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Delegations will find attached document C(2016) 8381 final ANNEX 7.

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ANNEX 7

ANNEX

to the

Commission Delegated Regulation (EU) .../...

supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to technical and general requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery

ANNEX VII

Method for data evaluation and calculation

1. General requirements

Calculation of emissions shall be performed according to either section 2. (mass based calculations) or section 3. (molar based calculations). Mixture between the two methods is not permitted. It shall not be required to perform the calculations according to both section 2. and section 3..

The specific requirements for particle number (PN) measurement, where applicable, are laid down in Appendix 5.

1.1. General symbols

Section 2.	*Section 3.*	*Unit*	*Quantity*
	A	m²	Area
	A_t	m²	Venturi throat cross-sectional area
b, D_0	a_0	t.b.d.[3]	y intercept of the regression line
A/F_{st}		-	Stoichiometric air to fuel ratio
	C	-	Coefficient
C_d	C_d	-	Discharge coefficient
	C_f	-	Flow coefficient
c	x	ppm, % vol	Concentration/mole fraction (µmol/mol = ppm)
c_d	[1]	ppm, % vol	Concentration on dry basis
c_w	[1]	ppm, % vol	Concentration on wet basis
c_b	[1]	ppm, % vol	Background concentration
D	x_{dil}	-	Dilution factor(2)
D_0		m³/rev	PDP calibration intercept
d	d	m	Diameter
d_V		m	Throat diameter of venturi
e	e	g/kWh	Brake specific basis
e_{gas}	e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	e_{PM}	g/kWh	Specific emission of particulates

Section 2.	*Section 3.*	*Unit*	*Quantity*
E	$1 - PF$	%	Conversion efficiency (PF = Penetration fraction)
F_s		-	Stoichiometric factor
	f	Hz	Frequency
f_c		-	Carbon factor
	γ	-	Ratio of specific heats
H		g/kg	Absolute humidity
	K	-	Correction factor
K_V		$[(\sqrt{\mathrm{K}} \cdot \mathrm{m}^4 \cdot \mathrm{s})/$	CFV calibration function
k_f		m^3/kg fuel	Fuel specific factor
k_h		-	Humidity correction factor for NO_x, diesel engines
k_{Dr}	k_{Dr}	-	Downward adjustment factor
k_r	k_r	-	Multiplicative regeneration factor
k_{Ur}	k_{Ur}	-	Upward adjustment factor
$k_{w,a}$		-	Dry to wet correction factor for the intake air
$k_{w,d}$		-	Dry to wet correction factor for the dilution air
$k_{w,e}$		-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$		-	Dry to wet correction factor for the raw exhaust gas
μ	μ	kg/(m·s)	Dynamic viscosity
M	M	g/mol	Molar mass(3)
M_a	1	g/mol	Molar mass of the intake air
M_e	v	g/mol	Molar mass of the exhaust gas
M_{gas}	M_{gas}	g/mol	Molar mass of gaseous components
m	m	kg	Mass
m	a_1	t.b.d.[3]	Slope of the regression line
	v	m^2/s	Kinematic viscosity
m_d	v	kg	Mass of the dilution air sample passed through the particulate sampling filters
m_{ed}	1	kg	Total diluted exhaust gas mass over the cycle

Section 2.	*Section 3.*	*Unit*	*Quantity*
m_edf	[1]	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_ew	[1]	kg	Total exhaust gas mass over the cycle
m_f	[1]	mg	Particulate sample mass collected
$m_\mathrm{f,d}$	[1]	mg	Particulate sample mass of the dilution air collected
m_gas	m_gas	g	Mass of gaseous emissions over the test cycle
m_PM	m_PM	g	Mass of particulate emissions over the test cycle
m_se	[1]	kg	Exhaust gas sample mass over the test cycle
m_sed	[1]	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_sep	[1]	kg	Mass of diluted exhaust gas passing the particulate collection filters
m_ssd		kg	Mass of secondary dilution air
	N	-	Total number of a series
	n	mol	Amount of substance
	$\dot{n}$	mol/s	Amount of substance rate
n	f_n	min^{-1}	Engine rotational speed
n_p		r/s	PDP pump speed
P	P	kW	Power
p	p	kPa	Pressure
p_a		kPa	Dry atmospheric pressure
p_b		kPa	Total atmospheric pressure
p_d		kPa	Saturation vapour pressure of the dilution air
p_p	p_abs	kPa	Absolute pressure
p_r	p_H2O	kPa	Water vapour pressure
p_s		kPa	Dry atmospheric pressure
$1 - E$	PF	%	Penetration fraction
q_m	$\dot{m}$	kg/s	Mass rate
$q_{m\mathrm{ad}}$	$\dot{m}$ [1]	kg/s	Intake air mass flow rate on dry basis
$q_{m\mathrm{aw}}$	[1]	kg/s	Intake air mass flow rate on wet basis

Section 2.	*Section 3.*	*Unit*	*Quantity*
$q_{m\mathrm{Ce}}$	[1]	kg/s	Carbon mass flow rate in the raw exhaust gas
$q_{m\mathrm{Cf}}$	[1]	kg/s	Carbon mass flow rate into the engine
$q_{m\mathrm{Cp}}$	[1]	kg/s	Carbon mass flow rate in the partial flow dilution system
$q_{m\mathrm{dew}}$	[1]	kg/s	Diluted exhaust gas mass flow rate on wet basis
$q_{m\mathrm{dw}}$	[1]	kg/s	Dilution air mass flow rate on wet basis
$q_{m\mathrm{edf}}$	[1]	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
$q_{m\mathrm{ew}}$	[1]	kg/s	Exhaust gas mass flow rate on wet basis
$q_{m\mathrm{ex}}$	[1]	kg/s	Sample mass flow rate extracted from dilution tunnel
$q_{m\mathrm{f}}$	[1]	kg/s	Fuel mass flow rate
$q_{m\mathrm{p}}$	[1]	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_V	$\dot{V}$	m^3/s	Volume flow rate
$q_{V\mathrm{CVS}}$	[1]	m^3/s	CVS volume rate
$q_{V\mathrm{s}}$	[1]	$\mathrm{dm}^3/\mathrm{min}$	System flow rate of exhaust gas analyzer system
$q_{V\mathrm{t}}$	[1]	$\mathrm{cm}^3/\mathrm{min}$	Tracer gas flow rate
ρ	ρ	$\mathrm{kg/m}^3$	Mass density
ρ_e		$\mathrm{kg/m}^3$	Exhaust gas density
	r	-	Ratio of pressures
r_d	DR	-	Dilution ratio[2]
	Ra	µm	Average surface roughness
RH		%	Relative humidity
r_D	β	m/m	Ratio of diameters (CVS systems)
r_p		-	Pressure ratio of SSV
Re	$Re^{\#}$	-	Reynolds number
	S	K	Sutherland constant
σ	σ	-	Standard deviation
T	T	°C	Temperature
	T	Nm	Engine torque

Section 2.	*Section 3.*	*Unit*	*Quantity*
T_a		K	Absolute temperature
t	t	s	Time
Δt	Δt	s	Time interval
u		-	Ratio between densities of gas component and exhaust gas
V	V	m^3	Volume
q_V	$\dot{V}$	m^3/s	Volume rate
V_0		m^3/r	PDP gas volume pumped per revolution
W	W	kWh	Work
W_{act}	W_{act}	kWh	Actual cycle work of the test cycle
WF	WF	-	Weighting factor
w	w	g/g	Mass fraction
	$\bar{x}$	mol/mol	Flow-weighted mean concentration
X_0	K_s	s/rev	PDP calibration function
	y	-	Generic variable
$\bar{y}$	$\bar{y}$		Arithmetic mean
	Z	-	Compressibility factor

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1 See subscripts; e.g.: $\dot{m}_{air}$ for mass rate of dry air, $\dot{m}_{fuel}$ for fuel mass rate, etc.

2 Dilution ratio r_d in section 2. and DR in section 3.: different symbols but same meaning and same equations. Dilution factor D in section 2. and x_{dil} in section 3.: different symbols but same physical meaning; equation (A.7-47) (7-124) shows the relationship between x_{dil} and DR.

3 t.b.d.= to be defined

1.2. Subscripts

Section 2.[1]	Section 3.	Quantity
act	act	Actual quantity
i		Instantaneous measurement (e.g.: 1 Hz)
	i	An individual of a series

(1) In section 2. the meaning of subscript is determined by the associated quantity; for example, the subscript "d" can indicate a dry basis as in "c_d = concentration on dry basis", dilution air as in "p_d = saturation vapour pressure of the dilution air" or "$k_\mathrm{w,d}$ = dry to wet correction factor for the dilution air", dilution ratio as in "r_d".

1.3. Symbols and abbreviations for the chemical components (used also as a subscript)

Section 2.	Section 3.	Quantity
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH_4	CH_4	Methane
C_2H_6	C_2H_6	Ethane
C_3H_8	C_3H_8	Propane
CO	CO	Carbon monoxide
CO_2	CO_2	Carbon dioxide
	H	Atomic hydrogen
	H_2	Molecular hydrogen
HC	HC	Hydrocarbon
H_2O	H_2O	Water
	He	Helium
	N	Atomic nitrogen
	N_2	Molecular nitrogen
NO_x	NO_x	Oxides of nitrogen
NO	NO	Nitric oxide
NO_2	NO_2	Nitrogen dioxide
	O	Atomic oxygen

PM	PM	Particulate matter
S	S	Sulphur

1.4. Symbols and abbreviations for the fuel composition

Section 2.(1)	Section 3.(2)	Quantity
w_C(4)	w_C(4)	Carbon content of fuel, mass fraction [g/g] or [% mass]
w_H	w_H	Hydrogen content of fuel, mass fraction [g/g] or [% mass]
w_N	w_N	Nitrogen content of fuel, mass fraction [g/g] or [% mass]
w_O	w_O	Oxygen content of fuel, mass fraction [g/g] or [% mass]
w_S	w_S	Sulphur content of fuel, mass fraction [g/g] or [% mass]
α	α	Atomic hydrogen-to-carbon ratio (H/C)
ε	β	Atomic oxygen-to-carbon ratio (O/C)(3)
γ	γ	Atomic sulphur-to-carbon ratio (S/C)
δ	δ	Atomic nitrogen-to-carbon ratio (N/C)

(1) Referred to a fuel with chemical formula $CH_\alpha O_\varepsilon N_\delta S_\gamma$

(2) Referred to a fuel with chemical formula $CH_\alpha O_\beta S_\gamma N_\delta$

(3) Attention should be paid to the different meaning of symbol β in the two emissions calculation sections: in section 2. it refers to a fuel having the chemical formula $CH_\alpha S_\gamma N_\delta O_\varepsilon$ (i.e. the formula $C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon$ where $\beta = 1$, assuming one carbon atom per molecule), while in section 3 it refers to the oxygen-to-carbon ratio with $CH_\alpha O_\beta S_\gamma N_\delta$. Then β of section 3. corresponds to ε of section 2..

(4) Mass fraction w accompanied by the symbol of the chemical component as a subscript.

2. Mass based emissions calculations

2.1. Raw gaseous emissions

2.1.1. Discrete-mode NRSC tests

The emission rate of a gaseous emission $q_{m\mathrm{gas},i}$ [g/h] for each mode i of the steady state test shall be calculated by multiplying the concentration of the gaseous emission with its respective flow, as follows:

$$q_{m\mathrm{gas},i} = k_\mathrm{h} \cdot k \cdot u_\mathrm{gas} \cdot q_{m\mathrm{ew},i} \cdot c_{\mathrm{gas},i} \cdot 3600 \qquad (7\text{-}1)$$

where:

k = 1 for $c_{\mathrm{gasr,w,i}}$ in [ppm] and k = 10,000 for $c_{\mathrm{gasr,w,i}}$ in [% vol]

k_h = NO_x correction factor [-], for NO_x emission calculation (see point 2.1.4.)

u_{gas} = component specific factor or ratio between densities of gas component and exhaust gas [-]

$q_{mew,i}$ = exhaust gas mass flow rate in mode *i* on a wet basis [kg/s]

$c_{gas,i}$ = emission concentration in the raw exhaust gas in mode *i*, on a wet basis [ppm] or [% vol]

2.1.2. Transient (NRTC and LSI-NRTC) test cycles and RMC tests

The total mass per test of a gaseous emission m_{gas} [g/test] shall be calculated by multiplication of the time aligned instantaneous concentrations and exhaust gas flows and integration over the test cycle by means of equation (7-2):

$$m_{gas} = \frac{1}{f} \cdot k_h \cdot k \cdot u_{gas} \cdot \sum_{i=1}^{N} \left(q_{mew,i} \cdot c_{gas,i} \right) \qquad (7\text{-}2)$$

where:

f = data sampling rate [Hz]

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm] and k = 10,000 for $c_{gasr,w,i}$ in [% vol]

u_{gas} = component specific factor [-] (see point 2.1.5.)

