerations of the extra-urban cycle (Part Two) shall be effected by removing the foot completely from the accelerator, the clutch remaining engaged. The clutch shall be disengaged, without use of the gear lever, at a speed of 50 km/h for the last deceleration.

6.4.4.2.   If the period of deceleration is longer than that prescribed for the corresponding phase, the vehicle's brakes shall be used to enable compliance with the timing of the cycle.

6.4.4.3.   If the period of deceleration is shorter than that prescribed for the corresponding phase, the timing of the theoretical cycle shall be restored by constant speed or an idling period merging into the following operation.

6.4.4.4.   At the end of the deceleration period (halt of the vehicle on the rollers) of the elementary urban cycle (Part One), the gears shall be placed in neutral and the clutch engaged.

6.4.5.   Steady speeds

6.4.5.1.   "Pumping" or the closing of the throttle shall be avoided when passing from acceleration to the following steady speed.

6.4.5.2.   Periods of constant speed shall be achieved by keeping the accelerator position fixed.

6.4.6.   Sampling

Sampling shall begin (BS) before or at the initiation of the engine start up procedure and end on conclusion of the final idling period in the extra-urban cycle (Part Two, end of sampling (ES)) or, in the case of test Type VI, on conclusion of the final idling period of the last elementary urban cycle (Part One).

6.4.7.   During the test the speed is recorded against time or collected by the data-acquisition system so that the correctness of the cycles performed can be assessed.

6.4.8.   Particles shall be measured continuously in the particle sampling system. The average concentrations shall be determined by integrating the analyser signals over the test cycle.

6.5.   Post-test procedures

6.5.1.   Gas analyser check

Zero and span gas reading of the analysers used for continuous measurement shall be checked. The test shall be considered acceptable if the difference between the pre-test and post-test results is less than 2 per cent of the span gas value.

6.5.2.   Particulate filter weighing

Reference filters shall be weighed within 8 hours of the test filter weighing. The contaminated particulate test filter shall be taken to the weighing chamber within one hour following the analyses of the exhaust gases. The test filter shall be conditioned for at least 2 hours and not more than 80 hours and then weighed.

6.5.3.   Bag analysis

6.5.3.1.   The exhaust gases contained in the bag shall be analysed as soon as possible and in any event not later than 20 minutes after the end of the test cycle.

6.5.3.2.   Prior to each sample analysis, the analyser range to be used for each pollutant shall be set to zero with the appropriate zero gas.

6.5.3.3.   The analysers shall then be set to the calibration curves by means of span gases of nominal concentrations of 70 to 100 per cent of the range.

6.5.3.4.   The analysers' zero settings shall then be rechecked: if any reading differs by more than 2 per cent of the range from that set in paragraph 6.5.3.2. above, the procedure shall be repeated for that analyser.

6.5.3.5.   The samples shall then be analysed.

6.5.3.6.   After the analysis, zero and span points shall be rechecked using the same gases. If these rechecks are within ± 2 per cent of those in paragraph 6.5.3.3. above, the analysis shall be considered acceptable.

6.5.3.7.   At all points in this paragraph, the flow-rates and pressures of the various gases shall be the same as those used during calibration of the analysers.

6.5.3.8.   The figure adopted for the content of the gases in each of the pollutants measured shall be that read off after stabilisation of the measuring device. Hydrocarbon mass emissions of compression-ignition engines shall be calculated from the integrated HFID reading, corrected for varying flow if necessary, as shown in paragraph 6.6.6. below.

6.6.   Calculation of emissions

6.6.1.   Determination of volume

6.6.1.1.   Calculation of the volume when a variable dilution device with constant flow control by orifice or venturi is used.

Record continuously the parameters showing the volumetric flow, and calculate the total volume for the duration of the test.

6.6.1.2.   Calculation of volume when a positive displacement pump is used

The volume of diluted exhaust gas measured in systems comprising a positive displacement pump is calculated with the following formula:

$$V = V_o \cdot N$$

where:
   V = volume of the diluted gas expressed in litres per test (prior to correction),
   V_o = volume of gas delivered by the positive displacement pump in testing conditions in litres per revolution,
   N = number of revolutions per test.

6.6.1.3.   Correction of Volume to Standard Conditions

The diluted exhaust-gas volume is corrected by means of the following formula:

$$V_{mix} = V \cdot K_1 \cdot \left(\frac{P_B - P_1}{T_p} \right) \tag{1}$$

where:

$$K_1 = \frac{273.2\,(\text{K})}{101.33\,(\text{kPa})} = 2.6961 \qquad (2)$$

    P_B =   barometric pressure in the test room in kPa,

    P_1 =   vacuum at the inlet to the positive displacement pump in kPa relative to the ambient barometric pressure,

    T_p =   average temperature of the diluted exhaust gas entering the positive displacement pump during the test (K).

6.6.2.   Total mass of gaseous and particulate pollutants emitted

The mass M of each pollutant emitted by the vehicle during the test shall be determined by obtaining the product of the volumetric concentration and the volume of the gas in question, with due regard for the following densities under above-mentioned reference conditions:

In the case of carbon monoxide (CO):   d = 1.25 g/l

In the case of hydrocarbons:
        for petrol ($CH_{1.85}$)   d = 0.619 g/1
        for diesel ($CH_{1.86}$)   d = 0.619 g/1
        for LPG ($CH_{2.525}$)   d = 0.649 g/1
        for NG (CH_4)   d = 0.714 g/1

In the case of nitrogen oxides (NO_x):   d = 2.05 g/1

6.6.3.   Mass emissions of gaseous pollutants shall be calculated by means of the following formula:

$$M_i = \frac{V_{mix} \cdot Q_i \cdot k_h \cdot C_i \cdot 10^{-6}}{d} \qquad (3)$$

where:

    M_i =   mass emission of the pollutant i in grams per kilometre,

    V_{mix} = volume of the diluted exhaust gas expressed in litres per test and corrected to standard conditions (273.2 K and 101.33 kPa),

    Q_i =   density of the pollutant i in grams per litre at normal temperature and pressure (273.2 K and 101.33 kPa),

    k_h =   humidity correction factor used for the calculation of the mass emissions of oxides of nitrogen. There is no humidity correction for HC and CO,

    C_i =   concentration of the pollutant i in the diluted exhaust gas expressed in ppm and corrected by the amount of the pollutant i contained in the dilution air,

    d =   distance corresponding to the operating cycle in kilometres.

6.6.4.   Correction for dilution air concentration

The concentration of pollutant in the diluted exhaust gas shall be corrected by the amount of the pollutant in the dilution air as follows:

$$C_i = C_e - C_d \cdot \left(1 - \frac{1}{DF}\right) \tag{4}$$

where:

C_i =   concentration of the pollutant i in the diluted exhaust gas, expressed in ppm and corrected by the amount of i contained in the dilution air,

C_e =   measured concentration of pollutant i in the diluted exhaust gas, expressed in ppm,

C_d =   concentration of pollutant i in the air used for dilution, expressed in ppm,

DF =   dilution factor.

The dilution factor is calculated as follows:

$$DF = \frac{13.4}{C_{CO2} + (C_{HC} + C_{CO}) \cdot 10^{-4}} \quad \text{for petrol and diesel} \tag{5a}$$

$$DF = \frac{11.9}{C_{CO2} + (C_{HC} + C_{CO}) \cdot 10^{-4}} \quad \text{for LPG} \tag{5b}$$

$$DF = \frac{9.5}{C_{CO2} + (C_{HC} + C_{CO}) \cdot 10^{-4}} \quad \text{for NG} \tag{5c}$$

In these equations:

C_{CO2} =   concentration of CO_2 in the diluted exhaust gas contained in the sampling bag, expressed in per cent volume,

C_{HC} =   concentration of HC in the diluted exhaust gas contained in the sampling bag, expressed in ppm carbon equivalent,

C_{CO} =   concentration of CO in the diluted exhaust gas contained in the sampling bag, expressed in ppm.

6.6.5.   Calculation of the NO humidity correction factor

In order to correct the influence of humidity on the results of oxides of nitrogen, the following calculations are applied:

$$k_h = \frac{1}{1 - 0.0329 \cdot (H - 10.71)} \tag{6}$$

in which:

$$H = \frac{6.211 \cdot R_a \cdot P_d}{P_B - P_d \cdot R_a \cdot 10^{-2}}$$

where:

H = absolute humidity expressed in grams of water per kilogram of dry air,
R_a = relative humidity of the ambient air expressed as a percentage,
P_d = saturation vapour pressure at ambient temperature expressed in kPa,
P_B = atmospheric pressure in the room, expressed in kPa.

6.6.6. Determination of HC for compression-ignition engines

To calculate HC-mass emission for compression-ignition engines, the average HC concentration is calculated as follows:

$$C_e = \frac{\int_{t_1}^{t_2} C_{HC} \cdot dt}{t_2 - t_1} \tag{7}$$

where:

$\int_{t_1}^{t_2} C_{HC} \cdot dt$ = integral of the recording of the heated FID over the test (t_2-t_1)

C_e = concentration of HC measured in the diluted exhaust in ppm of C_i is substituted for C_{HC} in all relevant equations.

6.6.7. Determination of particulates

Particulate emission M_p (g/km) is calculated by means of the following equation:

$$M_p = \frac{(V_{mix} + V_{ep}) \cdot P_e}{V_{ep} \cdot d}$$

where exhaust gases are vented outside tunnel;

$$M_p = \frac{V_{mix} \cdot P_e}{V_{ep} \cdot d}$$

where exhaust gases are returned to the tunnel;

where:

V_{mix} = volume of diluted exhaust gases (see paragraph 6.6.1.), under standard conditions,

V_{ep} = volume of exhaust gas flowing through particulate filter under standard conditions,

P_e = particulate mass collected by filter(s),

d = distance corresponding to the operating cycle in km,

M_p = particulate emission in g/km.

Where correction for the particulate background level from the dilution system has been used, this shall be determined in accordance with paragraph 6.2.4. In this case, the particulate mass (g/km) shall be calculated as follows:

$$M_p = \left[\frac{P_e}{V_{ep}} - \left(\frac{P_a}{V_{ap}} \cdot \left(1 - \frac{1}{DF} \right) \right) \right] \cdot \frac{(V_{mix} + V_{ep})}{d}$$

where exhaust gases are vented outside tunnel;

$$M_p = \left[\frac{P_e}{V_{ep}} - \left(\frac{P_a}{V_{ap}} \cdot \left(1 - \frac{1}{DF} \right) \right) \right] \cdot \frac{V_{mix}}{d}$$

where exhaust gases are returned to the tunnel.

Where:

V_{ap} = volume of tunnel air flowing through the background particulate filter under standard conditions,

P_a = particulate mass collected by background filter,

DF = dilution factor as determined in paragraph 6.6.4.

Where application of a background correction results in a negative particulate mass (in g/km) the result shall be considered to be zero g/km particulate mass.

6.6.8.   Determination of particle numbers

Number emission of particles shall be calculated by means of the following equation:

$$N = \frac{V.k.\overline{C_s}.\overline{f_r}.10^3}{d}$$

where:

N = particle number emission expressed in particles per kilometre,

V = volume of the diluted exhaust gas expressed in litres per test and corrected to standard conditions (273.2 K and 101.33 kPa),

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,

$\overline{C}_s$ = corrected concentration of particles from the diluted exhaust gas expressed as the average particles per cubic centimetre figure from the emissions test including the full duration of the drive cycle. If the volumetric mean concentration results ($\overline{C}$) from the particle number counter are not output at standard conditions (273.2 K and 101.33 kPa), then the concentrations should be corrected to those conditions ($\overline{C}_s$),

$\overline{f}_r$ = mean particle concentration reduction factor of the volatile particle remover at the dilution setting used for the test,

d = distance corresponding to the operating cycle expressed in kilometres.

$\overline{C}$ shall be calculated from the following equation:

$$\overline{C} = \frac{\sum_{i=1}^{i=n} C_i}{n}$$

where:

C_i = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter expressed in particles per cubic centimetre and corrected for coincidence,

n = total number of discrete particle concentration measurements made during the operating cycle.

n shall be calculated from the following equation:

$$n = T.f$$

where:

T = time duration of the operating cycle expressed in seconds,

f = data logging frequency of the particle counter expressed in Hz.

6.6.9.   Allowance for mass emissions from vehicles equipped with periodically regenerating devices

When the vehicle is equipped with a periodically regenerating system as defined in Regulation No. 83, 05 series of amendments, Annex 13: Emissions test procedure for a vehicle equipped with a periodically regenerating system:

6.6.9.1.   The provisions of Annex 13 shall apply for the purposes of particulate mass measurements only and not particle number measurements.

6.6.9.2.   For particulate mass sampling during a test in which the vehicle undergoes a scheduled regeneration, the filter face temperature shall not exceed 192 °C.

6.6.9.3.   For particulate mass sampling during a test when the regenerating device is in a stabilized loading condition (i.e. the vehicle is not undergoing a regeneration), it is recommended that the vehicle has completed > 1/3 of the mileage between scheduled regenerations or that the periodically regenerating device has undergone equivalent loading off the vehicle.

For the purposes of Conformity of Production testing, the manufacturer may ensure that this is included within the evolution coefficient. In this case, paragraph 8.2.3.2.2. of this Regulation is replaced by paragraph 6.6.9.3.1. of this annex.

6.6.9.3.1. If the manufacturer wishes to run in the vehicles, ("x" km, where x ≤ 3,000 km for vehicles equipped with a positive ignition engine and x ≤ 15,000 km for vehicles equipped with a compression ignition engine and where the vehicle is at > 1/3 distance between successive regenerations), the procedure will be as follows:
(a)   The pollutant emissions (type I) will be measured at zero and at "x" km on the first tested vehicle,
(b)   The evolution coefficient of the emissions between zero and "x" km will be calculated for each of the pollutants:

$$\text{Evolution coefficient} = \frac{\text{Emissions at "x" km}}{\text{Emissions at zero km}}$$

This may be less than 1,
(a)   The other vehicles will not be run in, but their zero km emissions will be multiplied by the evolution coefficient.

In this case, the values to be taken will be:
(a)   The values at 'x' km for the first vehicle,
(b)   The values at zero km multiplied by the evolution coefficient for the other vehicles.

Table 1 - Elementary urban operating cycle on the chassis dynamometer (Part One)

No. of operation	Operation	Phase	Acceleration (m/s²)	Speed (km/h)	Duration of each Operation (s)	Phase (s)	Cumulative time (s)	Gear to be used in the case of a manual gearbox
1	Idling	1			11	11	11	6 s PM + 5 s K$_1$ (*)
2	Acceleration	2	1.04	0-15	4	4	15	1
3	Steady speed	3		15	9	8	23	1
4	Deceleration	4	-0.69	15-10	2	5	25	1
5	Deceleration, clutch disengaged		-0.92	10-0	3		28	K$_1$ (*)
6	Idling	5			21	21	49	16 s PM + 5 s K$_1$ (*)
7	Acceleration	6	0.83	0-15	5	12	54	1
8	Gear change				2		56	
9	Acceleration		0.94	15-32	5		61	2
10	Steady speed	7		32	24	24	85	2
11	Deceleration	8	-0.75	32-10	8	11	93	2
12	Deceleration, clutch disengaged		-0.92	10-0	3		96	K$_2$ (*)
13	Idling	9	0-15	0-15	21		117	16 s PM + 5 s K$_1$ (*)
14	Acceleration	10			5	26	122	1
15	Gear change				2		124	
16	Acceleration		0.62	15-35	9		133	2
17	Gear change				2		135	
18	Acceleration		0.52	35-50	8		143	3
19	Steady speed	11		50	12	12	155	3
20	Deceleration	12	-0.52	50-35	8	8	163	3
21	Steady speed	13		35	13	13	176	3
22	Gear change	14			2	12	178	
23	Deceleration		-0.86	32-10	7		185	2
24	Deceleration clutch disengaged		-0.92	10-0	3		188	K$_2$ (*)
25	Idling	15			7	7	195	7 s PM (*)

(*)   PM = gearbox in neutral, clutch engaged. K$_1$, K$_2$ = first or second gear engaged, clutch disengaged.

Table 2 - Extra-urban cycle (Part Two) for the Type I test

No. of operation	Operation	Phase	Acceleration (m/s^2)	Speed (km/h)	Duration of each		Cumulative time(s)	Gear to be used in the case of a manual gearbox
					Operation(s)	Phase(s)		
1	Idling	1			20	20	20	K$_1$ (1)
2	Acceleration	2	0.83	0	5	41	25	1
3	Gear change				2		27	-
4	Acceleration		0.62	15-35	9		36	2
5	Gear change				2		38	-
6	Acceleration		0.52	35-30	8		46	3
7	Gear change				2		48	-
8	Acceleration		0.43	50-70	13		61	4
9	Steady speed	3		70	50	50	111	5
10	Deceleration	4	-0.69	70-50	8	8	119	4 s.5 + 4 s.4
11	Steady speed	5		50	69	69	188	4
12	Acceleration	6	0.43	50-70	13	13	201	4
13	Steady speed	7		70	50	50	251	5
14	Acceleration	8	0.24	70-100	35	35	286	5
15	Steady speed (2)	9		100	30	30	316	5 (2)
16	Acceleration (2)	10	0.28	100-120	20	20	336	5 (2)
17	Steady speed (2)	11		120	10	20	346	5 (2)
18	Deceleration (2)	12	-0.69	120-80	16	34	362	5 (2)
19	Deceleration (2)		-1.04	80-50	8		370	5 (2)
20	Deceleration, clutch disengaged		1.39	50-0	10		380	K$_5$ (1)
21	Idle	13			20	20	400	PM (1)

(1) PM = gearbox in neutral, clutch engaged.   K$_1$, K$_5$ = first or second gear engaged, clutch disengaged

(2) Additional gears can be used according to manufacturer recommendations if the vehicle is equipped with a transmission with more than five gears.

Table 3 – Simulated inertia and dyno loading requirements

Reference mass of vehicle RW (kg)	Equivalent inertia	Power and load absorbed by the dynamometer at 80 km/h		Road Load Coefficients	
	kg	kW	N	a (N)	b(N/kph)
RW ≤ 480	455	3.8	171	3.8	0.0261
480 < RW ≤ 540	510	4.1	185	4.2	0.0282
540 < RW ≤ 595	570	4.3	194	4.4	0.0296
595 < RW ≤ 650	625	4.5	203	4.6	0.0309
650 < RW ≤ 710	680	4.7	212	4.8	0.0323
710 < RW ≤ 765	740	4.9	221	5.0	0.0337
765 < RW ≤ 850	800	5.1	230	5.2	0.0351
850 < RW ≤ 965	910	5.6	252	5.7	0.0385
965 < RW ≤ 1080	1020	6.0	270	6.1	0.0412
1080 < RW ≤ 1190	1130	6.3	284	6.4	0.0433
1190 < RW ≤ 1305	1250	6.7	302	6.8	0.0460
1305 < RW ≤ 1420	1360	7.0	315	7.1	0.0481
1420 < RW ≤ 1530	1470	7.3	329	7.4	0.0502
1530 < RW ≤ 1640	1590	7.5	338	7.6	0.0515
1640 < RW ≤ 1760	1700	7.8	351	7.9	0.0536
1760 < RW ≤ 1870	1810	8.1	365	8.2	0.0557
1870 < RW ≤ 1980	1930	8.4	378	8.5	0.0577
1980 < RW ≤ 2100	2040	8.6	387	8.7	0.0591
2100 < RW ≤ 2210	2150	8.8	396	8.9	0.0605
2210 < RW ≤ 2380	2270	9.0	405	9.1	0.0619
2380 < RW ≤ 2610	2270	9.4	423	9.5	0.0646
2610 < RW	2270	9.8	441	9.9	0.0674

Figure 1

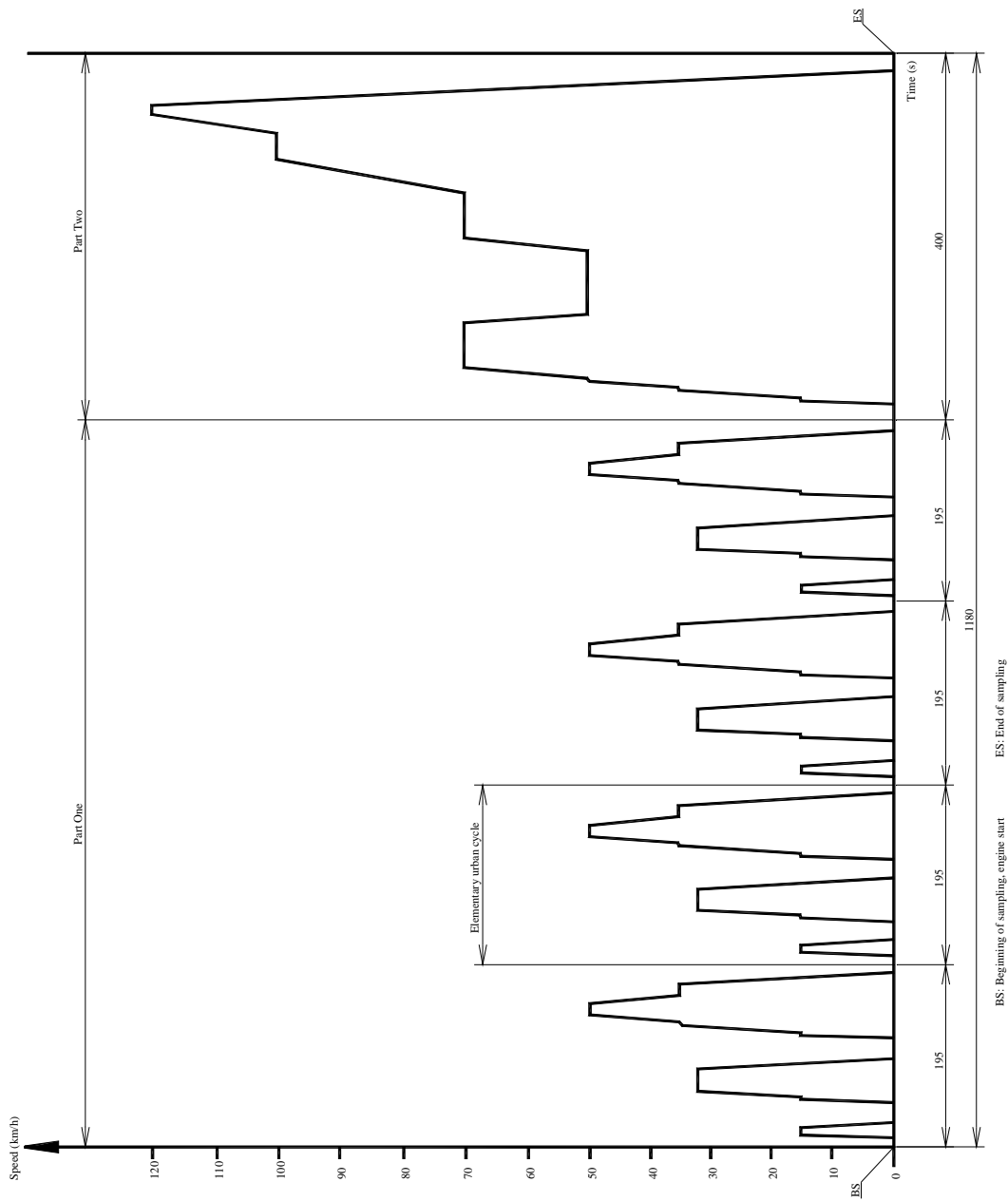Operating cycle for the Type I test

Figure 2

Elementary urban cycle for the Type I test
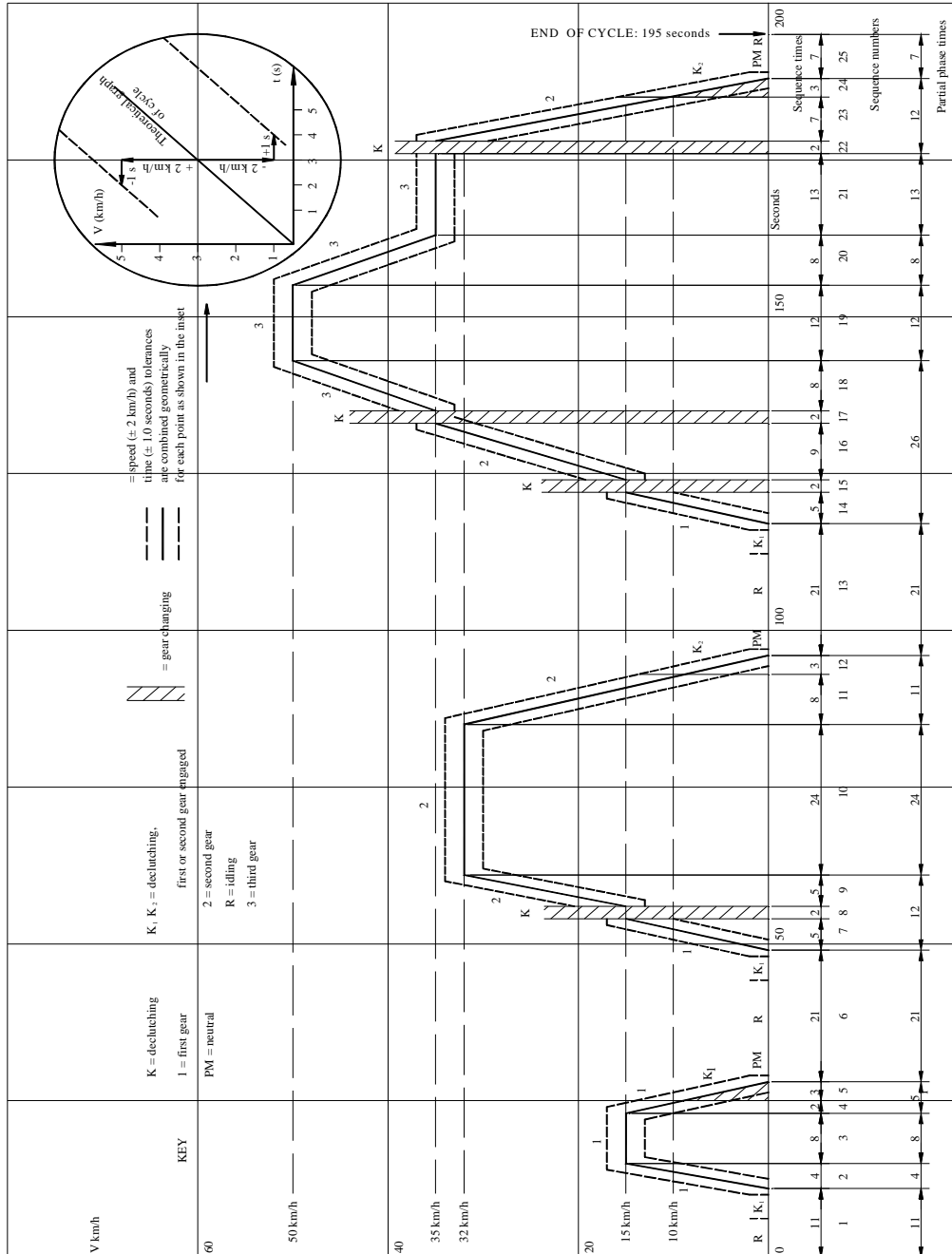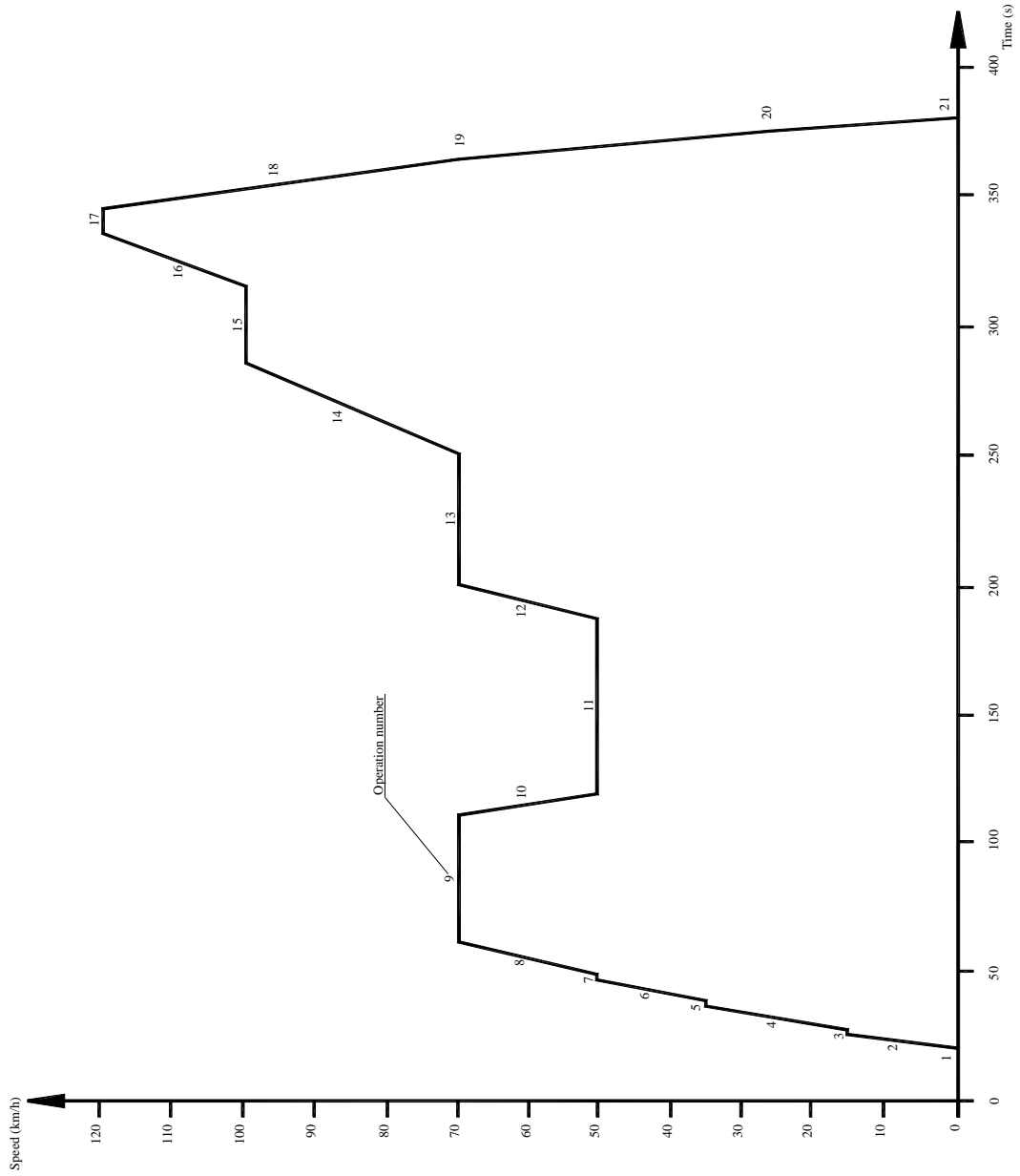
Figure 3