N = number of measurements [-]

$q_{mew,i}$ = instantaneous exhaust gas mass flow rate on a wet basis [kg/s]

$c_{gas,i}$ = instantaneous emission concentration in the raw exhaust gas, on a wet basis [ppm] or [% vol]

2.1.3. Dry-to-wet concentration conversion

If the emissions are measured on a dry basis, the measured concentration c_d on dry basis shall be converted to the concentration c_w on a wet basis by means of equation (7-3):

$$c_w = k_w \cdot c_d \qquad (7\text{-}3)$$

where:

k_w = dry-to-wet conversion factor [-]

c_d = emission concentration on a dry basis [ppm] or [% vol]

For complete combustion, the dry-to-wet conversion factor for raw exhaust gas is written as $k_{w,a}$ [-] and shall be calculated by means of equation (7-4):

$$k_{\mathrm{w,a}} = \frac{\left(1 - \dfrac{1.2442 \cdot H_{\mathrm{a}} + 111.19 \cdot w_{\mathrm{H}} \cdot \dfrac{q_{m\mathrm{f},i}}{q_{m\mathrm{ad},i}}}{773.4 + 1.2442 \cdot H_{\mathrm{a}} + \dfrac{q_{m\mathrm{f},i}}{q_{m\mathrm{ad},i}} \cdot k_{\mathrm{f}} \cdot 1000}\right)}{\left(1 - \dfrac{p_{\mathrm{r}}}{p_{\mathrm{b}}}\right)} \tag{7-4}$$

where:

H_a = intake air humidity [g H_2O/kg dry air]

$q_{mf,i}$ = instantaneous fuel flow rate [kg/s]

$q_{mad,i}$ = instantaneous dry intake air flow rate [kg/s]

p_r = water pressure after cooler [kPa]

p_b = total barometric pressure [kPa]

w_H = hydrogen content of the fuel [% mass]

k_f = combustion additional volume [m^3/kg fuel]

with:

$$k_{\mathrm{f}} = 0.055594 \cdot w_{\mathrm{H}} + 0.0080021 \cdot w_{\mathrm{N}} + 0.0070046 \cdot w_{\mathrm{O}} \tag{7-5}$$

where:

w_H = hydrogen content of fuel [% mass]

w_N = nitrogen content of fuel [% mass]

w_O = oxygen content of fuel [% mass]

In equation (7-4), the ratio $p_{\mathrm{r}} / p_{\mathrm{b}}$ may be assumed:

$$\frac{1}{\left(1 - \dfrac{p_{\mathrm{r}}}{p_{\mathrm{b}}}\right)} = 1.008 \tag{7-6}$$

For incomplete combustion (rich fuel air mixtures) and also for emission tests without direct air flow measurements, a second method of $k_{w,a}$ calculation is preferred:

$$k_{\mathrm{w,a}} = \frac{\dfrac{1}{1+\alpha \cdot 0.005 \cdot \left(c_{\mathrm{CO2}} + c_{\mathrm{CO}}\right)} - k_{\mathrm{w1}}}{1 - \dfrac{p_r}{p_b}} \qquad (7\text{-}7)$$

where:

c_{CO2} = concentration of CO_2 in the raw exhaust gas, on a dry basis [per cent vol]

c_{CO} = concentration of CO in the raw exhaust gas, on a dry basis [ppm]

p_r = water pressure after cooler [kPa]

p_b = total barometric pressure [kPa]

α = molar to carbon hydrogen ratio [-]

k_{w1} = intake air moisture [-]

$$k_{\mathrm{w1}} = \frac{1.608 \cdot H_{\mathrm{a}}}{1000 + 1.608 \cdot H_{\mathrm{a}}} \qquad (7\text{-}8)$$

2.1.4. NO_x correction for humidity and temperature

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for ambient air temperature and humidity with the factors $k_{h,D}$ or $k_{h,G}$ [-] given in equations (7-9) and (7-10). These factors are valid for a humidity range between 0 and 25 g H_2O/kg dry air.

(a) for compression-ignition engines

$$k_{\mathrm{h,D}} = \frac{15.698 \times H_a}{1{,}000} + 0.832 \qquad (7\text{-}9)$$

(b) for spark ignition engines

$$k_{h.G} = 0.6272 + 44.030 \text{ x } 10^{-3} \text{ x } H_a - 0.862 \text{ x } 10^{-3} \text{ x } H_a^2 \qquad (7\text{-}10)$$

where:

H_a = humidity of the intake air [g H_2O/kg dry air]

2.1.5. Component specific factor u

Two calculation procedures are described in points 2.1.5.1. and 2.1.5.2.. The procedure set out in point 2.1.5.1. is more straightforward, since it uses tabulated u values for the ratio between component and exhaust gas density. The procedure set out in point 2.1.5.2. is more accurate for fuel qualities that deviate from the specifications in Annex VIII, but requires elementary analysis of the fuel composition.

2.1.5.1. Tabulated values

Applying some simplifications (assumption on the λ value and on intake air conditions as shown in Table 7.1.) to the equations set out in point 2.1.5.2., the resulting values for u_{gas} are given in Table 7.1..

Table 7.1.

Raw exhaust gas u and component densities (for emission concentration expressed in ppm)

Fuel	ρ_e	*Gas*					
		NO_x	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m³]					
		2,053	*1,250*	[a]	*1,9636*	*1,4277*	*0,716*
		u_{gas}[b]					
Diesel (non-road gas-oil)	1,2943	0,001586	0,000966	0,000482	0,001517	0,001103	0,000553
Ethanol for dedicated compression ignition engines (ED95)	1,2768	0,001609	0,000980	0,000780	0,001539	0,001119	0,000561
Natural gas / bio-methane[c]	1,2661	0,001621	0,000987	0,000528[d]	0,001551	0,001128	0,000565
Propane	1,2805	0,001603	0,000976	0,000512	0,001533	0,001115	0,000559
Butane	1,2832	0,001600	0,000974	0,000505	0,001530	0,001113	0,000558
LPG[e]	1,2811	0,001602	0,000976	0,000510	0,001533	0,001115	0,000559
Petrol (E10)	1,2931	0,001587	0,000966	0,000499	0,001518	0,001104	0,000553
Ethanol (E85)	1,2797	0,001604	0,000977	0,000730	0,001534	0,001116	0,000559

[a] depending on fuel

[b] at $\lambda = 2$, dry air, 273 K, 101,3 kPa

[c] u accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %

[d] NMHC on the basis of $CH_{2,93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)

[e] u accurate within 0,2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

2.1.5.2. Calculated values

The component specific factor, $u_{gas,i}$, may be calculated by the density ratio of the component and the exhaust gas or alternatively by the corresponding ratio of molar masses [equations (7-11) or (7-12)]:

$$u_{gas,i} = M_{gas} / \left(M_{e,i} \cdot 1000 \right) \tag{7-11}$$

or

$$u_{gas,i} = \rho_{gas} / \left(\rho_{e,i} \cdot 1000 \right) \tag{7-12}$$

where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{e,i}$ = instantaneous molar mass of the wet raw exhaust gas [g/mol]

ρ_{gas} = density of the gas component [kg/m^3]

$\rho_{e,i}$ = instantaneous density of the wet raw exhaust gas [kg/m^3]

The molar mass of the exhaust gas, $M_{e,i}$ shall be derived for a general fuel composition $CH_{\alpha}O_{\varepsilon}N_{\delta}S_{\gamma}$ under the assumption of complete combustion, and shall be calculated by means of equation (7-13):

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \cdot \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.001 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.0065 \cdot \gamma} + \frac{\frac{H_a \cdot 10^{-3}}{2 \times 1.00794 + 15.9994} + \frac{1}{M_a}}{1 + H_a \cdot 10^{-3}}} \tag{7-13}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate on wet basis [kg/s]

$q_{maw,i}$ = instantaneous intake air mass flow rate on wet basis [kg/s]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

γ = atomic sulphur-to-carbon ratio [-]

H_a = intake air humidity [g H_2O/kg dry air]

M_a = dry intake air molecular mass = 28,965 g/mol

The instantaneous raw exhaust gas density $\rho_{e,i}$ [kg/m^3] shall be calculated by means of equation (7-14):

$$\rho_{e,i} = \frac{1000 + H_a + 1000 \cdot \left(q_{mf,i} / q_{mad,i} \right)}{773.4 + 1.2434 \cdot H_a + k_f \cdot 1000 \cdot \left(q_{mf,i} / q_{mad,i} \right)} \tag{7-14}$$

where:

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

$q_{mad,i}$ = instantaneous dry intake air mass flow rate [kg/s]

H_a = intake air humidity [g H_2O/kg dry air]

k_f = combustion additional volume [m^3/kg fuel] [see equation (7-5)]

2.1.6. Mass flow rate of the exhaust gas

2.1.6.1. Air and fuel measurement method

The method involves measurement of the air flow and the fuel flow with suitable flowmeters. The instantaneous exhaust gas flow $q_{mew,i}$ [kg/s] shall be calculated by means of equation (7-15):

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \tag{7-15}$$

where:

$q_{maw,i}$ = instantaneous intake air mass flow rate [kg/s]

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

2.1.6.2. Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust gas. The instantaneous exhaust gas flow $q_{\mathrm{mew,i}}$ [kg/s] shall be calculated by means of equation (7-16):

$$q_{m\mathrm{ew},i} = \frac{q_{V\mathrm{t}} \cdot \rho_{\mathrm{e}}}{10^{-6} \cdot \left(c_{\mathrm{mix},i} - c_{\mathrm{b}}\right)} \qquad (7\text{-}16)$$

where:

$q_{V\mathrm{t}}$ = tracer gas flow rate [m³/s]

$c_{\mathrm{mix},i}$ = instantaneous concentration of the tracer gas after mixing [ppm]

ρ_{e} = density of the raw exhaust gas [kg/m³]

c_{b} = background concentration of the tracer gas in the intake air [ppm]

The background concentration of the tracer gas c_{b} may be determined by averaging the background concentration measured immediately before the test run and after the test run. When the background concentration is less than 1 % of the concentration of the tracer gas after mixing $c_{\mathrm{mix},i}$ at maximum exhaust gas flow, the background concentration may be neglected.