Extra-urban cycle (Part Two) for the Type I test

Appendix 1

CHASSIS DYNAMOMETER SYSTEM

1.   SPECIFICATION

1.1.   General Requirements

1.1.1.   The dynamometer shall be capable of simulating road load within one of the following classifications:
(a)   Dynamometer with fixed load curve, i.e. a dynamometer whose physical characteristics provide a fixed load curve shape,
(b)   Dynamometer with adjustable load curve, i.e. a dynamometer with at least two road load parameters that can be adjusted to shape the load curve.

1.1.2.   Dynamometers with electric inertia simulation shall be demonstrated to be equivalent to mechanical inertia systems. The means by which equivalence is established are described in Appendix 6 to this annex.

1.1.3.   In the event that the total resistance to progress on the road cannot be reproduced on the chassis dynamometer between speeds of 10 km/h and 120 km/h, it is recommended that a chassis dynamometer having the characteristics defined below should be used.

1.1.3.1.   The load absorbed by the brake and the chassis dynamometer internal frictional effects between the speeds of 0 and 120 km/h is as follows:

$$F = (a + b \cdot V^2) \pm 0.1 \cdot F_{80}$$ (without being negative)

where:
F =   total load absorbed by the chassis dynamometer (N)
a =   value equivalent to rolling resistance (N)
b =   value equivalent to coefficient of air resistance $(N/(km/h)^2)$
V =   speed (km/h)
F_{80} =   load at 80 km/h (N).

1.2.   Specific Requirements

1.2.1.   The setting of the dynamometer shall not be affected by the lapse of time. It shall not produce any vibrations perceptible to the vehicle and likely to impair the vehicle's normal operations.

1.2.2.   The chassis dynamometer may have one or two rollers. The front roller shall drive, directly or indirectly, the inertial masses and the power absorption device.

1.2.3.   It shall be possible to measure and read the indicated load to an accuracy of ±5 per cent.

1.2.4.   In the case of a dynamometer with a fixed load curve, the accuracy of the load setting at 80 km/h shall be ±5 per cent. In the case of a dynamometer with adjustable load curve, the accuracy of matching dynamometer load to road load shall be ±5 per cent at 120, 100, 80, 60, and 40 km/h and ±10 per cent at 20 km/h. Below this, dynamometer absorption shall be positive.

1.2.5.   The total inertia of the rotating parts (including the simulated inertia where applicable) shall be known and shall be within ±20 kg of the inertia class for the test.

1.2.6.   The speed of the vehicle shall be measured by the speed of rotation of the roller (the front roller in the case of a two-roller dynamometer). It shall be measured with an accuracy of ±1 km/h at speeds above 10 km/h.

The distance actually driven by the vehicle shall be measured by the movement of rotation of the roller (the front roller in the case of a two-roller dynamometer).

2.   DYNAMOMETER CALIBRATION PROCEDURE

2.1.   Introduction

This section describes the method to be used to determine the load absorbed by a dynamometer brake. The load absorbed comprises the load absorbed by frictional effects and the load absorbed by the power-absorption device.

The dynamometer is brought into operation beyond the range of test speeds. The device used for starting up the dynamometer is then disconnected: the rotational speed of the driven roller decreases.

The kinetic energy of the rollers is dissipated by the power-absorption unit and by the frictional effects. This method disregards variations in the roller's internal frictional effects caused by rollers with or without the vehicle. The frictional effects of the rear roller shall be disregarded when the roller is free.

2.2.   Calibration of the load indicator at 80 km/h

The following procedure shall be used for calibration of the load indicator to 80 km/h as a function of the load absorbed (see also Figure 4):

2.2.1.   Measure the rotational speed of the roller if this has not already been done. A fifth wheel, a revolution counter or some other method may be used.

2.2.2.   Place the vehicle on the dynamometer or devise some other method of starting-up the dynamometer.

2.2.3.   Use the flywheel or any other system of inertia simulation for the particular inertia class to be used.

Diagram illustrating the power absorbed by the chassis dynamometer

Figure 4
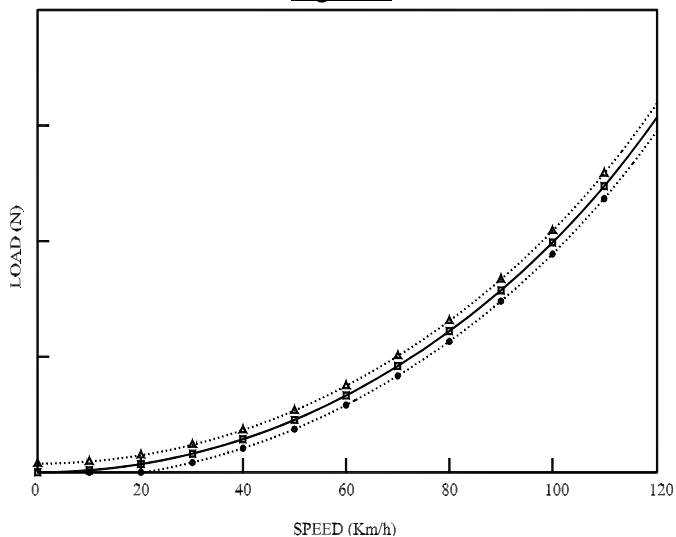
$$\square = F = a + b \cdot V^2 \qquad \bullet = (a + b \cdot V^2) - 0.1 \cdot F_{80} \qquad \Delta = (a + b \cdot V^2) + 0.1 \cdot F_{80}$$

2.2.4.   Bring the dynamometer to a speed of 80 km/h.

2.2.5.   Note the load indicated F_i (N).

2.2.6.   Bring the dynamometer to a speed of 90 km/h.

2.2.7.   Disconnect the device used to start-up the dynamometer.

2.2.8.   Note the time taken by the dynamometer to pass from a speed of 85 km/h to a speed of 75 km/h.

2.2.9.   Set the power-absorption device at a different level.

2.2.10.   The requirements of paragraphs 2.2.4. to 2.2.9. shall be repeated sufficiently often to cover the range of loads used.

2.2.11.   Calculate the load absorbed using the formula:

$$F = \frac{M_i \cdot \Delta V}{t}$$

where:

F	=	load absorbed (N),
M_i	=	equivalent inertia in kg (excluding the inertial effects of the free rear roller),
ΔV	=	Speed deviation in m/s (10 km/h = 2.775 m/s),
t	=	time taken by the roller to pass from 85 km/h to 75 km/h.

2.2.12.   Figure 5 shows the load indicated at 80 km/h in terms of load absorbed at 80 km/h.

Figure 5: Load indicated at 80 km/h in terms of load absorbed at 80 km/h
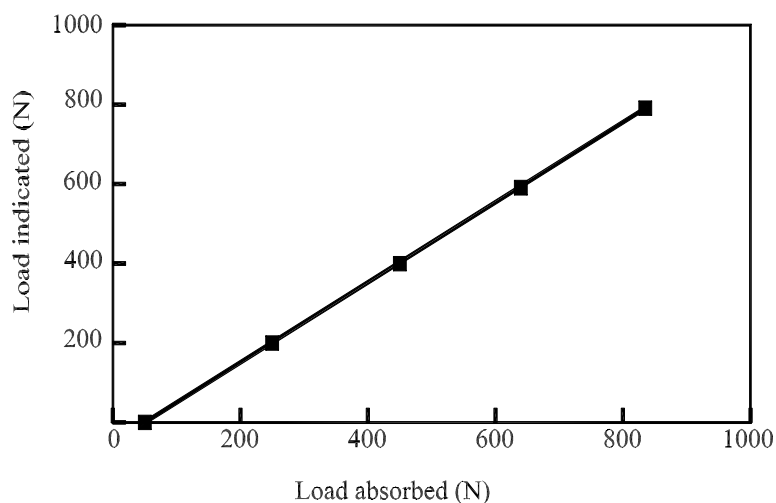
2.2.13.   The requirements of paragraphs 2.2.3. to 2.2.12. above shall be repeated for all inertia classes to be used.

2.3.   Calibration of the load indicator at other speeds

The procedures described in paragraph 2.2. above shall be repeated as often as necessary for the chosen speeds.

2.4.   Calibration of force or torque

The same procedure shall be used for force or torque calibration.

3.   VERIFICATION OF THE LOAD CURVE

3.1.   Procedure

The load-absorption curve of the dynamometer from a reference setting at a speed of 80 km/h shall be verified as follows:

3.1.1.   Place the vehicle on the dynamometer or devise some other method of starting-up the dynamometer.

3.1.2.   Adjust the dynamometer to the absorbed load (F) at 80 km/h.

3.1.3.   Note the load absorbed at 120, 100, 80, 60, 40 and 20 km/h.

3.1.4.   Draw the curve F(V) and verify that it corresponds to the requirements of paragraph 1.1.3.1. of this appendix.

3.1.5.   Repeat the procedure set out in paragraphs 3.1.1. to 3.1.4. above for other values of power F at 80 km/h and for other values of inertias.

Appendix 2

EXHAUST DILUTION SYSTEM

1.   SYSTEM SPECIFICATION

1.1.   System Overview

A full-flow exhaust dilution system shall be used. This requires that the vehicle exhaust be continuously diluted with ambient air under controlled conditions. The total volume of the mixture of exhaust and dilution air shall be measured and a continuously proportional sample of the volume shall be collected for analysis. The quantities of pollutants are determined from the sample concentrations, corrected for the pollutant content of the ambient air and the totalised flow over the test period.

The exhaust dilution system shall consist of a transfer tube, a mixing chamber and dilution tunnel, a dilution air conditioning, a suction device and a flow measurement device. Sampling probes shall be fitted in the dilution tunnel as specified in Appendices 3, 4 and 5.

The mixing chamber described above will be a vessel, such as those illustrated in Figures 6 and 7, in which vehicle exhaust gases and the dilution air are combined so as to produce a homogeneous mixture at the chamber outlet.

1.2.   General Requirements

1.2.1. The vehicle exhaust gases shall be diluted with a sufficient amount of ambient air to prevent any water condensation in the sampling and measuring system at all conditions which may occur during a test.

1.2.2. The mixture of air and exhaust gases shall be homogeneous at the point where the sampling probe is located (see paragraph 1.3.3. below). The sampling probe shall extract a representative sample of the diluted exhaust gas.

1.2.3. The system shall enable the total volume of the diluted exhaust gases to be measured.

1.2.4. The sampling system shall be gas-tight. The design of the variable-dilution sampling system and the materials that go to make it up shall be such that they do not affect the pollutant concentration in the diluted exhaust gases. Should any component in the system (heat exchanger, cyclone separator, blower, etc.) change the concentration of any of the pollutants in the diluted exhaust gases and the fault cannot be corrected, then sampling for that pollutant shall be carried out upstream from that component.

1.2.5. All parts of the dilution system that are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition or alteration of the particulates or 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.

1.2.6.   If the vehicle being tested is equipped with an exhaust pipe comprising several branches, the connecting tubes shall be connected as near as possible to the vehicle without adversely affecting its operation.

1.2.7.   The variable-dilution system shall be so designed as to enable the exhaust gases to be sampled without appreciably changing the back-pressure at the exhaust pipe outlet.

1.2.8.   The connecting tube between the vehicle and dilution system shall be designed so as to minimize heat loss.

1.3.   Specific Requirements

1.3.1.   Connection to Vehicle Exhaust

The connecting tube between the vehicle exhaust outlets and the dilution system shall be as short as possible; and satisfy the following requirements:
(a)   Be less than 3.6 m long, or less than 6.1 m long if heat insulated. Its internal diameter may not exceed 105 mm;
(b)   Shall not cause the static pressure at the exhaust outlets on the vehicle being tested to; differ by more than ±0.75 kPa at 50 km/h, or more than ±1.25 kPa for the whole duration of the test from the static pressures recorded when nothing is connected to the vehicle exhaust outlets. The pressure shall be measured in the exhaust outlet or in an extension having the same diameter, as near as possible to the end of the pipe. Sampling systems capable of maintaining the static pressure to within ±0.25 kPa may be used if a written request from a manufacturer to the Technical Service substantiates the need for the closer tolerance;
(c)   Shall not change the nature of the exhaust gas;
(d)   Any elastomer connectors employed shall be as thermally stable as possible and have minimum exposure to the exhaust gases.

1.3.2.   Dilution Air Conditioning

The dilution air used for the primary dilution of the exhaust in the CVS tunnel shall be passed through a medium capable of reducing particles in the most penetrating particle size of the filter material by ≥ 99.95 per cent, or through a filter of at least class H13 of EN 1822:1998. This represents the specification of High Efficiency Particulate Air (HEPA) filters. The dilution air may optionally be charcoal scrubbed before being passed to the HEPA filter. It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal scrubber, if used.

At the vehicle manufacturer's request, the dilution air may be sampled according to good engineering practice to determine the tunnel contribution to background particulate mass levels, which can then be subtracted from the values measured in the diluted exhaust.