2.1.6.3. Air flow and air to fuel ratio measurement method

This involves exhaust gas mass calculation from the air flow and the air to fuel ratio. The instantaneous exhaust gas mass flow $q_{\mathrm{mew},i}$ [kg/s] shall be calculated by means of equation (7-17):

$$q_{m\mathrm{ew},i} = q_{m\mathrm{aw},i} \cdot \left(1 + \frac{1}{A/F_{\mathrm{st}} \cdot \lambda_i}\right) \qquad (7\text{-}17)$$

with:

$$A/F_{\mathrm{st}} = \frac{138.0 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} \qquad (7\text{-}18)$$

$$\lambda_i = \frac{\left(100 - \frac{c_{\mathrm{COd}} \cdot 10^{-4}}{2} - c_{\mathrm{HCw}} \cdot 10^{-4}\right) + \left(\frac{\alpha}{4} \cdot \frac{1 - \frac{2 \cdot c_{\mathrm{COd}} \cdot 10^{-4}}{3.5 \cdot c_{\mathrm{CO2d}}}}{1 + \frac{c_{\mathrm{COd}} \cdot 10^{-4}}{3.5 \cdot c_{\mathrm{CO2d}}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \cdot \left(c_{\mathrm{CO2d}} + c_{\mathrm{COd}} \cdot 10^{-4}\right)}{4.764 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \cdot \left(c_{\mathrm{CO2d}} + c_{\mathrm{COd}} \cdot 10^{-4} + c_{\mathrm{HCw}} \cdot 10^{-4}\right)} \tag{7-19}$$

where:

$q_{m\mathrm{aw},i}$ = wet intake air mass flow rate [kg/s]

A/F_{st} = stoichiometric air-to-fuel ratio [-]

λ_i = instantaneous excess air ratio [-]

c_{COd} = concentration of CO in the raw exhaust gas on a dry basis [ppm]

c_{CO2d} = concentration of CO_2 in the raw exhaust gas on a dry basis [per cent]

c_{HCw} = concentration of HC in the raw exhaust gas on a wet basis [ppm C1]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

γ = atomic sulphur-to-carbon ratio [-]

2.1.6.4. Carbon balance method, 1 step-procedure

The following 1-step formula set out in equation (7-20) can be used for the calculation of the wet exhaust gas mass flow rate $q_{m\mathrm{ew},i}$ [kg/s]:

$$q_{m\mathrm{ew},i} = q_{m\mathrm{f},i} \cdot \left[\frac{1.4 \cdot w_{\mathrm{C}}^2}{\left(1.0828 \cdot w_{\mathrm{C}} + k_{\mathrm{fd}} \cdot f_{\mathrm{c}}\right) f_{\mathrm{c}}} \left(1 + \frac{H_{\mathrm{a}}}{1000}\right) + 1\right] \tag{7-20}$$

with the carbon factor f_{c} [-] given by:

$$f_{\mathrm{c}} = 0.5441 \cdot \left(c_{\mathrm{CO2d}} - c_{\mathrm{CO2d,a}}\right) + \frac{c_{\mathrm{COd}}}{18522} + \frac{c_{\mathrm{HCw}}}{17355} \tag{7-21}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

w_C = carbon content of fuel [% mass]

H_a = intake air humidity [g H_2O/kg dry air]

k_{fd} = combustion additional volume on a dry basis [m^3/kg fuel]

c_{CO2d} = dry CO_2 concentration in the raw exhaust ga [%]

$c_{CO2d,a}$ = dry CO_2 concentration in the ambient air [%]

c_{COd} = dry CO concentration in the raw exhaust gas [ppm]

c_{HCw} = wet HC concentration in the raw exhaust gas [ppm]

and factor k_{fd} [m^3/kg fuel] that is calculated by means of equation (7-22) on a dry basis by subtracting the water formed by combustion from k_f:

$$k_{fd} = k_f - 0.11118 \cdot w_H \tag{7-22}$$

where:

k_f = fuel specific factor of equation (7-5) [m^3/kg fuel]

w_H = hydrogen content of fuel [% mass]

2.2. Diluted gaseous emissions

2.2.1. Mass of the gaseous emissions

The exhaust gas mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a positive displacement pump (PDP), a critical flow venturi (CFV) or a subsonic venturi (SSV).

For systems with constant mass flow (i.e. with heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined by means of equation (7-23):

$$m_{gas} = k_h \cdot k \cdot u_{gas} \cdot c_{gas} \cdot m_{ed} \tag{7-23}$$

where:

u_{gas} is the ratio between density of exhaust gas component and density of air, as given in Table 7.2. or calculated by means of equation (7-34) [-]

c_{gas} = mean background corrected concentration of the component on a wet basis [ppm] or [% vol] respectively

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm], k = 10,000 for $c_{gasr,w,i}$ in [% vol]

m_{ed} = total diluted exhaust gas mass over the cycle [kg/test]

For systems with flow compensation (without heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined by calculation of the instantaneous mass emissions, by integration and by background correction by means of equation (7-24):

$$m_{gas} = k_h \cdot k \cdot \left\{ \sum_{i=1}^{N} \left[\left(m_{ed,i} \cdot c_e \cdot u_{gas} \right) \right] - \left[\left(m_{ed} \cdot c_d \cdot \left(1 - \frac{1}{D} \right) \cdot u_{gas} \right) \right] \right\} \qquad (7\text{-}24)$$

Where:

c_e = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [% vol]

c_d = emission concentration in the dilution air, on a wet basis [ppm] or [% vol]

$m_{ed,i}$ = mass of the diluted exhaust gas during time interval i [kg]

m_{ed} = total mass of diluted exhaust gas over the cycle [kg]

u_{gas} = tabulated value from Table 7.2. [-]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for c in [ppm], k = 10,000 for c in [% vol]

The concentrations c_{gas}, c_e and c_d can be either values measured in a batch sample (bag, but not allowed for NO_x and HC) or be averaged by integration from continuous measurements. Also $m_{ed,i}$ has to be averaged by integration over the test cycle.

The following equations show how the needed quantities (c_e, u_{gas} and m_{ed}) shall be calculated.

2.2.2. Dry-to-wet concentration conversion

All concentrations set out in point 2.2.1. measured dry shall be converted to a wet basis by means of equation (7-3).

2.2.2.1. Diluted exhaust gas

Dry concentrations shall be converted to wet concentrations by means of one of the following two equations [(7-25) or (7-26)] applied to equation:

$$k_{\mathrm{w,e}} = \left[\left(1 - \frac{\alpha \cdot c_{\mathrm{CO2w}}}{200} \right) - k_{\mathrm{w2}} \right] \cdot 1.008 \tag{7-25}$$

or

$$k_{\mathrm{w,e}} = \left(\frac{\left(1 - k_{\mathrm{w2}} \right)}{1 + \frac{\alpha \cdot c_{\mathrm{CO2d}}}{200}} \right) \cdot 1.008 \tag{7-26}$$

where:

α = molar hydrogen to carbon ratio of the fuel [-]

c_{CO2w} = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

c_{CO2d} = concentration of CO_2 in the diluted exhaust gas on a dry basis [per cent vol]

The dry to wet correction factor k_{w2} takes into consideration the water content of both intake air and dilution air and shall be calculated by means of equation (7-27):

$$k_{\mathrm{w2}} = \frac{1.608 \cdot \left[H_{\mathrm{d}} \cdot \left(1 - \frac{1}{D} \right) + H_{\mathrm{a}} \cdot \left(\frac{1}{D} \right) \right]}{1000 + \left\{ 1.608 \cdot \left[H_{\mathrm{d}} \cdot \left(1 - \frac{1}{D} \right) + H_{\mathrm{a}} \cdot \left(\frac{1}{D} \right) \right] \right\}} \tag{7-27}$$

Where:

H_{a} = intake air humidity [g H_2O/kg dry air]

H_{d} = dilution air humidity [g H_2O/kg dry air]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

2.2.2.2. Dilution factor

The dilution factor D [-] (which is necessary for the background correction and the k_{w2} calculation) shall be calculated by means of equation (7-28):

$$D = \frac{F_S}{c_{CO2,e} + \left(c_{HC,e} + c_{CO,e}\right) \cdot 10^{-4}} \tag{7-28}$$

where:

F_S = stoichiometric factor [-]

$c_{CO2,e}$ = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

$c_{HC,e}$ = concentration of HC in the diluted exhaust gas on a wet basis [ppm C1]

$c_{CO,e}$ = concentration of CO in the diluted exhaust gas on a wet basis [ppm]

The stoichiometric factor shall be calculated by means of equation (7-29):

$$F_S = 100 \cdot \frac{1}{1 + \frac{\alpha}{2} + 3.76 \cdot \left(1 + \frac{\alpha}{4}\right)} \tag{7-29}$$

Where:

α = molar hydrogen to carbon ratio in the fuel [-]

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

F_S (diesel) = 13,4

F_S (LPG) = 11,6

F_S (NG) = 9,5

F_S (E10) = 13,3

F_S (E85) = 11,5

If a direct measurement is made of the exhaust gas flow, the dilution factor D [-] may be calculated by means of equation (7-30):

$$D = \frac{q_{VCVS}}{q_{Vew}} \tag{7-30}$$

Where:

$q_{V\mathrm{CVS}}$ is the volumetric flow rate of diluted exhaust gas [m^3/s]

$q_{V\mathrm{ew}}$ = volumetric flow rate of raw exhaust gas [m^3/s]

2.2.2.3. Dilution air

$$k_{\mathrm{w,d}} = (1 - k_{\mathrm{w3}}) \cdot 1.008 \qquad (7\text{-}31)$$

with

$$k_{\mathrm{w3}} = \frac{1.608 \cdot H_{\mathrm{d}}}{1000 + 1.608 \cdot H_{\mathrm{d}}} \qquad (7\text{-}32)$$

where:

H_{d} = dilution air humidity [g H_2O/kg dry air]

2.2.2.4. Determination of the background corrected concentration

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be determined by the sample bag method or by continuous measurement with integration. Equation (7-33) shall be used:

$$c_{\mathrm{gas}} = c_{\mathrm{gas,e}} - c_{\mathrm{d}} \cdot \left(1 - \frac{1}{D}\right) \qquad (7\text{-}33)$$

Where:

c_{gas} = net concentration of the gaseous pollutant [ppm] or [% vol]

$c_{\mathrm{gas,e}}$ = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [% vol]

c_{d} = emission concentration in the dilution air, on a wet basis [ppm] or [% vol]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

2.2.3. Component specific factor u

The component specific factor u_{gas} of diluted gas can either be calculated by means of equation (7-34) or be taken from Table 7.2.; in Table 7.2. the density of the diluted exhaust gas has been assumed equal to air density.

$$u = \frac{M_{\text{gas}}}{M_{\text{d,w}} \cdot 1000} = \frac{M_{\text{gas}}}{\left[M_{\text{da,w}} \cdot \left(1 - \frac{1}{D} \right) + M_{\text{r,w}} \cdot \left(\frac{1}{D} \right) \right] \cdot 1000} \qquad (7\text{-}34)$$

Where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{\text{d,w}}$ = molar mass of diluted exhaust gas [g/mol]

$M_{\text{da,w}}$ = molar mass of dilution air [g/mol]

$M_{\text{r,w}}$ = molar mass of raw exhaust gas [g/mol]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

Table 7.2.

Diluted exhaust gas u values (for emission concentration expressed in ppm) and component densities

Fuel	ρ_e	*Gas*					
		NO_x	*CO*	*HC*	*CO_2*	*O_2*	*CH_4*
		ρ_{gas} [kg/m^3]					
		2,053	*1,250*	[a]	*1,9636*	*1,4277*	*0,716*
		u_{gas}[b]					
Diesel (non-road gas-oil)	1,2943	0,001586	0,000966	0,000482	0,001517	0,001103	0,000553
Ethanol for dedicated compression ignition engines (ED95)	1,2768	0,001609	0,000980	0,000780	0,001539	0,001119	0,000561
Natural gas / bio-methane[c]	1,2661	0,001621	0,000987	0,000528[d]	0,001551	0,001128	0,000565
Propane	1,2805	0,001603	0,000976	0,000512	0,001533	0,001115	0,000559
Butane	1,2832	0,001600	0,000974	0,000505	0,001530	0,001113	0,000558
LPG[e]	1,2811	0,001602	0,000976	0,000510	0,001533	0,001115	0,000559
Petrol (E10)	1,2931	0,001587	0,000966	0,000499	0,001518	0,001104	0,000553

Ethanol (E85)	1,2797	0,001604	0,000977	0,000730	0,001534	0,001116	0,000559

[a] depending on fuel

[b] at $\lambda = 2$, dry air, 273 K, 101,3 kPa

[c] u accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %

[d] NMHC on the basis of $CH_{2,93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)

[e] u accurate within 0,2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

2.2.4. Exhaust gas mass flow calculation

2.2.4.1. PDP-CVS system

The mass of the diluted exhaust gas [kg/test] over the cycle shall be calculated by means of equation (7-35), if the temperature of the diluted exhaust gas m_{ed} is kept within ±6 K over the cycle by using a heat exchanger:

$$m_{\text{ed}} = 1.293 \cdot V_0 \cdot n_{\text{P}} \cdot \frac{p_{\text{p}}}{101.325} \cdot \frac{273.15}{T} \qquad (7\text{-}35)$$

where:

V_0 = volume of gas pumped per revolution under test conditions [m^3/rev]

n_{P} = total revolutions of pump per test [rev/test]

p_{p} = absolute pressure at pump inlet [kPa]

$\overline{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1,293 kg/m^3 = air density at 273,15 K and 101,325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated by means of equation (7-36):

$$m_{\text{ed},i} = 1.293 \cdot V_0 \cdot n_{\text{P},i} \cdot \frac{p_p}{101.325} \cdot \frac{273.15}{\overline{T}} \qquad (7\text{-}36)$$

where:

V_0 = volume of gas pumped per revolution under test conditions [m³/rev]

p_p = absolute pressure at pump inlet [kPa]

$n_{\mathrm{P},i}$ = total revolutions of pump per time interval i $[\mathrm{rev}/\Delta t]$

$\overline{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1,293 kg/m³ = air density at 273,15 K and 101,325 kPa

2.2.4.2. CFV-CVS system

The mass flow over the cycle m_ed [g/test] shall be calculated by means of equation (7-37), if the temperature of the diluted exhaust gas is kept within ±11 K over the cycle by using a heat exchanger:

$$m_\mathrm{ed} = \frac{1.293 \cdot t \cdot K_\mathrm{V} \cdot p_\mathrm{p}}{T^{0.5}} \tag{7-37}$$

Where:

t = cycle time [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\mathrm{K}} \cdot \mathrm{m}^4 \cdot \mathrm{s}\right)/\mathrm{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1,293 kg/m³ = air density at 273,15 K and 101,325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{\mathrm{ed},i}$ [kg] during the time interval shall be calculated by means of equation (7-38):

$$m_{\mathrm{ed},i} = \frac{1.293 \cdot \Delta t_i \cdot K_\mathrm{V} \cdot p_\mathrm{p}}{T^{0.5}} \tag{7-38}$$

where:

Δt_i = time interval of the test [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\mathrm{K}}\cdot\mathrm{m}^4\cdot\mathrm{s}\right)/\mathrm{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1,293 kg/m^3 = air density at 273,15 K and 101,325 kPa

2.2.4.3. SSV-CVS system

The diluted exhaust gas mass over the cycle m_ed [kg/test] shall be calculated by means of equation (7-39), if the temperature of the diluted exhaust gas is kept within ±11K over the cycle by using a heat exchanger:

$$m_\mathrm{ed} = 1.293 \cdot q_{V\mathrm{SSV}} \cdot \Delta t \qquad (7\text{-}39)$$

Where:

1,293 kg/m^3 = air density at 273,15 K and 101,325 kPa

Δt = cycle time [s]

$q_{V\mathrm{SSV}}$ = air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s]

with

$$q_{V\mathrm{SSV}} = \frac{A_0}{60} d_\mathrm{V}^{\,2} C_\mathrm{d} p_\mathrm{p} \sqrt{\left[\frac{1}{T}\left(r_\mathrm{p}^{\,1.4286} - r_\mathrm{p}^{\,1.7143}\right)\cdot\left(\frac{1}{1 - r_\mathrm{D}^{\,4} r_\mathrm{p}^{\,1.4286}}\right)\right]} \qquad (7\text{-}40)$$

Where:

A_0 = collection of constants and units conversions = 0,0056940 $\left[\frac{\mathrm{m}^3}{\mathrm{min}}\cdot\frac{\mathrm{K}^{\frac{1}{2}}}{\mathrm{kPa}}\cdot\frac{1}{\mathrm{mm}^2}\right]$

d_V = diameter of the SSV throat [mm]

C_d = discharge coefficient of the SSV [-]

p_p = absolute pressure at venturi inlet [kPa]

T_in = temperature at the venturi inlet [K]

r_p = ratio of the SSV throat to inlet absolute static pressure, $\left(1-\frac{\Delta p}{p_a}\right)$ [-]

r_D = ratio of the SSV throat diameter to the inlet pipe inner diameter $\frac{d}{D}$ [-]

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{\mathrm{ed},i}$ [kg] during the time interval shall be calculated by means of equation (7-41):

$$m_{\mathrm{ed},i} = 1.293 \cdot q_{V\mathrm{SSV}} \cdot \Delta t_{\mathrm{i}} \quad (7\text{-}41)$$

Where:

1,293 kg/m^3 = air density at 273,15 K and 101,325 kPa

Δt_i = time interval [s]

$q_{V\mathrm{SSV}}$ = volumetric flow rate of the SSV [m^3/s]

2.3. Calculation of particulate emission

2.3.1. Transient (NRTC and LSI-NRTC) test cycles and RMC

The particulate mass shall be calculated after buoyancy correction of the particulate sample mass according to point 8.1.12.2.5..

2.3.1.1. Partial flow dilution system

2.3.1.1.1. Calculation based on sample ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated by means of equation (7-42):

$$m_{\mathrm{PM}} = \frac{m_{\mathrm{f}}}{r_{\mathrm{s}} \cdot 1000} \quad (7\text{-}42)$$

where:

m_{f} = particulate mass sampled over the cycle [mg]

r_{s} = average sample ratio over the test cycle [-]

with:

$$r_s = \frac{m_{se}}{m_{ew}} \cdot \frac{m_{sep}}{m_{sed}} \quad (7\text{-}43)$$

Where:

m_{se} = sample mass of raw exhaust gas over the cycle [kg]

m_{ew} = total mass of raw exhaust gas over the cycle [kg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sed} = mass of diluted exhaust gas passing the dilution tunnel [kg]

In case of the total sampling type system, m_{sep} and m_{sed} are identical.

2.3.1.1.2. Calculation based on dilution ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated by means of equation (7-44):

$$m_{PM} = \frac{m_f}{m_{sep}} \cdot \frac{m_{edf}}{1000} \quad (7\text{-}44)$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{edf} = mass of equivalent diluted exhaust gas over the cycle [kg]

The total mass of equivalent diluted exhaust gas mass over the cycle m_{edf} [kg] shall be determined by means of equation (7-45):

$$m_{edf} = \frac{1}{f} \cdot \sum_{i=1}^{N} q_{medf,i} \quad (7\text{-}45)$$

With:

$$q_{medf,i} = q_{mew,i} \cdot r_{d,i} \quad (7\text{-}46)$$

$$r_{d,i} = \frac{q_{mdew,i}}{q_{mdew,i} - q_{mdw,i}} \quad (7\text{-}47)$$

Where:

$q_{m\mathrm{edf},i}$ = instantaneous equivalent diluted exhaust gas mass flow rate [kg/s]

$q_{m\mathrm{ew},i}$ = instantaneous exhaust gas mass flow rate on a wet basis [kg/s]

$r_{\mathrm{d},i}$ = instantaneous dilution ratio [-]

$q_{m\mathrm{dew},i}$ = instantaneous diluted exhaust gas mass flow rate on a wet basis [kg/s]

$q_{m\mathrm{dw,i}}$ = instantaneous dilution air mass flow rate [kg/s]

f = data sampling rate [Hz]

N = number of measurements [-]

2.3.1.2. Full flow dilution system

The mass emission shall be calculated by means of equation (7-48):

$$m_{\mathrm{PM}} = \frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} \cdot \frac{m_{\mathrm{ed}}}{1000} \qquad (7\text{-}48)$$

where:

m_{f} is the particulate mass sampled over the cycle [mg]

m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{ed} is the mass of diluted exhaust gas over the cycle [kg]

with

$$m_{\mathrm{sep}} = m_{\mathrm{set}} - m_{\mathrm{ssd}} \qquad (7\text{-}49)$$

Where:

m_{set} = mass of double diluted exhaust gas through particulate filter [kg]

m_{ssd} = mass of secondary dilution air [kg]

2.3.1.2.1. Background correction

The particulate mass $m_{\mathrm{PM,c}}$ [g] may be background corrected by means of equation (7-50):

$$m_{\mathrm{PM,c}} = \left\{ \frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} - \left[\frac{m_{\mathrm{b}}}{m_{\mathrm{sd}}} \cdot \left(1 - \frac{1}{D} \right) \right] \right\} \cdot \frac{m_{\mathrm{ed}}}{1000} \qquad (7\text{-}50)$$

Where:

m_{f} = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sd} = mass of dilution air sampled by background particulate sampler [kg]

m_{b} = mass of collected background particulates of dilution air [mg]

m_{ed} = mass of diluted exhaust gas over the cycle [kg]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

2.3.2. Calculation for discrete-mode NRSC

2.3.2.1. Dilution system

All calculations shall be based upon the average values of the individual modes *i* during the sampling period.

(a) For partial-flow dilution, the equivalent mass flow of diluted exhaust gas shall be determined by means of equation (7-51) and the system with flow measurement shown in Figure 9.2.:

$$q_{m\mathrm{edf}} = q_{m\mathrm{ew}} \cdot r_{\mathrm{d}} \qquad (7\text{-}51)$$

$$r_{\mathrm{d}} = \frac{q_{m\mathrm{dew}}}{q_{m\mathrm{dew}} - q_{m\mathrm{dw}}} \qquad (7\text{-}52)$$

Where:

$q_{m\mathrm{edf}}$ = equivalent diluted exhaust gas mass flow rate [kg/s]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on a wet basis [kg/s]

r_{d} = dilution ratio [-]

$q_{m\mathrm{dew}}$ = diluted exhaust gas mass flow rate on a wet basis [kg/s]

$q_{m\mathrm{dw}}$ = dilution air mass flow rate [kg/s]

(b) For full-flow dilution systems $q_{m\mathrm{dew}}$ is used as $q_{m\mathrm{edf}}$.

2.3.2.2. Calculation of the particulate mass flow rate

The particulate emission flow rate over the cycle q_{mPM} [g/h] shall be calculated by means of equations (7-53), (7-56), (7-57) or (7-58):

(a) For the single-filter method

$$q_{m\mathrm{PM}} = \frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} \cdot \overline{q_{m\mathrm{edf}}} \cdot \frac{3600}{1000} \tag{7-53}$$

$$\overline{q_{m\mathrm{edf}}} = \sum_{i=1}^{\mathrm{N}} q_{m\mathrm{edf}i} \cdot WF_i \tag{7-54}$$

$$m_{\mathrm{sep}} = \sum_{i=1}^{\mathrm{N}} m_{\mathrm{sep}i} \tag{7-55}$$

Where:

$q_{m\mathrm{PM}}$ = particulate mass flow rate [g/h]

m_{f} = particulate mass sampled over the cycle [mg]

$\overline{q_{m\mathrm{edf}}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

$q_{m\mathrm{edf}i}$ = equivalent diluted exhaust gas mass flow rate on wet basis at mode *i* [kg/s]

WF_i = weighting factor for the mode *i* [-]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

$m_{\mathrm{sep}i}$ = mass of diluted exhaust gas sample passed through the particulate sampling filter at mode *i* [kg]

N = number of measurements [-]

(b) For the multiple-filter method

$$q_{m\text{PM}i} = \frac{m_{\text{f}i}}{m_{\text{sep}i}} \cdot q_{m\text{edf}i} \cdot \frac{3600}{1000} \tag{7-56}$$

Where:

$q_{m\text{PM}i}$ = particulate mass flow rate for the mode i [g/h]

$m_{\text{f}i}$ = particulate sample mass collected at mode i [mg]

$q_{m\text{edf}i}$ = equivalent diluted exhaust gas mass flow rate on wet basis at mode i [kg/s]

$m_{\text{sep}i}$ = mass of diluted exhaust gas sample passed through the particulate sampling filter at mode i [kg]

The PM mass is determined over the test cycle by summation of the average values of the individual modes i during the sampling period.