1.3.3.   Dilution Tunnel

Provision shall be made for the vehicle exhaust gases and the dilution air to be mixed. A mixing orifice may be used.

In order to minimise the effects on the conditions at the exhaust outlet and to limit the drop in pressure inside the dilution-air conditioning device, if any, the pressure at the mixing point shall not differ by more than ±0.25 kPa from atmospheric pressure.

The homogeneity of the mixture in any cross-section at the location of the sampling probe shall not vary by more than ±2 per cent from the average of the values obtained for at least five points located at equal intervals on the diameter of the gas stream.

For particulate and particle emissions sampling, a dilution tunnel shall be used which:
(a)   Shall consist of a straight tube of electrically-conductive material, which shall be earthed;
(b)   Shall be small enough in diameter to cause turbulent flow (Reynolds number ≥ 4000) and of sufficient length to cause complete mixing of the exhaust and dilution air;
(c)   Shall be at least 200 mm in diameter;
(d)   May be insulated.

1.3.4.   Suction Device

This device may have a range of fixed speeds to ensure sufficient flow to prevent any water condensation. This result is generally obtained if the flow is either:
(a)   Twice as high as the maximum flow of exhaust gas produced by accelerations of the driving cycle; or
(b)   Sufficient to ensure that the CO_2 concentration in the dilute-exhaust sample bag is less than 3 per cent by volume for petrol and diesel, less than 2.2 per cent by volume for LPG and less than 1.5 per cent by volume for NG.

1.3.5.   Volume Measurement in the Primary Dilution System

The method of measuring total dilute exhaust volume incorporated in the constant volume sampler shall be such that measurement is accurate to ±2 per cent under all operating conditions.   If the device cannot compensate for variations in the

temperature of the mixture of exhaust gases and dilution air at the measuring point, a heat exchanger shall be used to maintain the temperature to within ±6 K of the specified operating temperature.

If necessary, some form of protection for the volume measuring device may be used e.g. a cyclone separator, bulk stream filter, etc.

A temperature sensor shall be installed immediately before the volume measuring device. This temperature sensor shall have an accuracy and a precision of ±1 K and a response time of 0.1 s at 62 per cent of a given temperature variation (value measured in silicone oil).

The measurement of the pressure difference from atmospheric pressure shall be taken upstream from and, if necessary, downstream from the volume measuring device.

The pressure measurements shall have a precision and an accuracy of ±0.4 kPa during the test.

1.4.   Recommended System Descriptions

Figure 6 and Figure 7 are schematic drawings of two types of recommended exhaust dilution systems that meet the requirements of this annex.

Since various configurations can produce accurate results, exact conformity with these figures is not essential. Additional components such as instruments, valves, solenoids and switches may be used to provide additional information and co-ordinate the functions of the component system.

1.4.1.   Figure 6: Positive Displacement Pump Dilution System
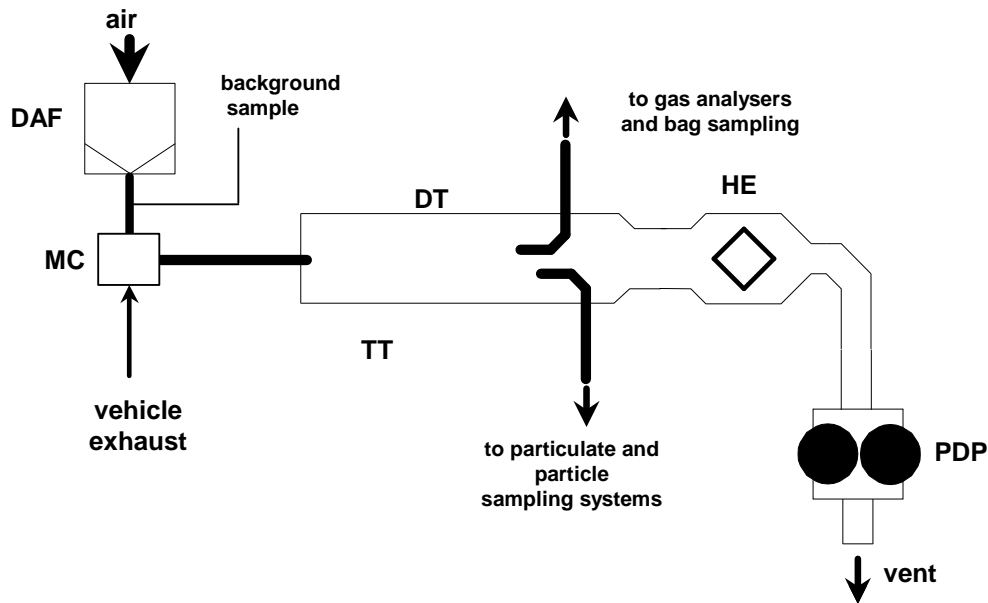
Full Flow Dilution System with Positive Displacement Pump

The positive displacement pump (PDP) full flow dilution system satisfies the requirements of this annex by metering the flow of gas through the pump at constant temperature and pressure. The total volume is measured by counting the revolutions made by the calibrated positive displacement pump. The proportional sample is achieved by sampling with pump, flow-meter and flow control valve at a constant flow rate. The collecting equipment consists of:

1.4.1.1.   A filter (DAF) for the dilution air, which can be preheated if necessary. This filter shall consist of the following filters in sequence: an optional activated charcoal filter (inlet side), and a high efficiency particulate air (HEPA) filter (outlet side). It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal filter, if used. The purpose of the charcoal filter is to reduce and stabilize the hydrocarbon concentrations of ambient emissions in the dilution air;

1.4.1.2.   A transfer tube (TT) by which vehicle exhaust is admitted into a dilution tunnel (DT) in which the exhaust gas and dilution air are mixed homogeneously;

1.4.1.3.   The positive displacement pump (PDP), producing a constant-volume flow of the air/exhaust-gas mixture. The PDP revolutions, together with associated temperature and pressure measurement are used to determine the flowrate;

1.4.1.4. A heat exchanger (HE) of a capacity sufficient to ensure that throughout the test the temperature of the air/exhaust-gas mixture measured at a point immediately upstream of the positive displacement pump is within 6 K of the average operating temperature during the test. This device shall not affect the pollutant concentrations of diluted gases taken off after for analysis.

1.4.1.5. A mixing chamber (MC) in which exhaust gas and air are mixed homogeneously, and which may be located close to the vehicle so that the length of the transfer tube (TT) is minimized.

1.4.2. Figure 7: Critical-Flow Venturi Dilution System
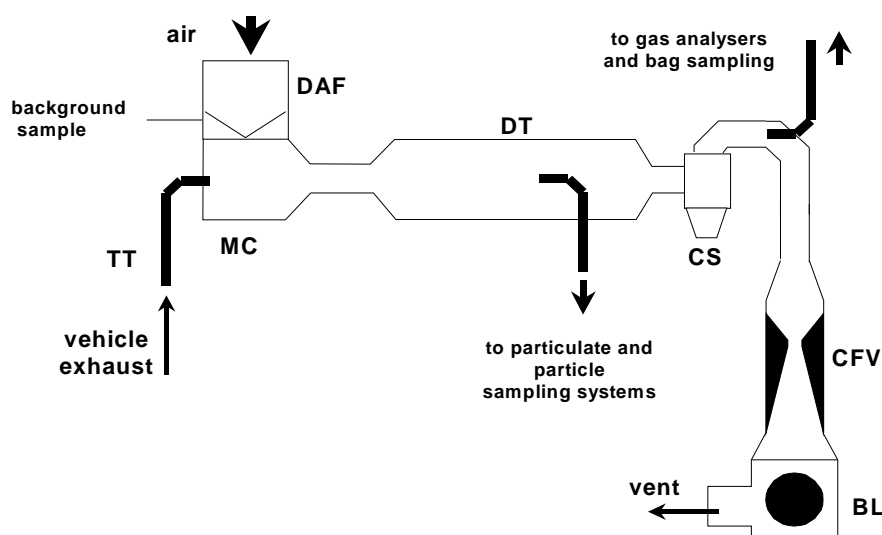
Full Flow Dilution System with Critical Flow Venturi

The use of a critical-flow venturi (CFV) for the full-flow dilution system is based on the principles of flow mechanics for critical flow. The variable mixture flow rate of dilution and exhaust gas is maintained at sonic velocity which is directly proportional to the square root of the gas temperature. Flow is continually monitored, computed and integrated throughout the test.

The use of an additional critical-flow sampling venturi ensures the proportionality of the gas samples taken from the dilution tunnel. As both pressure and temperature are equal at the two venturi inlets the volume of the gas flow diverted for sampling is proportional to the total volume of diluted exhaust-gas mixture produced, and thus the requirements of this annex are met. The collecting equipment consists of:

1.4.2.1. A filter (DAF) for the dilution air, which can be preheated if necessary. This filter shall consist of the following filters in sequence: an optional activated charcoal filter (inlet side), and a high efficiency particulate air (HEPA) filter (outlet side). It is

recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal filter, if used. The purpose of the charcoal filter is to reduce and stabilize the hydrocarbon concentrations of ambient emissions in the dilution air;

1.4.2.2.   A mixing chamber (MC) in which exhaust gas and air are mixed homogeneously, and which may be located close to the vehicle so that the length of the transfer tube (TT) is minimized;

1.4.2.3.   A dilution tunnel (DT) from which particulates and particles are sampled;

1.4.2.4.   Some form of protection for the measurement system may be used e.g. a cyclone separator, bulk stream filter, etc.;

1.4.2.5.   A measuring critical-flow venturi tube (CFV), to measure the flow volume of the diluted exhaust gas;

1.4.2.6.   A blower (BL), of sufficient capacity to handle the total volume of diluted exhaust gas.

2.   CVS CALIBRATION PROCEDURE

2.1.   General Requirements

The CVS system shall be calibrated by using an accurate flow-meter and a restricting device. The flow through the system shall be measured at various pressure readings and the control parameters of the system measured and related to the flows. The flow-metering device shall be dynamic and suitable for the high flow-rate encountered in constant volume sampler testing. The device shall be of certified accuracy traceable to an approved national or international standard.

2.1.1.   Various types of flow-meter may be used, e.g. calibrated venturi, laminar flow-meter, calibrated turbine-meter, provided that they are dynamic measurement systems and can meet the requirements of paragraph 1.3.5. of this appendix.

2.1.2.   The following paragraphs give details of methods of calibrating PDP and CFV units, using a laminar flow-meter, which gives the required accuracy, together with a statistical check on the calibration validity.

2.2.   Calibration of the positive displacement pump (PDP)

2.2.1.   The following calibration procedure outlines the equipment, the test configuration and the various parameters that are measured to establish the flow-rate of the CVS pump. All the parameters related to the pump are simultaneously measured with the parameters related to the flow-meter which is connected in series with the pump.

The calculated flow-rate (given in m^3/min at pump inlet, absolute pressure and temperature) can then be plotted versus a correlation function that is the value of a specific combination of pump parameters. The linear equation that relates the pump flow and the correlation function is then determined. In the event that a CVS has a multiple speed drive, a calibration for each range used shall be performed.

2.2.2.   This calibration procedure is based on the measurement of the absolute values of the pump and flow-meter parameters that relate the flow rate at each point. Three conditions shall be maintained to ensure the accuracy and integrity of the calibration curve:

2.2.2.1.   The pump pressures shall be measured at tappings on the pump rather than at the external piping on the pump inlet and outlet. Pressure taps that are mounted at the top centre and bottom centre of the pump drive headplate are exposed to the actual pump cavity pressures, and therefore reflect the absolute pressure differentials;

2.2.2.2.   Temperature stability shall be maintained during the calibration. The laminar flow-meter is sensitive to inlet temperature oscillations which cause the data points to be scattered. Gradual changes of ± 1 K in temperature are acceptable as long as they occur over a period of several minutes;

2.2.2.3.   All connections between the flow-meter and the CVS pump shall be free of any leakage.

2.2.3.   During an exhaust emission test, the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

2.2.4.   Figure 8 of this appendix shows one possible test set-up. Variations are permissible, provided that the Technical Service approves them as being of comparable accuracy. If the set-up shown in Figure 8 is used, the following data shall be found within the limits of precision given:

Barometric pressure (corrected)(P_b)	± 0.03 kPa
Ambient temperature (T)	± 0.2 K
Air temperature at LFE (ETI)	± 0.15 K
Pressure depression upstream of LFE (EPI)	± 0.01 kPa
Pressure drop across the LFE matrix (EDP)	± 0.0015 kPa
Air temperature at CVS pump inlet (PTI)	± 0.2 K
Air temperature at CVS pump outlet (PTO)	± 0.2 K
Pressure depression at CVS pump inlet (PPI)	± 0.22 kPa
Pressure head at CVS pump outlet (PPO)	± 0.22 kPa
Pump revolutions during test period (n)	± 1 min^{-1}
Elapsed time for period (minimum 250 s) (t)	± 0.1 s

Figure 8: PDP Calibration Configuration
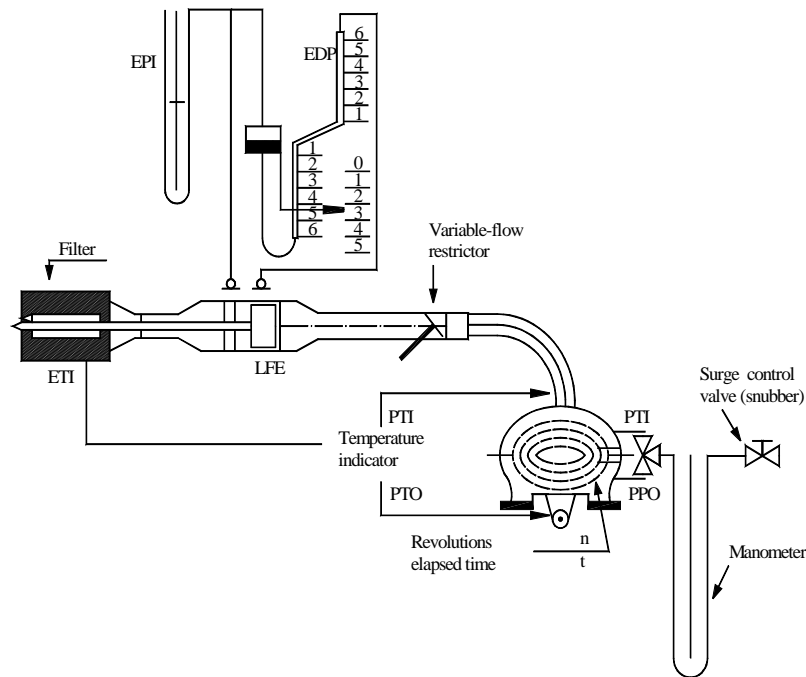
2.2.5.   After the system has been connected as shown in Figure 8 of this appendix, set the variable restrictor in the wide-open position and run the CVS pump for 20 minutes before starting the calibration.

2.2.6.   Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression (about 1 kPa) that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for three minutes and repeat the data acquisition.

2.2.7.   The air flow rate (Q_s) at each test point is calculated in standard m^3/min from the flow-meter data using the manufacturer's prescribed method.

2.2.8.   The air flow-rate is then converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure.

$$V_0 = \frac{Q_s}{n} \cdot \frac{T_p}{273.2} \cdot \frac{101.33}{P_p}$$

where:

V_0 = pump flow rate at T_p and P_p (m^3/rev),
Q_s = air flow at 101.33 kPa and 273.2 K (m^3/min),
T_p = pump inlet temperature (K),

P_p = absolute pump inlet pressure (kPa),

N = pump speed (min^{-1}).

2.2.9.　　To compensate for the interaction of pump speed pressure variations at the pump and the pump slip rate, the correlation function (x_0) between the pump speed (n), the pressure differential from pump inlet to pump outlet and the absolute pump outlet pressure is then calculated as follows:

$$x_0 = \frac{1}{n}\sqrt{\frac{\Delta P_p}{P_e}}$$

where:

x_0 = 　correlation function,

ΔP_p = 　pressure differential from pump inlet to pump outlet (kPa),

P_e = 　absolute outlet pressure (PPO + P_b) (kPa).

A linear least-square fit is performed to generate the calibration equations which have the formula:

$$V_0 = D_0 - M (x_0)$$

$$n = A - B (\Delta P_p)$$

D_0, M, A and B are the slope-intercept constants describing the lines.

2.2.10.　　A CVS system that has multiple speeds shall be calibrated on each speed used. The calibration curves generated for the ranges shall be approximately parallel and the intercept values (D_0) shall increase as the pump flow range decreases.

2.2.11.　　If the calibration has been performed carefully, the calculated values from the equation will be within 0.5 per cent of the measured value of V_0. Values of M will vary from one pump to another. Calibration is performed at pump start-up and after major maintenance.

2.3.　　Calibration of the critical-flow venturi (CFV)

2.3.1.　　Calibration of the CFV is based upon the flow equation for a critical venturi:

$$Q_s = \frac{K_v P}{\sqrt{T}}$$

where:

Q_s = 　flow,

K_v = 　calibration coefficient,

P = 　absolute pressure (kPa),

T = 　absolute temperature (K).

Gas flow is a function of inlet pressure and temperature.

The calibration procedure described below establishes the value of the calibration coefficient at measured values of pressure, temperature and air flow.

2.3.2.   The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

2.3.3.   Measurements for flow calibration of the critical flow venturi are required and the following data shall be found within the limits of precision given:

Barometric pressure (corrected) (P_b)	± 0.03 kPa,
LFE air temperature, flow-meter (ETI)	± 0.15 K,
Pressure depression upstream of LFE (EPI)	± 0.01 kPa,
Pressure drop across (EDP) LFE matrix	± 0.0015 kPa,
Air flow (Q_s)	± 0.5 per cent,
CFV inlet depression (PPI)	± 0.02 kPa,
Temperature at venturi inlet (T_v)	± 0.2 K.

2.3.4.   The equipment shall be set up as shown in Figure 9 of this appendix and checked for leaks. Any leaks between the flow-measuring device and the critical-flow venturi will seriously affect the accuracy of the calibration.

Figure 9: CFV Calibration Configuration
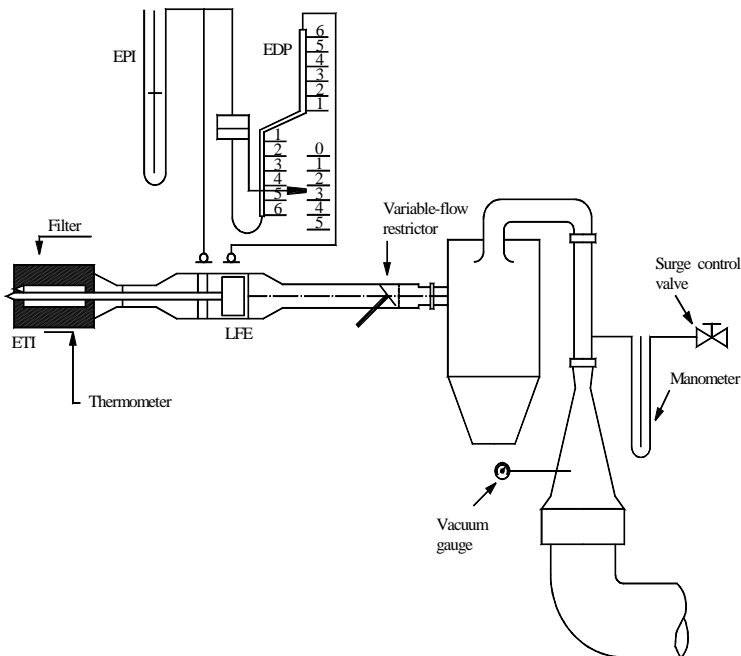
2.3.5.   The variable-flow restrictor shall be set to the open position, the blower shall be started and the system stabilized. Data from all instruments shall be recorded.

2.3.6.   The flow restrictor shall be varied and at least eight readings across the critical flow range of the venturi shall be made.

2.3.7.   The data recorded during the calibration shall be used in the following calculations. The air flow-rate (Q_s) at each test point is calculated from the flow-meter data using the manufacturer's prescribed method.

Calculate values of the calibration coefficient for each test point:

$$K_v = \frac{Q_s \sqrt{T_v}}{P_v}$$

where:
Q_s = flow-rate in m^3/min at 273.2 K and 101.33 kPa,
T_v = temperature at the venturi inlet (K),
P_v = absolute pressure at the venturi inlet (kPa).

Plot K_v as a function of venturi inlet pressure. For sonic flow, K_v will have a relatively constant value. As pressure decreases (vacuum increases) the venturi becomes unchoked and K_v decreases. The resultant K_v changes are not permissible.

For a minimum of eight points in the critical region, calculate an average K_v and the standard deviation.

If the standard deviation exceeds 0.3 per cent of the average K_v, take corrective action.

3.   SYSTEM VERIFICATION PROCEDURE

3.1.   General Requirements

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system whilst it is being operated as if during a normal test and then analysing and calculating the pollutant mass according to the formula in paragraph 6.6. of Annex 4a except that the density of propane shall be taken as 1.967 grams per litre at standard conditions. The following two techniques are known to give sufficient accuracy.

The maximum permissible deviation between the quantity of gas introduced and the quantity of gas measured is 5 per cent.

3.2. CFO Method

3.2.1. Metering a constant flow of pure gas (CO or C_3H_8) using a critical flow orifice device.

3.2.2. A known quantity of pure gas (CO or C_3H_8) is fed into the CVS system through the calibrated critical orifice. If the inlet pressure is high enough, the flow-rate (q), which is adjusted by means of the critical flow orifice, is independent of orifice outlet pressure (critical flow). If deviations exceeding 5 per cent occur, the cause of the malfunction shall be determined and corrected. The CVS system is operated as in an exhaust emission test for about 5 to 10 minutes. The gas collected in the sampling bag is analysed by the usual equipment and the results compared to the concentration of the gas samples which was known beforehand.

3.3. Gravimetric Method

3.3.1. Metering a limited quantity of pure gas (CO or C_3H_8) by means of a gravimetric technique.

3.3.2. The following gravimetric procedure may be used to verify the CVS system.

The weight of a small cylinder filled with either carbon monoxide or propane is determined with a precision of ± 0.01 g. For about 5 to 10 minutes, the CVS system is operated as in a normal exhaust emission test, while CO or propane is injected into the system. The quantity of pure gas involved is determined by means of differential weighing. The gas accumulated in the bag is then analysed by means of the equipment normally used for exhaust-gas analysis. The results are then compared to the concentration figures computed previously.

Appendix 3

GASEOUS EMISSIONS MEASUREMENT EQUIPMENT

1.   SPECIFICATION

1.1.   System Overview

          A continuously proportional sample of the diluted exhaust gases and the dilution air
          shall be collected for analysis.

          Mass gaseous emissions shall be determined from the proportional sample
          concentrations and the total volume measured during the test. The sample
          concentrations shall be corrected to take account of the pollutant content of the
          ambient air.

1.2.   Sampling System Requirements

1.2.1.   The sample of dilute exhaust gases shall be taken upstream from the suction device
          but downstream from the conditioning devices (if any).

1.2.2.   The flow rate shall not deviate from the average by more than ± 2 per cent.

1.2.3.   The sampling rate shall not fall below 5 litres per minute and shall not exceed
          0.2 per cent of the flow rate of the dilute exhaust gases. An equivalent limit shall
          apply to constant-mass sampling systems.

1.2.4.   A sample of the dilution air shall be taken at a constant flow rate near the ambient air-
          inlet (after the filter if one is fitted).

1.2.5.   The dilution air sample shall not be contaminated by exhaust gases from the mixing
          area.

1.2.6.   The sampling rate for the dilution air shall be comparable to that used in the case of
          the dilute exhaust gases.

1.2.7.   The materials used for the sampling operations shall be such as not to change the
          pollutant concentration.

1.2.8.   Filters may be used in order to extract the solid particles from the sample.

1.2.9.   The various valves used to direct the exhaust gases shall be of a quick-adjustment,
          quick-acting type.

1.2.10.   Quick-fastening gas-tight connections may be used between the three-way valves and
          the sampling bags, the connections sealing themselves automatically on the bag side.

Other systems may be used for conveying the samples to the analyser (three-way stop valves, for example).

1.2.11.   Storage of the sample

The gas samples shall be collected in sampling bags of sufficient capacity not to impede the sample flow; the bag material shall be such as to affect neither the measurements themselves nor the chemical composition of the gas samples by more than ± 2 per cent after 20 minutes (for instance: laminated polyethylene/polyamide films, or fluorinated polyhydrocarbons).

1.2.12.   Hydrocarbon Sampling System – Diesel Engines

1.2.12.1.   The hydrocarbon sampling system shall consist of a heated sampling probe, line, filter and pump. The sampling probe shall be installed at the same distance from the exhaust gas inlet as the particulate sampling probe, in such a way that neither interferes with samples taken by the other. It shall have a minimum internal diameter of 4 mm.

1.2.12.2.   All heated parts shall be maintained at a temperature of 463 K (190 °C) ± 10 K by the heating system.

1.2.12.3.   The average concentration of the measured hydrocarbons shall be determined by integration.

1.2.12.4.   The heated sampling line shall be fitted with a heated filter (F_H) 99 per cent efficient with particles ≥ 0.3 μm, to extract any solid particles from the continuous flow of gas required for analysis.

1.2.12.5.   The sampling system response time (from the probe to the analyser inlet) shall be no more than four seconds.

1.2.12.6.   The HFID shall be used with a constant flow (heat exchanger) system to ensure a representative sample, unless compensation for varying CFV or CFO flow is made.

1.3.   Gas Analysis Requirements

1.3.1.   Carbon monoxide (CO) and carbon dioxide (CO_2) analyses:

Analysers shall be of the non-dispersive infra-red (NDIR) absorption type.

1.3.2.   Hydrocarbons (HC) analysis - spark-ignition engines:

The analyser shall be of the flame ionisation (FID) type calibrated with propane gas expressed equivalent to carbon atoms (C_1).

1.3.3.   Hydrocarbons (HC) analysis - compression-ignition engines:

The analyser shall be of the flame ionisation type with detector, valves, pipework, etc., heated to 463 K (190 °C) ±10 K (HFID). It shall be calibrated with propane gas expressed equivalent to carbon atoms (C_1).

1.3.4.   Nitrogen oxide (NO_x) analysis:

The analyser shall be either of the chemi-luminescent (CLA) or of the non-dispersive ultra-violet resonance absorption (NDUVR) type, both with NO_x-NO converters.

1.3.5.   The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample pollutants.

1.3.6.   Measurement error shall not exceed ±2 per cent (intrinsic error of analyser) disregarding the true value for the calibration gases.

1.3.7.   For concentrations of less than 100 ppm, the measurement error shall not exceed ±2 ppm.

1.3.8.   The ambient air sample shall be measured on the same analyser with an appropriate range.

1.3.9.   No gas drying device shall be used before the analysers unless shown to have no effect on the pollutant content of the gas stream.

1.4.   Recommended System Descriptions

Figure 10 is a schematic drawing of the system for gaseous emissions sampling.

Figure 10: Gaseous Emissions Sampling Schematic
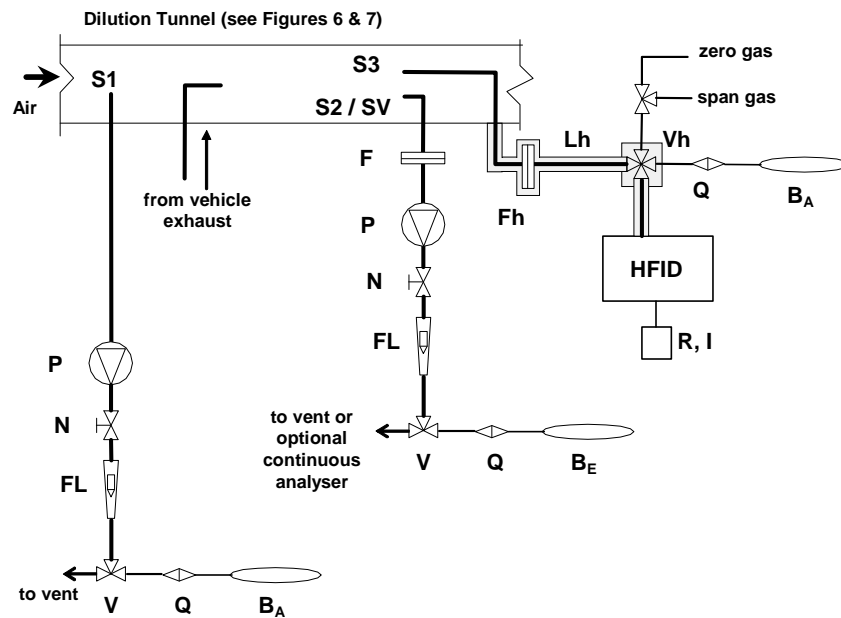
The components of the system are as follows:

1.4.1.　　Two sampling probes (S_1 and S_2) for continuous sampling of the dilution air and of the diluted exhaust-gas/air mixture;

1.4.2.　　A filter (F), to extract solid particles from the flows of gas collected for analysis;

1.4.3.　　Pumps (P), to collect a constant flow of the dilution air as well as of the diluted exhaust-gas/air mixture during the test;

1.4.4.　　Flow controller (N), to ensure a constant uniform flow of the gas samples taken during the course of the test from sampling probes S_1 and S_2 (for PDP-CVS) and flow of the gas samples shall be such that, at the end of each test, the quantity of the samples is sufficient for analysis (approximately 10 litres per minute);

1.4.5.　　Flow meters (FL), for adjusting and monitoring the constant flow of gas samples during the test;

1.4.6.　　Quick-acting valves (V), to divert a constant flow of gas samples into the sampling bags or to the outside vent;

1.4.7.　　Gas-tight, quick-lock coupling elements (Q) between the quick-acting valves and the sampling bags; the coupling shall close automatically on the sampling-bag side; as

an alternative, other ways of transporting the samples to the analyser may be used (three-way stopcocks, for instance);

1.4.8.   Bags (B), for collecting samples of the diluted exhaust gas and of the dilution air during the test;

1.4.9.   A sampling critical-flow venturi (SV), to take proportional samples of the diluted exhaust gas at sampling probe S_2 A(CFV-CVS only);

1.4.10.   A scrubber (PS), in the sampling line (CFV-CVS only);

1.4.11.   Components for hydrocarbon sampling using HFID:

Fh   is a heated filter,
S_3 is a sampling point close to the mixing chamber,
V_h is a heated multi-way valve,
Q   is a quick connector to allow the ambient air sample BA to be analysed on the HFID,
FID   is a heated flame ionisation analyser,
R and I   are a means of integrating and recording the instantaneous hydrocarbon concentrations,
L_h is a heated sample line.