The particulate mass flow rate $q_{m\text{PM}}$ [g/h] or $q_{m\text{PM}i}$ [g/h] may be background corrected as follows:

(c) For the single-filter method

$$q_{m\text{PM}} = \left\{ \frac{m_{\text{f}}}{m_{\text{sep}}} - \left[\frac{m_{\text{f,d}}}{m_{\text{d}}} \cdot \sum_{i=1}^{\text{N}} \left(1 - \frac{1}{D_i} \right) \cdot WF_i \right] \right\} \cdot \overline{q_{m\text{edf}}} \cdot \frac{3600}{1000} \tag{7-57}$$

Where:

$q_{m\text{PM}}$ = particulate mass flow rate [g/h]

m_{f} = particulate sample mass collected [mg]

m_{sep} = mass of diluted exhaust gas sample passed through the particulate sampling filter [kg]

$m_{\text{f,d}}$ = particulate sample mass of the dilution air collected [mg]

m_{d} = mass of the dilution air sample passed through the particulate sampling filters [kg]

D_i = dilution factor at mode i [see equation (7-28) of point 2.2.2.2.] [-]

WF_i = weighting factor for the mode i [-]

$\overline{q_{m\mathrm{edf}}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

(d) For the multiple-filter method

$$q_{m\mathrm{PM}i} = \left\{ \frac{m_{\mathrm{f}i}}{m_{\mathrm{sep}i}} - \left[\frac{m_{\mathrm{f,d}}}{m_{\mathrm{d}}} \cdot \left(1 - \frac{1}{D}\right)\right]\right\} \cdot q_{m\mathrm{edf}i} \cdot \frac{3600}{1000} \tag{7-58}$$

Where:

$q_{m\mathrm{PM}i}$ = particulate mass flow rate at mode i [g/h]

$m_{\mathrm{f}i}$ = particulate sample mass collected at mode i [mg]

$m_{\mathrm{sep}i}$ = mass of diluted exhaust gas sample passed through the particulate sampling filter at mode i [kg]

$m_{\mathrm{f,d}}$ = particulate sample mass of the dilution air collected [mg]

m_{d} = mass of the dilution air sample passed through the particulate sampling filters [kg]

D = dilution factor [see equation (7-28) of point 2.2.2.2.] [-]

$q_{\mathrm{medf}i}$ = equivalent diluted exhaust gas mass flow rate on wet basis at mode i [kg/s]

If more than one measurement is made, $m_{\mathrm{f,d}}/m_{\mathrm{d}}$ shall be replaced with $\overline{m_{\mathrm{f,d}}/m_{\mathrm{d}}}$.

2.4. Cycle work and specific emissions

2.4.1. Gaseous emissions

2.4.1.1. Transient (NRTC and LSI-NRTC) test cycles and RMC

Reference is made to points 2.1. and 2.2. for raw and diluted exhaust gas respectively. The resulting values for power P [kW] shall be integrated over a test interval. The total work W_{act} [kWh] is calculated by means of equation (7-59):

$$W_{\mathrm{act}} = \sum_{i=1}^{\mathrm{N}} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^{\mathrm{N}} \left(n_i \cdot T_i \right) \tag{7-59}$$

Where:

P_i = instantaneous engine power [kW]

n_i = instantaneous engine speed [rpm]

T_i = instantaneous engine torque [Nm]

W_act = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

Where auxiliaries were fitted in accordance with Appendix 2 of Annex VI there shall be no adjustment to the instantaneous engine torque in equation (7-59). Where, according to points 6.3.2. or 6.3.3. of Annex VI to this regulation necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value of T_i used in equation (7-59) shall be adjusted by means of equation (7-60):

$$T_i = T_{i,\text{meas}} + T_{i,\text{AUX}} \tag{7-60}$$

Where:

$T_{i,\text{meas}}$ = measured value of instantaneous engine torque

$T_{i,\text{AUX}}$ = corresponding value of torque required to drive auxiliaries determined according to point 7.7.2.3.2. of Annex VI to this regulation.

The specific emissions e_gas [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_\text{gas} = \frac{m_\text{gas}}{W_\text{act}} \tag{7-61}$$

Where:

m_gas = total mass of emission [g/test]

W_act = cycle work [kWh]

In case of the NRTC, for gaseous emissions other than CO_2 the final test result e_gas [g/kWh] shall be a weighted average from cold-start run and hot-start run by means of equation (7-62):

$$e_\text{gas} = \frac{(0.1 \cdot m_\text{cold}) + (0.9 \cdot m_\text{hot})}{(0.1 \cdot W_\text{act,cold}) + (0.9 \cdot W_\text{act,hot})} \tag{7-62}$$

Where:

m_{cold} is the gas mass emissions of the cold-start NRTC [g]

$W_{\text{act, cold}}$ is the actual cycle work of the cold-start NRTC [kWh]

m_{hot} is the gas mass emissions of the hot-start NRTC [g]

$W_{\text{act, hot}}$ is the actual cycle work of the hot-start NRTC [kWh]

In case of the NRTC, for CO_2 the final test result e_{CO2} [g/kWh] shall be calculated from the hot-start NRTC by means of equation (7-63):

$$e_{\text{CO2,hot}} = \frac{m_{\text{CO2,hot}}}{W_{\text{act,hot}}} \qquad (7\text{-}63)$$

Where:

$m_{\text{CO2, hot}}$ is the CO_2 mass emissions of the hot-start NRTC [g]

$W_{\text{act, hot}}$ is the actual cycle work of the hot-start NRTC [kWh]

2.4.1.2. Discrete-mode NRSC

The specific emissions e_{gas} [g/kWh] are calculated by means of equation (7-64):

$$e_{\text{gas}} = \frac{\sum_{i=1}^{N_{\text{mode}}} \left(q_{m\text{gas}i} \cdot WF_i \right)}{\sum_{i=1}^{N_{\text{mode}}} \left(P_i \cdot WF_i \right)} \qquad (7\text{-}64)$$

where:

$q_{m\text{gas},i}$ = mean emission mass flow rate for the mode i [g/h]

P_i = engine power for the mode i [kW] with $P_i = P_{\max i} + P_{\text{aux}i}$ (see points 6.3. and 7.7.1.3.)

WF_i = weighting factor for the mode i [-]

2.4.2. Particulate emissions

2.4.2.1. Transient (NRTC and LSI-NRTC) test cycles and RMC

The particulate specific emissions shall be calculated with equation (7-61) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{\text{PM}} = \frac{m_{\text{PM}}}{W_{\text{act}}} \qquad (7\text{-}65)$$

where:

m_{PM} = total mass of particulates emission, calculated in accordance with point 2.3.1.1. or 2.3.1.2. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold-start NRTC and hot-start NRTC) shall be calculated as shown in point 2.4.1.1..

2.4.2.2. Discrete-mode NRSC

The particulate specific emission e_{PM} [g/kWh] shall be calculated by means of equations (7-66) or (7-67):

(a) For the single-filter method

$$e_{\mathrm{PM}} = \frac{q_{m\mathrm{PM}}}{\sum_{i=1}^{\mathrm{N}} \left(P_i \cdot WF_i\right)} \tag{7-66}$$

where:

P_i = engine power for the mode i [kW] with $P_i = P_{\mathrm{max}i} + P_{\mathrm{aux}i}$

(see points 6.3. and 7.7.1.3. of Annex VI)

WF_i = weighting factor for the mode i [-]

$q_{m\mathrm{PM}}$ = particulate mass flow rate [g/h]

(b) For the multiple-filter method

$$e_{\mathrm{PM}} = \frac{\sum_{i=1}^{\mathrm{N}} \left(q_{m\mathrm{PM}i} \cdot WF_i\right)}{\sum_{i=1}^{\mathrm{N}} \left(P_i \cdot WF_i\right)} \tag{7-67}$$

Where:

P_i = engine power for the mode i [kW] with $P_i = P_{\mathrm{max}i} + P_{\mathrm{aux}i}$

(see points 6.3. and 7.7.1.3.)

WF_i = weighting factor for the mode i [-]

$q_{m\mathrm{PM}i}$ = particulate mass flow rate at mode i [g/h]

For the single-filter method, the effective weighting factor, $WF_{\mathrm{e}i}$, for each mode shall be calculated by means of equation (7-68):

$$WF_{\mathrm{e}i} = \frac{m_{\mathrm{sep}i} \cdot \overline{q_{m\mathrm{edf}}}}{m_{\mathrm{sep}} \cdot q_{m\mathrm{edf}i}} \qquad (7\text{-}68)$$

Where:

$m_{\mathrm{sep}i}$ = mass of the diluted exhaust gas sample passed through the particulate

sampling filters at mode i [kg]

$\overline{q_{m\mathrm{edf}}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

$q_{m\mathrm{edf}i}$ = equivalent diluted exhaust gas mass flow rate at mode i [kg/s]

m_{sep} = mass of the diluted exhaust gas sample passed through the particulate

sampling filters [kg]

The value of the effective weighting factors shall be within ± 0,005 (absolute value) of the weighting factors listed in Appendix 1 of Annex XVII.

2.4.3. Adjustment for emission controls that are regenerated on an infrequent (periodic) basis

In case of engines, other than those of category RLL, equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis (see point 6.6.2. of Annex VI), the specific emissions of gaseous and particulate pollutants calculated according to points 2.4.1. and 2.4.2. shall be corrected with either the applicable multiplicative adjustment factor or with the applicable additive adjustment factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{\mathrm{ru,m}}$ or $k_{\mathrm{ru,a}}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{\mathrm{rd,m}}$ or $k_{\mathrm{rd,a}}$). In the case of the discrete-mode NRSC, where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result.

2.4.4. Adjustment for deterioration factor

The specific emissions of gaseous and particulate pollutants calculated according to points 2.4.1. and 2.4.2., where applicable inclusive of the infrequent regeneration adjustment factor according to point 2.4.3., shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex III.

2.5. Diluted Exhaust Flow (CVS) Calibration and Related Calculations

The CVS system shall be calibrated by using an accurate flowmeter and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various types of flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbine meter.

2.5.1. Positive displacement pump (PDP)

All the parameters related to the pump shall be simultaneously measured along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m^3/s at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used.

Temperature stability shall be maintained during calibration.

Leaks in all the connections and ducting between the calibration venturi and the CVS pump shall be maintained lower than 0,3 % of the lowest flow point (highest restriction and lowest PDP speed point).

The airflow rate ($q_{V\mathrm{CVS}}$) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure by means of equation (7-69):

$$V_0 = \frac{q_{V\mathrm{CVS}}}{n} \cdot \frac{T}{273.15} \cdot \frac{101.325}{p_\mathrm{p}} \qquad (7\text{-}69)$$

where:

$q_{V\mathrm{CVS}}$ = airflow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s]

T = temperature at pump inlet [K]

p_p = absolute pressure at pump inlet [kPa]

n = pump speed [rev/s]

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) [s/rev] between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated by means of equation (7-70):

$$X_0 = \frac{1}{n} \cdot \sqrt{\frac{\Delta p_{\mathrm{p}}}{p_{\mathrm{p}}}} \qquad (7\text{-}70)$$

Where:

Δp_{p} = pressure differential from pump inlet to pump outlet [kPa]

p_{p} = absolute outlet pressure at pump outlet [kPa]

n = pump speed [rev/s]

A linear least-square fit shall be performed to generate the calibration by means of equation (7-71):

$$V_0 = D_0 - m \cdot X_0 \qquad (7\text{-}71)$$

with D_0 [m^3/rev] and m [m^3/s], intercept and slope respectively, describing the regression line.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D_0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ± 0,5 % of the measured value of V_0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

2.5.2. Critical flow venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of venturi inlet pressure and temperature.

To determine the range of critical flow, K_{V} shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, K_{V} will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_{V} decreases, which indicates that the CFV is operated outside the permissible range.

The airflow rate ($q_{V\mathrm{CVS}}$) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient K_{V} $\left[\left(\sqrt{\mathrm{K}} \cdot \mathrm{m}^4 \cdot \mathrm{s}\right)/\mathrm{kg}\right]$ shall be calculated from the calibration data for each setting by means of equation (7-72):

$$K_V = \frac{q_{V\mathrm{CVS}} \cdot \sqrt{T}}{p_p} \tag{7-72}$$

Where:

$q_{V\mathrm{SSV}}$ = air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s]

T = temperature at the venturi inlet [K]

p_p = absolute pressure at venturi inlet [kPa]

The average K_V and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0,3 % of the average K_V.