2.   CALIBRATION PROCEDURES

2.1.   Analyser Calibration Procedure

2.1.1.   Each analyser shall be calibrated as often as necessary and in any case in the month before type approval testing and at least once every six months for verifying conformity of production.

2.1.2.   Each normally used operating range shall be calibrated by the following procedure:

2.1.2.1.   The analyser calibration curve is established by at least five calibration points spaced as uniformly as possible. The nominal concentration of the calibration gas of the highest concentration shall be not less than 80 per cent of the full scale.

2.1.2.2.   The calibration gas concentration required may be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device shall be such that the concentrations of the diluted calibration gases may be determined to within ±2 per cent.

2.1.2.3.   The calibration curve is calculated by the least squares method. If the resulting polynomial degree is greater than 3, the number of calibration points shall be at least equal to this polynomial degree plus 2.

2.1.2.4.   The calibration curve shall not differ by more than ± 2 per cent from the nominal value of each calibration gas.

2.1.3.   Trace of the calibration curve

From the trace of the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser shall be indicated, particularly:
              The scale;
              The sensitivity;
              The zero point;
              The date of carrying out the calibration.

2.1.4.   If it can be shown to the satisfaction of the technical service that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.

2.2.   Analyser Verification Procedure

2.2.1.   Each normally used operating range shall be checked prior to each analysis in accordance with the following:

2.2.2.   The calibration shall be checked by use of a zero gas and by use of a span gas that has a nominal value within 80-95 per cent of the supposed value to be analysed.

2.2.3.   If, for the two points considered, the value found does not differ by more than ± 5 per cent of the full scale from the theoretical value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with paragraph 1. of this appendix.

2.2.4.   After testing, zero gas and the same span gas are used for re-checking. The analysis is considered acceptable if the difference between the two measuring results is less than 2 per cent.

2.3.   FID Hydrocarbon Response Check Procedure

2.3.1.   Detector response optimisation

The FID shall be adjusted, as specified by the instrument manufacturer. Propane in air should be used, to optimise the response, on the most common operating range.

2.3.2.   Calibration of the HC analyser

The analyser should be calibrated using propane in air and purified synthetic air (see paragraph 3 of this appendix).

Establish a calibration curve as described in paragraph 2.1. of this appendix.

2.3.3.   Response factors of different hydrocarbons and recommended limits

The response factor (Rf), for a particular hydrocarbon species is the ratio of the FID C_1 reading to the gas cylinder concentration, expressed as ppm C_1.

The concentration of the test gas shall be at a level to give a response of approximately 80 per cent of full-scale deflection, for the operating range. The concentration shall be known, to an accuracy of ± 2 per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be pre-conditioned for 24 hours at a temperature between 293 K and 303 K (20 and 30 °C).

Response factors should be determined when introducing an analyser into service and thereafter at major service intervals. The test gases to be used and the recommended response factors are:

Methane and purified air: $1.00 < Rf < 1.15$

or $1.00 < Rf < 1.05$ for NG fuelled vehicles

Propylene and purified air: $0.90 < Rf < 1.00$

Toluene and purified air: $0.90 < Rf < 1.00$

These are relative to a response factor (Rf) of 1.00 for propane and purified air.

2.3.4.   Oxygen interference check and recommended limits

The response factor shall be determined as described in paragraph 2.3.3. above. The test gas to be used and recommended response factor range is:

Propane and nitrogen: $0.95 < Rf < 1.05$

2.4. NO_x Converter Efficiency Test Procedure

The efficiency of the converter used for the conversion of NO_2 into NO is tested as follows:

Using the test set up as shown in Figure 11 and the procedure described below, the efficiency of converters can be tested by means of an ozonator.

2.4.1.   Calibrate the analyzer in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which shall amount to about 80 per cent of the operating range and the NO_2 concentration of the gas mixture shall be less than 5 per cent of the NO concentration). The NO_x analyser

shall be in the NO mode so that the span gas does not pass through the converter. Record the indicated concentration.

2.4.2.   Via a T-fitting, oxygen or synthetic air is added continuously to the span gas flow until the concentration indicated is about 10 per cent less than the indicated calibration concentration given in paragraph 2.4.1. above. Record the indicated concentration (C). The ozonator is kept deactivated throughout this process.

2.4.3.   The ozonator is now activated to generate enough ozone to bring the NO concentration down to 20 per cent (minimum 10 per cent) of the calibration concentration given in paragraph 2.4.1. above. Record the indicated concentration (d).

2.4.4.   The NO_x analyser is then switched to the NO_x mode, which means that the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. Record the indicated concentration (a).

2.4.5.   The ozonator is now deactivated. The mixture of gases described in paragraph 2.4.2. above passes through the converter into the detector. Record the indicated concentration (b).

Figure 11: NOx Converter Efficiency Test Configuration
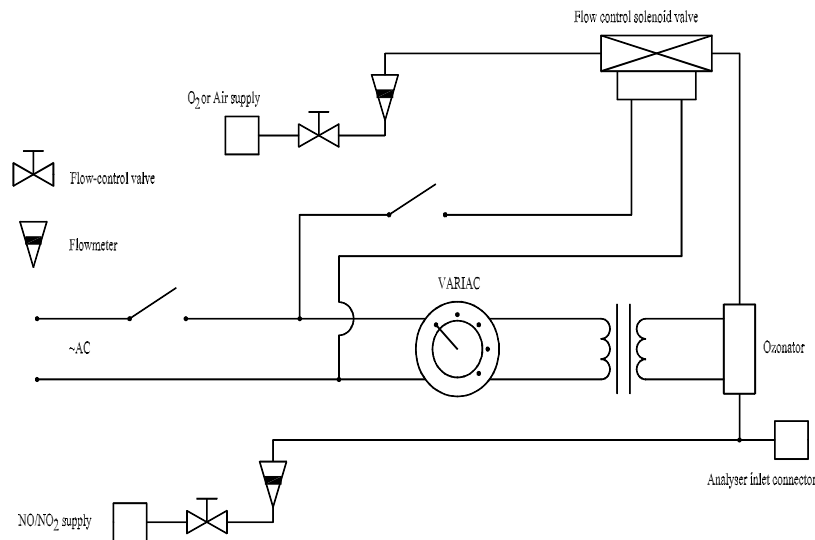
2.4.6.   With the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO_2 reading of the analyser shall then be no more than 5 per cent above the figure given in paragraph 2.4.1. above.

2.4.7.   The efficiency of the NO_x converter is calculated as follows:

$$\text{Efficiency} \quad (\text{per cent}) = \left(1 + \frac{a-b}{c-d}\right) \cdot 100$$

2.4.8.   The efficiency of the converter shall not be less than 95 per cent.

2.4.9.   The efficiency of the converter shall be tested at least once a week.

3.   REFERENCE GASES

3.1.   Pure gases

The following pure gases shall be available, if necessary, for calibration and operation:

Purified nitrogen: (purity: $\leq$1 ppm C, $\leq$1 ppm CO, $\leq$400 ppm CO_2, $\leq$0.1 ppm NO);

Purified synthetic air: (purity: $\leq$1 ppm C, $\leq$1 ppm CO, $\leq$400 ppm CO_2, $\leq$0.1 ppm NO); oxygen content between 18 and 21 per cent volume;

Purified oxygen: (purity > 99.5 per cent vol. O_2);

Purified hydrogen (and mixture containing helium): (purity $\leq$1 ppm C, $\leq$400 ppm CO_2);

Carbon monoxide: (minimum purity 99.5 per cent);

Propane: (minimum purity 99.5 per cent).

3.2.   Calibration and span gases

Mixtures of gases having the following chemical compositions shall be available:
(a) C_3H_8 and purified synthetic air (see paragraph 3.1. above);
(b)   CO and purified nitrogen;
(c) CO_2 and purified nitrogen.

NO and purified nitrogen (the amount of NO_2 contained in this calibration gas shall not exceed 5 per cent of the NO content).

The true concentration of a calibration gas shall be within $\pm$ 2 per cent of the stated figure.

Appendix 4

PARTICULATE MASS EMISSIONS MEASUREMENT EQUIPMENT

1.   SPECIFICATION

1.1.   System Overview

1.1.1.   The particulate sampling unit shall consist of a sampling probe located in the dilution tunnel, a particle transfer tube, a filter holder, a partial-flow pump, and flow rate regulators and measuring units.

1.1.2.   It is recommended that a particle size pre-classifier (e.g. cyclone or impactor) be employed upstream of the filter holder. However, a sampling probe, acting as an appropriate size-classification device such as that shown in Figure 13, is acceptable.

1.2.   General Requirements

1.2.1.   The sampling probe for the test gas flow for particulates shall be so arranged within the dilution tract that a representative sample gas flow can be taken from the homogeneous air/exhaust mixture.

1.2.2.   The particulate sample flow rate shall be proportional to the total flow of diluted exhaust gas in the dilution tunnel to within a tolerance of ± 5 per cent of the particulate sample flow rate.

1.2.3.   The sampled dilute exhaust gas shall be maintained at a temperature below 325 K (52 °C) within 20 cm upstream or downstream of the particulate filter face, except in the case of a regeneration test where the temperature must be below 192 °C.

1.2.4.   The particulate sample shall be collected on a single filter mounted within a holder in the sampled dilute exhaust gas flow.

1.2.5.   All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition or alteration of the particulates. 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.

1.2.6.   If it is not possible to compensate for variations in the flow rate, provision shall be made for a heat exchanger and a temperature control device as specified in Appendix 2 so as to ensure that the flow rate in the system is constant and the sampling rate accordingly proportional.

1.3.   Specific Requirements

1.3.1.   PM Sampling Probe

1.3.1.1.   The sample probe shall deliver the particle-size classification performance described in paragraph 1.3.1.4. It is recommended that this performance be achieved by the use of a sharp-edged, open-ended probe facing directly into the direction of flow plus a pre-classifier (cyclone impactor, etc.). An appropriate sampling probe, such as that indicated in Figure 13, may alternatively be used provided it achieves the pre-classification performance described in paragraph 1.3.1.4.

1.3.1.2.   The sample probe shall be installed near the tunnel centreline, between 10 and 20 tunnel diameters downstream of the exhaust gas inlet to the tunnel and have an internal diameter of at least 12 mm.

            If more than one simultaneous sample is drawn from a single sample probe, the flow drawn from that probe shall be split into identical sub-flows to avoid sampling artefacts.

            If multiple probes are used, each probe shall be sharp-edged, open-ended and facing directly into the direction of flow. Probes shall be equally spaced around the central longitudinal axis of the dilution tunnel, with the spacing between probes at least 5 cm.

1.3.1.3.   The distance from the sampling tip to the filter mount shall be at least five probe diameters, but shall not exceed 1,020 mm.

1.3.1.4.   The pre-classifier (e.g. cyclone, impactor, etc.) shall be located upstream of the filter holder assembly. 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 particulate mass 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 particulate mass emissions. However, a sampling probe, acting as an appropriate size-classification device, such as that shown in Figure 13, is acceptable as an alternative to a separate pre-classifier.

1.3.2.   Sample Pump and Flow Meter

1.3.2.1.   The sample gas flow measurement unit shall consist of pumps, gas flow regulators and flow measuring units.

1.3.2.2.   The temperature of the gas flow in the flow meter may not fluctuate by more than ± 3 K, except during regeneration tests on vehicles equipped with periodically regenerating aftertreatment devices. In addition, the sample mass flow rate must remain proportional to the total flow of diluted exhaust gas to within a tolerance of ± 5 per cent of the particulate sample mass flow rate. Should the volume of flow

change unacceptably as a result of excessive filter loading, the test shall be stopped. When it is repeated, the rate of flow shall be decreased.

1.3.3.   Filter and Filter Holder

1.3.3.1.   A valve shall be located downstream of the filter in the direction of flow. The valve shall be quick enough acting to open and close within 1 s of the start and end of test.

1.3.3.2.   It is recommended that the mass collected on the 47 mm diameter filter (P_e) is ≥ 20 µg and that the filter loading should be maximized consistent with the requirements of paragraphs 1.2.3. and 1.3.3.

1.3.3.3.   For a given test the gas filter face velocity shall be set to a single value within the range 20 cm/s to 80 cm/s unless the dilution system is being operated with sampling flow proportional to CVS flow rate.

1.3.3.4.   Fluorocarbon coated glass fibre filters or fluorocarbon membrane filters are required. All filter types shall have a 0.3 µm DOP (di-octylphthalate) collection efficiency of at least 99 per cent at a gas filter face velocity of at least 35 cm/s.

1.3.3.5.   The filter holder assembly shall be of a design that provides an even flow distribution across the filter stain area. The filter stain area shall be at least 1075 mm^2.

1.3.4.   Filter Weighing Chamber and Balance

1.3.4.1.   The microgram balance used to determine the weight of a filter shall have a precision (standard deviation) of 2 µg and resolution of 1 µg or better.

It is recommended that the microbalance be checked at the start of each weighing session by weighing one reference weight of 50 mg. This weight shall be weighed three times and the average result recorded. If the average result of the weighings is ±5 µg of the result from the previous weighing session then the weighing session and balance are considered valid.

The weighing chamber (or room) shall meet the following conditions during all filter conditioning and weighing operations:

Temperature maintained at 295 ± 3 K (22 ± 3 °C);

Relative humidity maintained at 45 ± 8 per cent;

Dewpoint maintained at 9.5 °C ± 3 °C.

It is recommended that temperature and humidity conditions are recorded along with sample and reference filter weights.

1.3.4.2.   Buoyancy Correction

All filter weights shall be corrected for filter buoyancy in air.

The buoyancy correction depends on the density of the sample filter medium, the density of air, and the density of the calibration weight used to calibrate the balance. The density of the air is dependent on the pressure, temperature and humidity.

It is recommended that the temperature and dewpoint of the weighing environment are controlled to 22 °C ± 1 °C and dewpoint of 9.5 °C ± 1 °C respectively. However, the minimum requirements stated in paragraph 1.3.4.1. will also result in an acceptable correction for buoyancy effects. The correction for buoyancy shall be applied as follows

$$m_{corr} = m_{uncorr} \bullet (1 - ((\rho_{air})/(\rho_{weight})))/(1 - ((\rho_{air})/(\rho_{media})))$$

where:

m_{corr} =   PM mass corrected for buoyancy
m_{uncorr} =   PM mass uncorrected for buoyancy
ρ_{air} =   density of air in balance environment
ρ_{weight} =   density of calibration weight used to span balance
ρ_{media} =   density of PM sample medium (filter) according to the table below:

Filter Medium	ρ_{media}
Teflon coated glass fibre (e.g. TX40)	2300 kg/m^3

ρ_{air} can be calculated as follows:

$$\rho_{air} = \frac{P_{abs} \cdot M_{mix}}{R \cdot T_{amb}}$$

where:

P_{abs} =   absolute pressure in balance environment
M_{mix} =   molar mass of air in balance environment (28.836 gmol^{-1})
R =   molar gas constant (8.314 Jmol^{-1}K^{-1})
T_{amb} =   absolute ambient temperature of balance environment.

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilisation.

Limited deviations from weighing room temperature and humidity specifications will be allowed provided their total duration does not exceed 30 minutes in any one filter conditioning period. The weighing room should meet the required specifications

prior to personal entrance into the weighing room. During the weighing operation no deviations from the specified conditions are permitted.

1.3.4.3.   The effects of static electricity shall be nullified. This may be achieved by grounding the balance through placement upon an antistatic mat and neutralisation of the particulate filters prior to weighing using a Polonium neutraliser or a device of similar effect. Alternatively nullification of static effects may be achieved through equalisation of the static charge.

1.3.4.4.   A test filter shall be removed from the chamber no earlier than an hour before the test begins.

1.4.   Recommended System Description

Figure 12 is a schematic drawing of the recommended particulate sampling system. Since various configurations can produce equivalent results, exact conformance with this figure is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and co-ordinate the functions of component systems. Further components that are not needed to maintain accuracy with other system configurations may be excluded if their exclusion is based upon good engineering judgement.

Figure 12: Particulate Sampling System
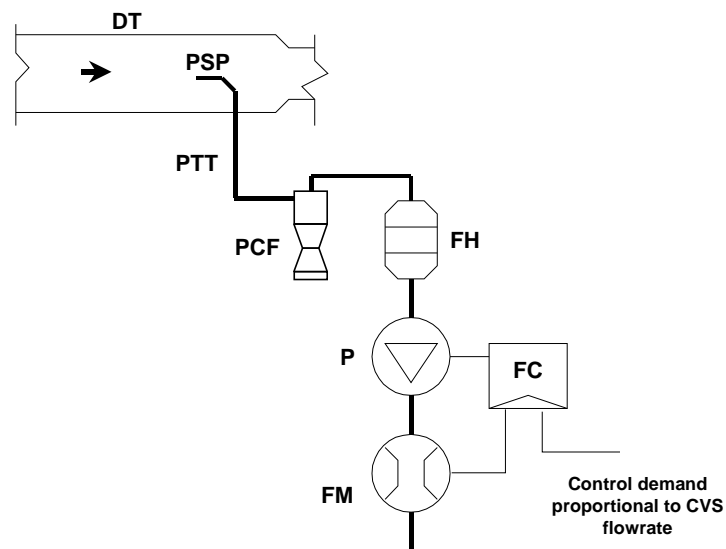
A sample of the diluted exhaust gas is taken from the full flow dilution tunnel DT through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the pump P. The sample is passed through the particle size pre-classifier PCF and the filter holder(s) FH that contain the particulate sampling filter(s). The flow rate for sampling is set by the flow controller FC.

2.   CALIBRATION AND VERIFICATION PROCEDURES

2.1.   Flow Meter Calibration

The Technical Service shall ensure the existence of a calibration certificate for the flow meter demonstrating compliance with a traceable standard within a 12 month period prior to the test, or since any repair or change which could influence calibration.

2.2.   Microbalance Calibration

The Technical Service shall ensure the existence of a calibration certificate for the microbalance demonstrating compliance with a traceable standard within a 12 months period prior to the test.

2.3.   Reference Filter Weighing

To determine the specific reference filter weights, at least two unused reference filters shall be weighed within 8 hours of, but preferably at the same time as, the sample filter weighings. Reference filters shall be of the same size and material as the sample filter.

If the specific weight of any reference filter changes by more than ±5µg between sample filter weighings, then the sample filter and reference filters shall be reconditioned in the weighing room and then reweighed.

The comparison of reference filter weighings shall be made between the specific weights and the rolling average of that reference filter's specific weights.

The rolling average shall be calculated from the specific weights collected in the period since the reference filters were placed in the weighing room. The averaging period shall be at least 1 day but not exceed 30 days.

Multiple reconditionings and reweighings of the sample and reference filters are permitted until a period of 80 h has elapsed following the measurement of gases from the emissions test.

If, prior to or at the 80 h point, more than half the number of reference filters meet the ±5 µg criterion, then the sample filter weighing can be considered valid.

If, at the 80 h point, two reference filters are employed and one filter fails the ±5 µg criterion, the sample filter weighing can be considered valid under the condition that the sum of the absolute differences between specific and rolling averages from the two reference filters must be less than or equal to 10 µg.

In case less than half of the reference filters meet the ± 5 µg criterion the sample filter shall be discarded, and the emissions test repeated. All reference filters must be discarded and replaced within 48 hours.

In all other cases, reference filters must be replaced at least every 30 days and in such a manner that no sample filter is weighed without comparison to a reference filter that has been present in the weighing room for at least 1 day.

If the weighing room stability criteria outlined in paragraph 1.3.4. are not met, but the reference filter weighings meet the above criteria, the vehicle manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

Figure 13: Particulate sampling probe configuration
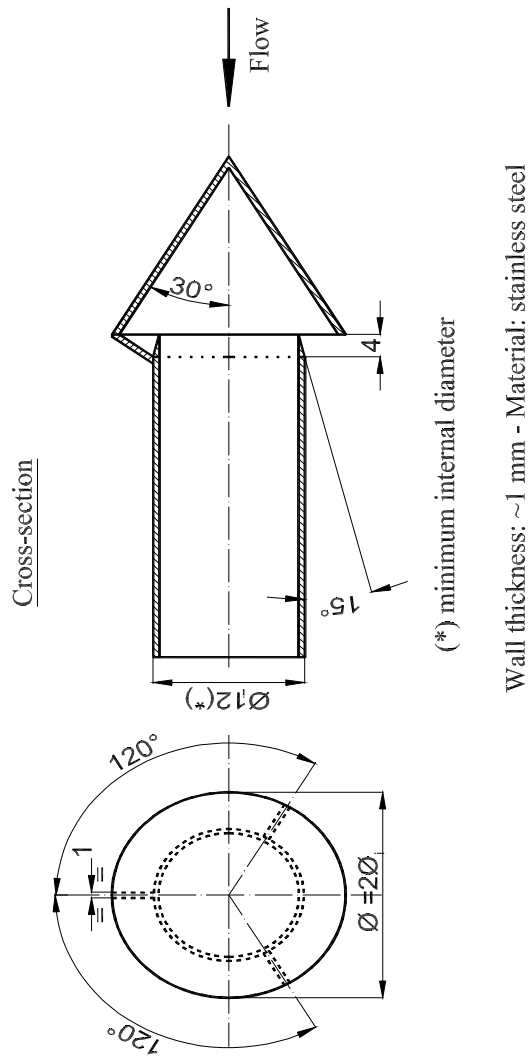
Appendix 5

PARTICLE NUMBER EMISSIONS MEASUREMENT EQUIPMENT

1.   SPECIFICATION

1.1.   System Overview

1.1.1.   The particle sampling system shall consist of a dilution tunnel, a sampling probe and a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing.

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 Figure 13, is an acceptable alternative to the use of a particle size pre-classifier.

1.2.   General Requirements

1.2.1.   The particle sampling point shall be located within a dilution tunnel.

The sampling probe tip (PSP) 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:

It 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.

It shall have an internal diameter of ≥ 8 mm.

Sample gas drawn through the PTS shall meet the following conditions:

It shall have a flow Reynolds number (Re) of < 1700;

It shall have a residence time in the PTS of ≤ 3 seconds.

Any other sampling configuration for the PTS for which equivalent particle penetration at 30 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 ≥ 4mm;

Sample Gas flow through the OT shall have a residence time of ≤ 0.8 seconds.

Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

1.2.2.   The VPR shall include devices for sample dilution and for volatile particle removal. The sampling probe for the test gas flow shall be so arranged within the dilution tract that a representative sample gas flow is taken from a homogeneous air/exhaust mixture.

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 minimise 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.

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-section, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Gradual changes in the cross-section are permissible.

1.3.   Specific Requirements

1.3.1.   The particle sample shall not pass through a pump before passing through the PNC.

1.3.2.   A sample pre-classifier is recommended.

1.3.3.   The sample preconditioning unit shall:

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;

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;

1.3.3.3.   Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in paragraph 2.2.2., 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;

1.3.3.4.   Also achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of $\geq 10,000$ cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane.

1.3.4.   The PNC shall:

1.3.4.1.   Operate under full flow operating conditions;

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;

1.3.4.3.   Have a readability of at least 0.1 particles cm^{-3} at concentrations below 100 cm^{-3};

1.3.4.4.   Have a linear response to particle concentrations over the full measurement range in single particle count mode;

1.3.4.5.   Have a data reporting frequency equal to or greater than 0.5 Hz;

1.3.4.6.   Have a T90 response time over the measured concentration range of less than 5 s;

1.3.4.7.   Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an internal calibration factor as determined in paragraph 2.1.3., but shall not make use of any other algorithm to correct for or define the counting efficiency;

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;

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.

1.3.5   The sum of the residence time of the PTS, VPR and OT plus the T90 response time of the PNC shall be no greater than 20 s.

1.4.   Recommended System Description

            The following section contains the recommended practice for measurement of particle number. However, any system meeting the performance specifications in paragraphs 1.2. and 1.3. is acceptable.

            Figure 14 is a schematic drawing of the recommended particle sampling system.

Figure 14: Schematic of Recommended Particle Sampling System

1.4.1.   Sampling System Description

The particle sampling system shall consist of a sampling probe tip in the dilution tunnel (PSP), 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 for the test gas flow shall be so arranged within the dilution tra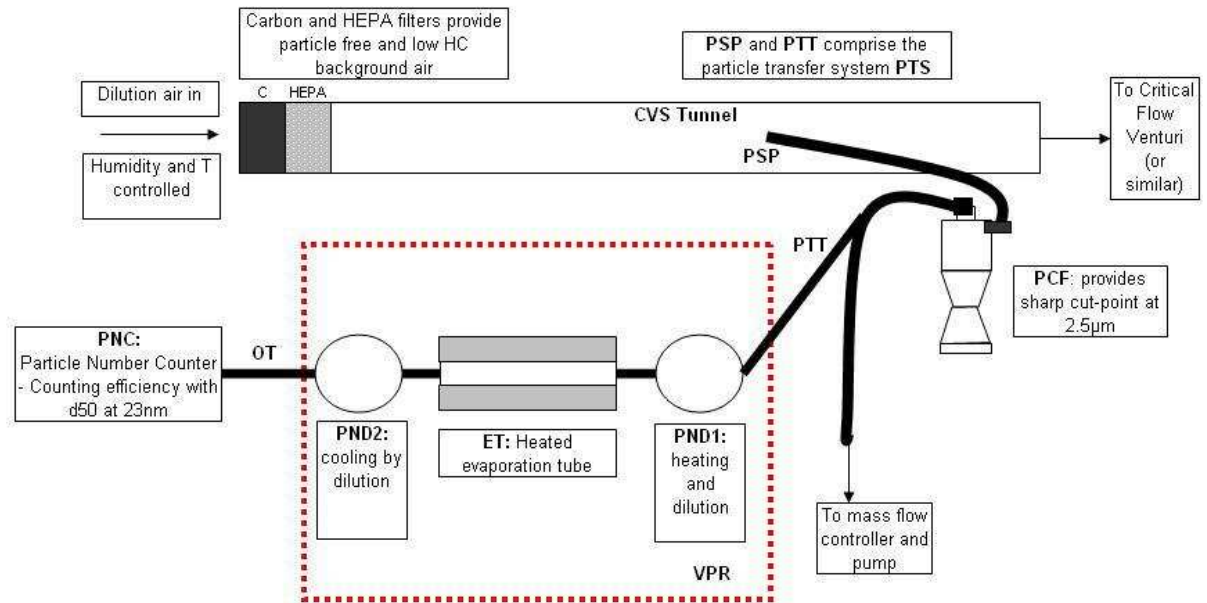ct that a representative sample gas flow is taken from a homogeneous air/exhaust mixture.   The sum of the residence time of the system plus the T90 response time of the PNC shall be no greater than 20 s.

1.4.2.   Particle Transfer System

The sampling probe tip (PSP) and particle transfer tube (PTT) together comprise the particle transfer system (PTS).   The PTS conducts the sample from the dilution tunnel to the entrance to the first particle number diluter.   The PTS shall meet the following conditions:

It 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.

It shall have an internal diameter of ≥ 8mm.

Sample gas drawn through the PTS shall meet the following conditions:

It shall have a flow Reynolds number (Re) of < 1700;

It shall have a residence time in the PTS of ≤ 3 seconds.

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.

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 seconds.

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.

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.

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 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 no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole.

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 - 400 °C. The wall temperature setpoint should not exceed the wall temperature of the ET (paragraph 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.

1.4.4.2. Evaporation Tube

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 value between 300 °C and 400 °C.

1.4.4.3. Second Particle Number Dilution Device (PND$_2$)

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 to the PNC is < 35 °C.

1.4.5. Particle Number Counter (PNC)

The PNC shall meet the requirements of paragraph 1.3.4.