2.5.3. Subsonic venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown in equation (7-40).

The airflow rate ($q_{V\mathrm{SSV}}$) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting by means of equation (7-73):

$$C_d = \frac{q_{V\mathrm{SSV}}}{\frac{A_0}{60} d_V^2 p_p \sqrt{\left[\frac{1}{T_{\mathrm{in,V}}}\left(r_p^{1.4286} - r_p^{1.7143}\right)\left(\frac{1}{1 - r_D^4 r_p^{1.4286}}\right)\right]}} \tag{7-73}$$

Where:

A_0 = collection of constants and units conversions =

$$0{,}0056940 \left[\frac{\mathrm{m}^3}{\mathrm{min}} \cdot \frac{\mathrm{K}^{\frac{1}{2}}}{\mathrm{kPa}} \cdot \frac{1}{\mathrm{mm}^2}\right]$$

$q_{V\mathrm{SSV}}$ = air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s]

$T_{\mathrm{in,V}}$ = temperature at the venturi inlet [K]

d_V = diameter of the SSV throat [mm]

r_p = ratio of the SSV throat to inlet absolute static pressure =

$1 - \Delta p / p_p$ [-]

r_D = ratio of the SSV throat diameter, d_V, to the inlet pipe inner diameter D [-]

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number Re, at the SSV throat. The Re at the SSV throat shall be calculated by means of equation (7-74):

$$Re = A_1 \cdot 60 \cdot \frac{q_{VSSV}}{d_V \cdot \mu} \qquad (7\text{-}74)$$

with

$$\mu = \frac{b \times T^{1.5}}{S + T} \qquad (7\text{-}75)$$

Where:

A_1 = collection of constants and units conversions = 27,43831 $\left[\frac{Kg}{m^3} \cdot \frac{min}{s} \cdot \frac{mm}{m}\right]$

q_{VSSV} = air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s]

d_V = diameter of the SSV throat [mm]

μ = absolute or dynamic viscosity of the gas [$kg/(m \cdot s)$]

b = 1,458 x 10^6 (empirical constant) [$kg/(m \cdot s \cdot K^{0,5})$]

S = 110,4 (empirical constant) [K]

Because q_{VSSV} is an input to the Re equation, the calculations shall be started with an initial guess for q_{VSSV} or C_d of the calibration venturi, and repeated until q_{VSSV} converges. The convergence method shall be accurate to 0,1 % of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ± 0,5 % of the measured C_d for each calibration point.

2.6. Drift Correction

2.6.1. General procedure

The calculations in this section shall be performed to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, the test interval's gas analyzer responses shall be corrected for drift in accordance with point 2.6.2.. The drift-corrected gas analyzer responses shall be used in all subsequent emission calculations. The acceptable threshold for gas analyzer drift over a test interval is specified in point 8.2.2.2. of Annex VI.

The general test procedure shall follow the provisions specified in Appendix 1 with concentrations x_i or $\overline{x}$ being replaced by concentrations c_i or $\overline{c}$.

2.6.2. Calculation procedure

The drift correction shall be calculated by means of equation (7-76):

$$c_{i\text{driftcor}} = c_{\text{refzero}} + \left(c_{\text{refspan}} - c_{\text{refzero}}\right)\frac{2c_i - \left(c_{\text{prezero}} + c_{\text{postzero}}\right)}{\left(c_{\text{prespan}} + c_{\text{postspan}}\right) - \left(c_{\text{prezero}} + c_{\text{postzero}}\right)} \tag{7-76}$$

Where:

$c_{i\text{driftcor}}$ = concentration corrected for drift [ppm]

c_{refzero} = reference concentration of the zero gas, which is usually zero unless known to be otherwise [ppm]

c_{refspan} = reference concentration of the span gas [ppm]

c_{prespan} = pre-test interval gas analyzer response to the span gas concentration [ppm]

c_{postspan} = post-test interval gas analyzer response to the span gas concentration [ppm]

c_i or $\overline{c}$ = concentration recorded, i.e. measured, during test, before drift correction [ppm]

c_{prezero} = pre-test interval gas analyzer response to the zero gas concentration [ppm]

c_{postzero} = post-test interval gas analyzer response to the zero gas concentration [ppm]

3. Molar based emissions calculation

3.1. Subscripts

	Quantity
abs	Absolute quantity
act	Actual quantity
air	Air, dry
atmos	Atmospheric
bkgnd	Background
C	Carbon
cal	Calibration quantity
CFV	Critical flow venturi
cor	Corrected quantity
dil	Dilution air
dexh	Diluted exhaust gas
dry	Dry quantity
exh	Raw exhaust gas
exp	Expected quantity
eq	Equivalent quantity
fuel	Fuel
	Instantaneous measurement (e.g.: 1 Hz)
i	An individual of a series
idle	Condition at idle
in	Quantity in
init	Initial quantity, typically before an emission test
max	Maximum (i.e. peak) value
meas	Measured quantity
min	Minimum value
mix	Molar mass of air
out	Quantity out
part	Partial quantity
PDP	Positive displacement pump
raw	Raw exhaust
ref	Reference quantity
rev	Revolution
sat	Saturated condition

slip	PDP slip
smpl	Sampling
span	Span quantity
SSV	Subsonic venturi
std	Standard quantity
test	Test quantity
total	Total quantity
uncor	Uncorrected quantity
vac	Vacuum quantity
weight	Calibration weight
wet	Wet quantity
zero	Zero quantity

3.2. Symbols for chemical balance

$x_{dil/exh}$ = Amount of dilution gas or excess air per mole of exhaust gas

x_{H2Oexh} = Amount of water in exhaust per mole of exhaust gas

$x_{Ccombdry}$ = Amount of carbon from fuel in the exhaust per mole of dry exhaust gas

$x_{H2Oexhdry}$ = Amount of water in exhaust per dry mole of dry exhaust gas

$x_{prod/intdry}$ = Amount of dry stoichiometric products per dry mole of intake air

$x_{dil/exhdry}$ = Amount of dilution gas and/or excess air per mole of dry exhaust gas

$x_{int/exhdry}$ = Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust gas

$x_{raw/exhdry}$ = Amount of undiluted exhaust gas, without excess air, per mole of dry (raw or diluted) exhaust gas

$x_{O2intdry}$ = Amount of intake air O_2 per mole of dry intake air

$x_{CO2intdry}$ = Amount of intake air CO_2 per mole of dry intake air

$x_{H2Ointdry}$ = Amount of intake air H_2O per mole of dry intake air

x_{CO2int} = Amount of intake air CO_2 per mole of intake air

x_{CO2dil} = Amount of dilution gas CO_2 per mole of dilution gas

$x_{CO2dildry}$ = Amount of dilution gas CO_2 per mole of dry dilution gas

$x_{H2Odildry}$ = Amount of dilution gas H_2O per mole of dry dilution gas

x_{H2Odil} = Amount of dilution gas H_2O per mole of dilution gas

$x_{[emission]meas}$ = Amount of measured emission in the sample at the respective gas analyzer

$x_{[emission]dry}$ = Amount of emission per dry mole of dry sample

$x_{H2O[emission]meas}$ = Amount of water in sample at emission-detection location

x_{H2Oint} = Amount of water in the intake air, based on a humidity measurement of intake air

3.3. Basic parameters and relationships

3.3.1. Dry air and chemical species

This section uses the following values for dry air composition:

$x_{\mathrm{O2airdry}} = 0{,}209445\ \mathrm{mol/mol}$

$x_{\mathrm{Arairdry}} = 0{,}00934\ \mathrm{mol/mol}$

$x_{\mathrm{N2airdry}} = 0{,}78084\ \mathrm{mol/mol}$

$x_{\mathrm{CO2airdry}} = 375\ \mu\mathrm{mol/mol}$

This section uses the following molar masses or effective molar masses of chemical species:

M_{air} = 28,96559 g/mol (dry air)

M_{Ar} = 39,948 g/mol (argon)

M_{C} = 12,0107 g/mol (carbon)

M_{CO} = 28,0101 g/mol (carbon monoxide)

M_{CO2} = 44,0095 g/mol (carbon dioxide)

M_{H} = 1,00794 g/mol (atomic hydrogen)

M_{H2} = 2,01588 g/mol (molecular hydrogen)

M_{H2O} = 18,01528 g/mol (water)

M_{He} = 4,002602 g/mol (helium)

M_{N} = 14,0067 g/mol (atomic nitrogen)

M_{N2} = 28,0134 g/mol (molecular nitrogen)

M_{NOx} = 46,0055 g/mol (oxides of nitrogen[(b)])

M_{O} = 15,9994 g/mol (atomic oxygen)

M_{O2} = 31,9988 g/mol (molecular oxygen)

M_{C3H8} = 44,09562 g/mol (propane)

M_{S} = 32,065 g/mol (sulphur)

M_{HC} = 13,875389 g/mol (total hydrocarbon[(a)])

(a) The effective molar mass of HC is defined by an atomic hydrogen-to-carbon ratio, α, of 1,85;

(b) The effective molar mass of NOx is defined by the molar mass of nitrogen dioxide, NO_2.

This section uses the following molar gas constant R for ideal gases:

$$R = 8.314472\,\mathrm{J}/(\mathrm{mol}\cdot\mathrm{K})$$

This section uses the following ratios of specific heats γ $[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]/[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]$ for dilution air and diluted exhaust:

γ_{air} = 1,399 (ratio of specific heats for intake air or dilution air)

γ_{dil} = 1,399 (ratio of specific heats for diluted exhaust gas)

γ_{exh} = 1,385 (ratio of specific heats for raw exhaust gas)

3.3.2. Wet air

This section describes how to determine the amount of water in an ideal gas:

3.3.2.1. Vapour pressure of water

The vapour pressure of water p_{H2O} [kPa] for a given saturation temperature condition, T_{sat} [K], shall be calculated by means of equations (7-77) or (7-78):

(a) For humidity measurements made at ambient temperatures from 0 to 100 °C or for humidity measurements made over super-cooled water at ambient temperatures from - 50 to 0 °C:

$$\log_{10}(p_{\mathrm{H2O}}) = 10.79574 \cdot \left(1 - \frac{273.16}{T_{\mathrm{sat}}}\right) - 5.02800 \cdot \log_{10}\left(\frac{T_{\mathrm{sat}}}{273.16}\right) +$$
$$+1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{T_{\mathrm{sat}}}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{\mathrm{sat}}}\right)} - 1\right) - 0.2138602$$

(7-77)

Where:

p_{H2O} = vapour pressure of water at saturation temperature condition [kPa]

T_{sat} = saturation temperature of water at measured condition [K]

(b) For humidity measurements made over ice at ambient temperatures from (-100 to 0) °C:

$$\log_{10}(p_{\mathrm{H2O}}) = -9.096853 \cdot \left(\frac{273.16}{T_{sat}} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{T_{sat}}\right)$$
$$+ 0.876812 \cdot \left(1 - \frac{T_{sat}}{273.16}\right) - 0.2138602$$

(7-78)

Where:

T_{sat} = saturation temperature of water at measured condition [K]

3.3.2.2. Dew point

If humidity is measured as a dew point, the amount of water in an ideal gas x_{H2O} [mol/mol] shall be obtained by means of equation (7-79):

$$x_{\mathrm{H2O}} = \frac{p_{\mathrm{H2O}}}{p_{\mathrm{abs}}}$$

(7-79)

Where:

x_{H2O} = amount of water in an ideal gas [mol/mol]

p_{H2O} = vapour pressure of water at the measured dew point, T_{sat}=T_{dew} [kPa]

p_{abs} = wet static absolute pressure at the location of dew point measurement [kPa]