2. CALIBRATION/VALIDATION OF THE PARTICLE SAMPLING SYSTEM [1]/

2.1. Calibration of the Particle Number Counter

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.

2.1.2 The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

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[1]/ Example calibration/validation methods are available at
http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmp19.html

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 1822:1998 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 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).

          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 1822:1998 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).

2.1.4   Calibration shall also include a check, against the requirements in paragraph 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.

2.2.   Calibration/Validation of the Volatile Particle Remover

2.2.1.   Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument manufacturer's recommended 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.

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.

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.

The particle concentration reduction factor at each particle size ($f_r(d_i)$) shall be calculated as follows;

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

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).

The mean particle concentration reduction ($\overline{f_r}$) at a given dilution setting shall be calculated as follows;

$$\overline{f_r} = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3}$$

It is recommended that the VPR is calibrated and validated as a complete unit.

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 $\geq$ 10,000 cm^{-3} when operated at its minimum dilution setting and manufacturers recommended operating temperature.

2.3.   Particle Number System Check Procedures

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 1822:1998 is attached to the inlet of the entire particle sampling system (VPR and PNC).

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.

2.3.3.   Each day, following the application of a HEPA filter of at least class H13 of EN 1822:1998 to the inlet of the particle counter, the particle counter shall report a concentration of $\leq$ 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 $\leq$ 0.2 cm^{-3} on replacement of the HEPA filter.

2.3.4.   The evaporation tube shall indicate a reading of 300 °C to 400 °C.

2.3.5.   The diluter PND_1 shall indicate a wall temperature reading of 150 °C - 400 °C but less than or equal to the set-point of the evaporation tube.

Appendix 6

VERIFICATION OF SIMULATED INERTIA

1.   OBJECT

The method described in this appendix makes it possible to check that the simulated total inertia of the dynamometer is carried out satisfactorily in the running phase of the operating cycle. The manufacturer of the dynamometer shall specify a method for verifying the specifications according to paragraph 3. of this appendix.

2.   PRINCIPLE

2.1.   Drawing-up working equations

Since the dynamometer is subjected to variations in the rotating speed of the roller(s), the force at the surface of the roller(s) can be expressed by the formula:

$$F = I \cdot \gamma = I_M \cdot \gamma + F_1$$

where:

F = force at the surface of the roller(s),

I = total inertia of the dynamometer (equivalent inertia of the vehicle: see the table in paragraph 5.1.),

I_M = inertia of the mechanical masses of the dynamometer,

γ = tangential acceleration at roller surface,

F_1 = inertia force.

Note: An explanation of this formula with reference to dynamometers with mechanically simulated inertia is appended.

Thus, total inertia is expressed as follows:

$$I = I_m + F_1 / \gamma$$

where:
I_m can be calculated or measured by traditional methods,
F_1 can be measured on the dynamometer,
γ can be calculated from the peripheral speed of the rollers.

The total inertia (I) will be determined during an acceleration or deceleration test with values higher than or equal to those obtained on an operating cycle.

2.2.   Specification for the calculation of total inertia

The test and calculation methods shall make it possible to determine the total inertia I with a relative error ($\Delta I/I$) of less than ± 2 per cent.

3.   SPECIFICATION

3.1.   The mass of the simulated total inertia I shall remain the same as the theoretical value of the equivalent inertia (see Appendix 1) within the following limits:

3.1.1.   ± 5 per cent of the theoretical value for each instantaneous value;

3.1.2.   ± 2 per cent of the theoretical value for the average value calculated for each sequence of the cycle.

The limit given in paragraph 3.1.1. above is brought to ± 50 per cent for one second when starting and, for vehicles with manual transmission, for two seconds during gear changes.

4.   VERIFICATION PROCEDURE

4.1.   Verification is carried out during each test throughout the cycle defined in paragraph 6.1. of Annex 4a.

4.2.   However, if the requirements of paragraph 3. above are met, with instantaneous accelerations which are at least three times greater or smaller than the values obtained in the sequences of the theoretical cycle, the verification described above will not be necessary.

Appendix 7

MEASUREMENT OF VEHICLE ROAD LOAD

RESISTANCE TO PROGRESS OF A VEHICLE MEASUREMENT METHOD
ON THE ROAD SIMULATION ON A CHASSIS DYNAMOMETER

1.   OBJECT OF THE METHODS

The object of the methods defined below is to measure the resistance to progress of a vehicle at stabilized speeds on the road and to simulate this resistance on a dynamometer, in accordance with the conditions set out in paragraph 6.2.1. of Annex 4a.

2.   DEFINITION OF THE ROAD

The road shall be level and sufficiently long to enable the measurements specified in this appendix to be made. The slope shall be constant to within ± 0.1 per cent and shall not exceed 1.5 per cent.

3.   ATMOSPHERIC CONDITIONS

3.1.   Wind

Testing shall be limited to wind speeds averaging less than 3 m/s with peak speeds of less than 5 m/s. In addition, the vector component of the wind speed across the test road shall be less than 2 m/s. Wind velocity shall be measured 0.7 m above the road surface.

3.2.   Humidity

The road shall be dry.

3.3.   Pressure and Temperature

Air density at the time of the test shall not deviate by more than ±7.5 per cent from the reference conditions, P = 100 kPa and T = 293.2 K.

4.   VEHICLE PREPARATION 1/

4.1.   Selection of the test vehicle

            If not all variants of a vehicle type are measured, the following criteria for the
            selection of the test vehicle shall be used.

4.1.1.   Body

            If there are different types of body, the test shall be performed on the least
            aerodynamic body. The manufacturer shall provide the necessary data for the
            selection.

4.1.2.   Tyres

            The widest tyre shall be chosen. If there are more than three tyre sizes, the widest
            minus one shall be chosen.

4.1.3.   Testing mass

            The testing mass shall be the reference mass of the vehicle with the highest inertia
            range.

4.1.4.   Engine

            The test vehicle shall have the largest heat exchanger(s).

4.1.5.   Transmission

            A test shall be carried out with each type of the following transmission:
                    Front-wheel drive,
                    Rear-wheel drive,
                    Full-time 4 x 4,
                    Part-time 4 x 4,
                    Automatic gearbox,
                    Manual gearbox.

1/   For HEV, and until uniform technical provisions have been established, the manufacturer
will agree with the technical service concerning the status of the vehicle when performing the
test as defined in this appendix.

4.2.   Running-in

      The vehicle shall be in normal running order and adjustment after having been run-in for at least 3,000 km. The tyres shall be run-in at the same time as the vehicle or have a tread depth within 90 and 50 per cent of the initial tread depth.

4.3.   Verifications

      The following checks shall be made in accordance with the manufacturer's specifications for the use considered:
      Wheels, wheel trims, tyres (make, type, pressure), front axle geometry, brake adjustment (elimination of parasitic drag), lubrication of front and rear axles, adjustment of the suspension and vehicle level, etc.

4.4.   Preparation for the test

4.4.1.   The vehicle shall be loaded to its reference mass. The level of the vehicle shall be that obtained when the centre of gravity of the load is situated midway between the "R" points of the front outer seats and on a straight line passing through those points.

4.4.2.   In the case of road tests, the windows of the vehicle shall be closed. Any covers of air climatisation systems, headlamps, etc. shall be in the non-operating position.

4.4.3.   The vehicle shall be clean.

4.4.4.   Immediately prior to the test, the vehicle shall be brought to normal running temperature in an appropriate manner.

5.   METHODS

5.1.   Energy variation during coast-down method

5.1.1.   On the road

5.1.1.1. Test equipment and error

      Time shall be measured to an error lower than $\pm$ 0.1 s.
      Speed shall be measured to an error lower than $\pm$ 2 per cent.

5.1.1.2. Test procedure

5.1.1.2.1. Accelerate the vehicle to a speed 10 km/h greater than the chosen test speed V.

5.1.1.2.2. Place the gearbox in "neutral" position.

5.1.1.2.3. Measure the time taken (t_1) for the vehicle to decelerate from speed

$$V_2 = V + \Delta V \quad km/h \quad to \quad V_1 = V - \Delta V \quad km/h$$

5.1.1.2.4. Perform the same test in the opposite direction: t_2.

5.1.1.2.5. Take the average T of the two times t_1 and t_2.

5.1.1.2.6. Repeat these tests several times such that the statistical accuracy (p) of the average

$$T = \frac{1}{n}\sum_{i=1}^{n} T_i \text{ is not more than 2 per cent} \quad (p \leq 2 \text{ per cent})$$

The statistical accuracy (p) is defined by:

$$p = \left(\frac{t \cdot s}{\sqrt{n}}\right) \cdot \frac{100}{T}$$

where:
  t = coefficient given by the following table,
  n = number of tests,

  s = standard deviation, $s = \sqrt{\sum_{i=1}^{n}\frac{(T_i - T)^2}{n-1}}$

n	4	5	6	7	8	9	10	11	12	13	14	15
t	3.2	2.8	2.6	2.5	2.4	2.3	2.3	2.2	2.2	2.2	2.2	2.2
$\frac{t}{\sqrt{n}}$	1.6	1.25	1.06	0.94	0.85	0.77	0.73	0.66	0.64	0.61	0.59	0.57

5.1.1.2.7. Calculate the power by the formula:
$$P = \frac{M \cdot V \cdot \Delta \cdot V}{500 \cdot T}$$

where:
  P   is expressed in kW,
  V = speed of the test in m/s,
  ΔV = speed deviation from speed V, in m/s as specified in
          paragraph 5.1.1.2.3. of this appendix,
  M = reference mass in kg,
  T = time in seconds (s).

5.1.1.2.8.   The power (P) determined on the track shall be corrected to the reference ambient conditions as follows:

$$P_{Corrected} = K \cdot P_{Measured}$$

$$K = \frac{R_R}{R_T} \cdot \left[1 + K_R\left(t - t_0\right)\right] + \frac{R_{AERO}}{R_T} \cdot \frac{\left(\rho_0\right)}{\rho}$$

where:

R_R	=	rolling resistance at speed V,
R_{AERO}	=	aerodynamic drag at speed V,
R_T	=	total driving resistance = $R_R + R_{AERO}$,
K_R	=	temperature correction factor of rolling resistance, taken to be equal to $8.64 \times 10^{-3}/°C$, or the manufacturer's correction factor that is approved by the authority,
t	=	road test ambient temperature in °C,
t_0	=	reference ambient temperature = 20 °C,
ρ	=	air density at the test conditions,
ρ_0	=	air density at the reference conditions (20 °C, 100 kPa).

The ratios R_R/R_T and R_{AERO}/R_T shall be specified by the vehicle manufacturer based on the data normally available to the company.

If these values are not available, subject to the agreement of the manufacturer and the technical service concerned, the figures for the rolling/ total resistance given by the following formula may be used:

$$\frac{R_R}{R_T} = a \cdot M + b$$

where:

M =   vehicle mass in kg and for each speed the coefficients a and b are shown in the following table:

V (km/h)	a	b
20	$7.24 \cdot 10^{-5}$	0.82
40	$1.59 \cdot 10^{-4}$	0.54
60	$1.96 \cdot 10^{-4}$	0.33
80	$1.85 \cdot 10^{-4}$	0.23
100	$1.63 \cdot 10^{-4}$	0.18
120	$1.57 \cdot 10^{-4}$	0.14

5.1.2.   On the dynamometer

5.1.2.1.   Measurement equipment and accuracy

The equipment shall be identical to that used on the road.

5.1.2.2.   Test procedure

5.1.2.2.1.   Install the vehicle on the test dynamometer.

5.1.2.2.2.   Adjust the tyre pressure (cold) of the driving wheels as required by the dynamometer.

5.1.2.2.3.   Adjust the equivalent inertia of the dynamometer.

5.1.2.2.4.   Bring the vehicle and dynamometer to operating temperature in a suitable manner.

5.1.2.2.5.   Carry out the operations specified in paragraph 5.1.1.2. above (with the exception of paragraphs 5.1.1.2.4. and 5.1.1.2.5.), replacing M by I in the formula set out in paragraph 5.1.1.2.7.

5.1.2.2.6.   Adjust the brake to reproduce the corrected power (paragraph 5.1.1.2.8.) and to take into account the difference between the vehicle mass (M) on the track and the equivalent inertia test mass (I) to be used. This may be done by calculating the mean corrected road coast down time from V_2 to V_1 and reproducing the same time on the dynamometer by the following relationship:

$$T_{corrected} = \frac{T_{measured}}{K} \cdot \frac{I}{M}$$

K = value specified in paragraph 5.1.1.2.8. above.

5.1.2.2.7.   The power P_a to be absorbed by the dynamometer shall be determined in order to enable the same power (paragraph 5.1.1.2.8.) to be reproduced for the same vehicle on different days.

5.2.   Torque measurements method at constant speed

5.2.1.   On the road

5.2.1.1.   Measurement equipment and error

Torque measurement shall be carried out with an appropriate measuring device accurate to within ±2 per cent.

Speed measurement shall be accurate to within ±2 per cent.

5.2.1.2.   Test procedure

5.2.1.2.1.   Bring the vehicle to the chosen stabilized speed V.

5.2.1.2.2. Record the torque C_t and speed over a period of at least 20 seconds. The accuracy of the data recording system shall be at least ± 1 Nm for the torque and ± 0.2 km/h for the speed.

5.2.1.2.3. Differences in torque C_t and speed relative to time shall not exceed 5 per cent for each second of the measurement period.

5.2.1.2.4. The torque C_{t1} is the average torque derived from the following formula:

$$C_{t1} = \frac{1}{\Delta t} \int_{t}^{t+\Delta t} C(t) dt$$

5.2.1.2.5. The test shall be carried out three times in each direction. Determine the average torque from these six measurements for the reference speed. If the average speed deviates by more than 1 km/h from the reference speed, a linear regression shall be used for calculating the average torque.

5.2.1.2.6. Determine the average of these two torques C_{t1} and C_{t2}, i.e. C_t.

5.2.1.2.7. The average torque C_T determined on the track shall be corrected to the reference ambient conditions as follows:

$$C_{Tcorrected} = K \cdot C_{Tmeasured}$$

where K has the value specified in paragraph 5.1.1.2.8. of this appendix.

5.2.2. On the dynamometer

5.2.2.1. Measurement equipment and error

The equipment shall be identical to that used on the road.

5.2.2.2. Test procedure

5.2.2.2.1. Perform the operations specified in paragraphs 5.1.2.2.1. to 5.1.2.2.4. above.

5.2.2.2.2. Perform the operations specified in paragraphs 5.2.1.2.1. to 5.2.1.2.4. above.

5.2.2.2.3. Adjust the power absorption unit to reproduce the corrected total track torque indicated in paragraph 5.2.1.2.7. above.

5.2.2.2.4. Proceed with the same operations as in paragraph 5.1.2.2.7., for the same purpose.

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