3.3.2.3. Relative humidity

If humidity is measured as a relative humidity *RH%*, the amount of water of an ideal gas x_{H2O} [mol/mol] is calculated by means of equation (7-80):

$$x_{\mathrm{H2O}} = \frac{RH\%}{100} \cdot \frac{p_{\mathrm{H2O}}}{p_{\mathrm{abs}}} \tag{7-80}$$

Where:

$RH\%$ = relative humidity [%]

p_{H2O} = water vapour pressure at 100 % relative humidity at the location of relative humidity measurement, $T_{\mathrm{sat}}=T_{\mathrm{amb}}$ [kPa]

p_{abs} = wet static absolute pressure at the location of relative humidity measurement [kPa]

3.3.2.4. Dew point determination from relative humidity and dry bulb temperature

If humidity is measured as a relative humidity, *RH%*, the dew point, T_{dew}, shall be determined from *RH%* and dry bulb temperature by means of equation (7-81):

$$T_{\mathrm{dew}} = \frac{2.0798233 \cdot 10^{2} - 2.0156028 \cdot 10^{1} \cdot \ln(p_{\mathrm{H2O}}) + 4.6778925 \cdot 10^{-1} \cdot \ln(p_{\mathrm{H2O}})^{2} - 9.2288067 \cdot 10^{-6} \cdot \ln(p_{\mathrm{H2O}})^{3}}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(p_{\mathrm{H2O}}) + 5.6577518 \cdot 10^{-3} \cdot \ln(p_{\mathrm{H2O}})^{2} - 7.517286510 \cdot 10^{-5} \cdot \ln(p_{\mathrm{H2O}})^{3}} \tag{7-81}$$

Where

p_{H2O} = water vapor pressure scaled to the relative humidity at the location of relative humidity measurement, $T_{\mathrm{sat}} = T_{\mathrm{amb}}$

T_{dew} = dew point as determined from relative humidity and dry bulb temperature measurements

3.3.3. Fuel properties

The general chemical formula of fuel is $\mathrm{CH}_{\alpha}\mathrm{O}_{\beta}\mathrm{S}_{\gamma}\mathrm{N}_{\delta}$ with α atomic hydrogen-to-carbon ratio (H/C), β atomic oxygen-to-carbon ratio (O/C), γ atomic sulphur-to-carbon ratio (S/C) and δ atomic nitrogen-to-carbon ratio (N/C). Based on this formula the carbon mass fraction of fuel w_{C} can be calculated. In case of diesel fuel the simple formula $\mathrm{CH}_{\alpha}\mathrm{O}_{\beta}$ may be used. Default values for fuel composition may be derived from Table 7.3.:

Table 7.3.

Default values of atomic hydrogen-to-carbon ratio, α, atomic oxygen-to-carbon ratio, β, atomic sulphur-to-carbon ratio, γ, atomic nitrogen-to-carbon ratio, δ, and carbon mass fraction of fuel, w_C for reference fuels

Fuel	Atomic hydrogen, oxygen, sulphur and nitrogen-to-carbon ratios $CH_{\alpha}O_{\beta}S_{\gamma}N_{\delta}$	Carbon mass concentration, w_C [g/g]
Diesel (non-road gas-oil)	$CH_{1,80}O_0S_0N_0$	0,869
Ethanol for dedicated compression ignition engines (ED95)	$CH_{2.92}O_{0.46}S_0N_0$	0.538
Petrol (E10)	$CH_{1,92}O_{0,03}S_0N_0$	0,833
Petrol (E0)	$CH_{1,85}O_0S_0N_0$	0,866
Ethanol (E85)	$CH_{2,73}O_{0,36}S_0N_0$	0,576
LPG	$CH_{2,64}O_0S_0N_0$	0,819
Natural Gas/Biomethane	$CH_{3,78}O_{0,016}S_0N_0$	0,747

3.3.3.1. Calculation of carbon mass concentration w_C

As an alternative to the default values in Table 7.3., or where default values are not given for the reference fuel being used, the carbon mass concentration w_C may be calculated from measured fuel properties by means of equation (7-82). Values for α and β shall be determined for the fuel and inserted into the equation in all cases, but γ and δ may optionally be set to zero if they are zero in the corresponding line of Table 7.3.:

$$w_C = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N} \tag{7-82}$$

where:

M_C = molar mass of carbon.

α = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_H = molar mass of hydrogen.

β = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_O = molar mass of oxygen.

γ = atomic sulphur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_S = molar mass of sulphur.

δ = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_N = molar mass of nitrogen.

3.3.4. Total HC (THC) concentration initial contamination correction

For HC measurement, $x_{\mathrm{THC[THC\text{-}FID]}}$ shall be calculated by using the initial THC contamination concentration $x_{\mathrm{THC[THC\text{-}FID]init}}$ from point 7.3.1.2. of Annex VI by means of equation (7-83):

$$x_{\mathrm{THC[THC\text{-}FID]cor}} = x_{\mathrm{THC[THC\text{-}FID]uncorr}} - x_{\mathrm{THC[THC\text{-}FID]init}} \qquad (7\text{-}83)$$

Where:

$x_{\mathrm{THC[THC\text{-}FID]cor}}$ = THC concentration corrected for contamination [mol/mol]

$x_{\mathrm{THC[THC\text{-}FID]uncorr}}$ = THC uncorrected concentration [mol/mol]

$x_{\mathrm{THC[THC\text{-}FID]init}}$ = initial THC contamination concentration [mol/mol]

3.3.5. Flow-weighted mean concentration

In some points of this section, it may be necessary to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust gas of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust gas molar flow rate, divided by the sum of the recorded flow rate values. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. A certain flow-weighted mean concentration of an emission at its standard might be already expected based on previous testing with similar engines or testing with similar equipment and instruments.

3.4. Chemical balances of fuel, intake air, and exhaust gas

3.4.1. General

Chemical balances of fuel, intake air and exhaust gas may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. With one flow rate of either fuel, intake air or exhaust gas, chemical balances may be used to determine the flows of the other two. For example, chemical balances along with either intake air or fuel flow to determine raw exhaust gas flow may be used.

3.4.2. Procedures that require chemical balances

Chemical balances are required to determine the following:

(a) The amount of water in a raw or diluted exhaust gas flow, x_{H2Oexh}, when the amount of water to correct for the amount of water removed by a sampling system is not measured;

(b) The flow-weighted mean fraction of dilution air in diluted exhaust gas, $x_{dil/exh,}$ when dilution air flow is not measured to correct for background emissions. It has to be noted that if chemical balances are used for this purpose, the exhaust gas is assumed to be stoichiometric, even if it is not.

3.4.3. Chemical balance procedure

The calculations for a chemical balance involve a system of equations that require iteration. The initial values of up to three quantities shall be guessed: the amount of water in the measured flow, x_{H2Oexh}, fraction of dilution air in diluted exhaust gas (or excess air in the raw exhaust gas), $x_{dil/exh}$, and the amount of products on a C1 basis per dry mole of dry measured flow, $x_{Ccombdry}$. Time-weighted mean values of combustion air humidity and dilution air humidity in the chemical balance may be used; as long as combustion air and dilution air humidity remain within tolerances of ± 0,0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x, and amount of water x_{H2Oexh}, their completely dry concentrations, x_{dry} and $x_{H2Oexhdry}$ shall be determined. The fuel atomic hydrogen-to-carbon ratio, α, oxygen-to-carbon ratio, β and carbon mass fraction of fuel, w_C shall also be used. For the test fuel, α and β or the default values in Table 7.3. may be used.

Use the following steps to complete a chemical balance:

(a) Measured concentrations such as, $x_{CO2meas}$, x_{NOmeas}, and x_{H2Oint}, shall be converted to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{H2OxCO2meas}$, $x_{H2OxNOmeas}$, and x_{H2Oint}. If the amount of water present during a "wet" measurement is the same as the unknown amount of water in the exhaust gas flow, x_{H2Oexh}, it has to be iteratively solved for that value in the system of equations. If only total NO_x are measured and not NO and NO_2 separately, good engineering judgement shall be used to estimate a split in the total NO_x concentration between NO and NO_2 for the chemical balances. The molar concentration of NO_x, x_{NOx}, may be assumed to be 75 % NO and 25 % NO_2. For NO_2 storage aftertreatment systems, x_{NOx} may be assumed to be 25 % NO and 75 % NO_2. For calculating the mass of NO_x emissions, the molar mass of NO_2 for the effective molar mass of all NO_x species, regardless of the actual NO_2 fraction of NO_x, shall be used;

(b) Equations (7-82) to (7-99) in paragraph (d) of this point have to be entered into a computer program to iteratively solve for x_{H2Oexh}, $x_{Ccombdry}$ and $x_{dil/exh}$. Good engineering judgment shall be used to guess initial values for x_{H2Oexh}, $x_{Ccombdry}$, and $x_{dil/exh}$. Guessing an initial amount of water that is about twice the amount of water in the intake or dilution air is recommended. Guessing an initial value of $x_{Ccombdry}$ as the sum of the measured CO_2, CO, and THC values is recommended. Guessing an initial x_{dil} between 0,75 and 0,95, such as 0,8 is also recommended. Values in the system of equations shall be iterated until the most recently updated guesses are all within ± 1 % of their respective most recently calculated values values;

(c) The following symbols and subscripts are used in the equation system of paragraph (d) of this point where x unit is mol/mol:

Symbol	Description
$x_{dil/exh}$	Amount of dilution gas or excess air per mole of exhaust gas
x_{H2Oexh}	Amount of H_2O in exhaust per mole of exhaust gas
$x_{Ccombdry}$	Amount of carbon from fuel in the exhaust per mole of dry exhaust gas
$x_{H2Oexhdry}$	Amount of water in exhaust per dry mole of dry exhaust gas
$x_{prod/intdry}$	Amount of dry stoichiometric products per dry mole of intake air
$x_{dil/exhdry}$	Amount of dilution gas and/or excess air per mole of dry exhaust gas
$x_{int/exhdry}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust gas
$x_{raw/exhdry}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust gas
$x_{O2intdry}$	Amount of intake air O_2 per mole of dry intake air; $x_{O2intdry}$ = 0,209445 mol/mol may be assumed
$x_{CO2intdry}$	Amount of intake air CO_2 per mole of dry intake air. $x_{CO2intdry}$ = 375 µmol/mol may be used, but measuring the actual concentration in the intake air is recommended
$x_{H2Ointdry}$	Amount of the intake air H_2O per mole of dry intake air
x_{CO2int}	Amount of intake air CO_2 per mole of intake air
x_{CO2dil}	Amount of dilution gas CO_2 per mole of dilution gas
$x_{CO2dildry}$	Amount of dilution gas CO_2 per mole of dry dilution gas. If air is used as diluent, $x_{CO2dildry}$ = 375 µmol/mol may be used, but measuring the actual

	concentration in the intake air is recommended
$x_{\text{H2Odildry}}$	Amount of dilution gas H_2O per mole of dry dilution gas
x_{H2Odil}	Amount of dilution gas H_2O per mole of dilution gas
$x_{\text{[emission]meas}}$	Amount of measured emission in the sample at the respective gas analyzer
$x_{\text{[emission]dry}}$	Amount of emission per dry mole of dry sample
$x_{\text{H2O[emission]meas}}$	Amount of water in sample at emission-detection location. These values shall be measured or estimated according to point 9.3.2.3.1.
x_{H2Oint}	Amount of water in the intake air, based on a humidity measurement of intake air
K_{H2Ogas}	Water-gas reaction equilibrium coefficient. 3,5 or a different value might be calculated using good engineering judgement.
α	Atomic hydrogen-to-carbon ratio of the mixture of fuel(s) $(\text{CH}_{\alpha}\text{O}_{\beta})$ being combusted, weighted by molar consumption
β	Atomic oxygen-to-carbon ratio of the mixture of fuel(s) $(\text{CH}_{\alpha}\text{O}_{\beta})$ being combusted, weighted by molar consumption

(d) The following equations [(7-84) to (7-101)] shall be used to iteratively solve for $x_{\text{dil/exh}}$, x_{H2Oexh} and x_{Ccombdry}:

$$x_{\text{dil/exh}} = 1 - \frac{x_{\text{raw/exhdry}}}{1 + x_{\text{H2Oexhdry}}} \tag{7-84}$$

$$x_{\text{H2Oexh}} = \frac{x_{\text{H2Oexhdry}}}{1 + x_{\text{H2Oexhdry}}} \tag{7-85}$$

$$x_{\text{Ccombdry}} = x_{\text{CO2dry}} + x_{\text{COdry}} + x_{\text{THCdry}} - x_{\text{CO2dil}} \cdot x_{\text{dil/exhdry}} - x_{\text{CO2int}} \cdot x_{\text{int/exhdry}} \tag{7-86}$$

$$x_{\text{H2dry}} = \frac{x_{\text{COdry}} \cdot \left(x_{\text{H2Oexhdry}} - x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}}\right)}{K_{\text{H2Ogas}} \cdot \left(x_{\text{CO2dry}} - x_{\text{CO2dil}} \cdot x_{\text{dil/exhdry}}\right)}. \tag{7-87}$$

$$x_{\text{H2Oexhdry}} = \frac{\alpha}{2}\left(x_{\text{Ccombdry}} - x_{\text{THCdry}}\right) + x_{\text{H2Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H2Oint}} \cdot x_{\text{int/exhdry}} - x_{\text{H2dry}} \tag{7-88}$$

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H2Oexh}}} \tag{7-89}$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O2int}}}\left[\left(\frac{\alpha}{2} - \beta + 2 + 2\gamma\right)\left(x_{\text{Ccombdry}} - x_{\text{THCdry}}\right) - \left(x_{\text{COdry}} - x_{\text{NOdry}} - 2x_{\text{NO2dry}} + x_{\text{H2dry}}\right)\right]$$

(7-90)

$$x_{\text{raw/exhdry}} = \frac{1}{2}\left[\left(\frac{\alpha}{2}+\beta+\delta\right)\left(x_{\text{Ccombdry}} - x_{\text{THCdry}}\right) + \left(2x_{\text{THCdry}} + x_{\text{COdry}} - x_{\text{NO2dry}} + x_{\text{H2dry}}\right)\right] + x_{\text{int/exhdry}}$$

(7-91)

$$x_{\text{O2int}} = \frac{0.209820 - x_{\text{CO2intdry}}}{1 + x_{\text{H2Ointdry}}}$$

(7-92)

$$x_{\text{CO2int}} = \frac{x_{\text{CO2intdry}}}{1 + x_{\text{H2Ointdry}}}$$

(7-93)

$$x_{\text{H2Ointdry}} = \frac{x_{\text{H2Oint}}}{1 - x_{\text{H2Oint}}}$$

(7-94)

$$x_{\text{CO2dil}} = \frac{x_{\text{CO2dildry}}}{1 + x_{\text{H2Odildry}}}$$

(7-95)

$$x_{\text{H2Odildry}} = \frac{x_{\text{H2Odil}}}{1 - x_{\text{H2Odil}}}$$

(7-96)

$$x_{\text{COdry}} = \frac{x_{\text{COmeas}}}{1 - x_{\text{H2OCOmeas}}}$$

(7-97)

$$x_{\text{CO2dry}} = \frac{x_{\text{CO2meas}}}{1 - x_{\text{H2OCO2meas}}}$$

(7-98)

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H2ONOmeas}}}$$

(7-99)

$$x_{\text{NO2dry}} = \frac{x_{\text{NO2meas}}}{1 - x_{\text{H2ONO2meas}}}$$

(7-100)

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H2OTHCmeas}}}$$

(7-101)

At the end of the chemical balance, the molar flow rate is calculated as specified in points 3.5.3. and 3.6.3..

3.4.4. NO_x correction for humidity

All the NO_x concentrations, including dilution air background concentrations, shall be corrected for intake-air humidity using equation (7-102) or (7-103):

(a) For compression-ignition engines

$$x_{\text{NOxcor}} = x_{\text{NOxuncor}} \cdot (9.953 \cdot x_{\text{H2O}} + 0.832) \qquad (7\text{-}102)$$

(b) For spark-ignition engines

$$x_{\text{NOxcor}} = x_{\text{NOxuncor}} \cdot (18.840 \cdot x_{\text{H2O}} + 0.68094) \qquad (7\text{-}103)$$

Where:

x_{NOxuncor} = uncorrected NO_x molar concentration in the exhaust gas [µmol/mol]

x_{H2O} = amount of water in the intake air [mol/mol]

3.5. Raw gaseous emissions

3.5.1. Mass of gaseous emissions

To calculate the total mass per test of gaseous emission m_{gas} [g/test], its molar concentration shall be multiplied by its respective molar flow and by exhaust gas molar mass; then integration over test cycle shall be performed [equation (7-104)]:

$$m_{\text{gas}} = M_{\text{gas}} \cdot \int \dot{n}_{\text{exh}} \cdot x_{\text{gas}} \cdot \mathrm{d}t \qquad (7\text{-}104)$$

Where:

M_{gas} = molar mass of the generic gaseous emission [g/mol]

$\dot{n}_{\text{exh}}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gas} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

t = time [s]

Since equation (7-104) has to be solved by numerical integration, it is transformed in equation (7-105):

$$m_{\text{gas}} = M_{\text{gas}} \cdot \int \dot{n}_{\text{exh}} \cdot x_{\text{gas}} \cdot \mathrm{d}t \quad \Rightarrow m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \sum_{i=1}^{N} \dot{n}_{\text{exh}i} \cdot x_{\text{gas}i} \qquad (7\text{-}105)$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}i}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gas}i}$ = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

General equation may be modified according to which measurement system is used, batch or continuous sampling, and if a varying rather than a constant flow rate is sampled.

(a) For continuous sampling, in the general case of varying flow rate, the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of equation (7-106):

$$m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \sum_{i=1}^{\mathrm{N}} \dot{n}_{\text{exh}i} \cdot x_{\text{gas}i} \qquad (7\text{-}106)$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}i}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gas}i}$ = instantaneous gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(b) Still for continuous sampling but in the particular case of constant flow rate the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of equation (7-107):

$$m_{\text{gas}} = M_{\text{gas}} \cdot \dot{n}_{\text{exh}} \cdot \bar{x}_{\text{gas}} \cdot \Delta t \qquad (7\text{-}107)$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{\text{gas}}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(c) For the batch sampling, regardless the flow rate is varying or constant, equation (7-104) can be simplified by means of equation (7-108):

$$m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \overline{x}_{\text{gas}} \cdot \sum_{i=1}^{\text{N}} \dot{n}_{\text{exh}i} \tag{7-108}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}i}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{\text{gas}}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

3.5.2. Dry-to-wet concentration conversion

Parameters of this point are obtained from the results of the chemical balance calculated in point 3.4.3.. The following relation exists between gas molar concentrations in the measured flow x_{gasdry} and x_{gas} [mol/mol] expressed on a dry and wet basis respectively [equations (7-109) and (7-110)]:

$$x_{\text{gasdry}} = \frac{x_{\text{gas}}}{1 - x_{\text{H2O}}} \tag{7-109}$$

$$x_{\text{gas}} = \frac{x_{\text{gasdry}}}{1 + x_{\text{H2Odry}}} \tag{7-110}$$

where:

x_{H2O} = molar fraction of water in the measured flow on a wet basis [mol/mol]

x_{H2Odry} = molar fraction of water in the measured flow on a dry basis [mol/mol]

For gaseous emissions a removed water correction shall be performed for the generic concentration x [mol/mol] by means of equation (7-111):

$$x = x_{\mathrm{[emission]meas}} \left[\frac{\left(1 - x_{\mathrm{H2Oexh}}\right)}{1 - x_{\mathrm{H2O[emission]meas}}} \right] \qquad (7\text{-}111)$$

Where:

$x_{\mathrm{[emission]meas}}$ = molar fraction of emission in the measured flow at measurement location [mol/mol]

$x_{\mathrm{H2O[emission]meas}}$ = amount of water in the measured flow at the concentration measurement [mol/mol]

x_{H2Oexh} = amount of water at the flowmeter [mol/mol]

3.5.3. Exhaust gas molar flow rate

The flow rate of the raw exhaust gas can be directly measured or can be calculated based on the chemical balance of point 3.4.3.. Calculation of raw exhaust gas molar flow rate is performed from measured intake air molar flow rate or fuel mass flow rate. The raw exhaust gas molar flow rate can be calculated from the sampled emissions, $\dot{n}_{\mathrm{exh}}$, based on the measured intake air molar flow rate, $\dot{n}_{\mathrm{int}}$, or the measured fuel mass flow rate, $\dot{m}_{\mathrm{fuel}}$, and the values calculated using the chemical balance in point 3.4.3.. It shall be solved for the chemical balance in point 3.4.3. at the same frequency that $\dot{n}_{\mathrm{int}}$ or $\dot{m}_{\mathrm{fuel}}$ is updated and recorded.

(a) Crankcase flow rate. The raw exhaust gas flow can be calculated based on $\dot{n}_{\mathrm{int}}$ or $\dot{m}_{\mathrm{fuel}}$ only if at least one of the following is true about crankcase emission flow rate:

(i) The test engine has a production emission-control system with a closed crankcase that routes crankcase flow back to the intake air, downstream of intake air flow meter;

(ii) During emission testing open crankcase flow shall be routed to the exhaust gas according to point 6.10. of Annex VI;

(iii) Open crankcase emissions and flow are measured and added brake-specific emission calculations;

(iv) Using emission data or an engineering analysis, it can be demonstrated that neglecting the flow rate of open crankcase emissions does not adversely affect compliance with the applicable standards;

(b) Molar flow rate calculation based on intake air.

Based on $\dot{n}_{\mathrm{int}}$, exhaust gas molar flow rate $\dot{n}_{\mathrm{exh}}$ [mol/s] shall be calculated by means of equation (7-112):

$$\dot{n}_{\mathrm{exh}} = \frac{\dot{n}_{\mathrm{int}}}{\left[1 + \frac{\left(x_{\mathrm{int/exhdry}} - x_{\mathrm{raw/exhdry}}\right)}{\left(1 + x_{\mathrm{H2Oexhdry}}\right)}\right]} \qquad (7\text{-}112)$$

Where:

$\dot{n}_{\mathrm{exh}}$ = raw exhaust gas molar flow rate from which emissions are measured [mol/s]

$\dot{n}_{\mathrm{int}}$ = intake air molar flow rate including humidity in intake air [mol/s]

$x_{\mathrm{int/exhdry}}$ = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust gas [mol/mol]

$x_{\mathrm{raw/exhdry}}$ = amount of undiluted exhaust gas, without excess air, per mole of dry (raw or diluted) exhaust gas [mol/mol]

$x_{\mathrm{H2Oexhdry}}$ = amount of water in exhaust gas per mole of dry exhaust gas [mol/mol]

(c) Molar flow rate calculation based on fuel mass flow rate

Based on $\dot{m}_{\mathrm{fuel}}$, $\dot{n}_{\mathrm{exh}}$ [mol/s] shall be calculated as follows:

When conducting laboratory testing this calculation may only be used for discrete-mode NRSC and RMC [equation (7-113)]:

$$\dot{n}_{\mathrm{exh}} = \frac{\dot{m}_{\mathrm{fuel}} \cdot w_{\mathrm{C}} \cdot \left(1 + x_{\mathrm{H2Oexhdry}}\right)}{M_{\mathrm{C}} \cdot x_{\mathrm{Ccombdry}}} \qquad (7\text{-}113)$$

Where:

$\dot{n}_{\mathrm{exh}}$ = raw exhaust gas molar flow rate from which emissions are measured

$\dot{m}_{\text{fuel}}$ = fuel flow rate including humidity in intake air [g/s]

w_C = carbon mass fraction for the given fuel [g/g]

$x_{\text{H2Oexhdry}}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_C = molecular mass of carbon 12,0107 g/mol

x_{Ccombdry} = amount of carbon from fuel in the exhaust gas per mole of dry exhaust gas [mol/mol]

(d) Exhaust gas molar flow rate calculation based on measured intake air molar flow rate, diluted exhaust gas molar flow rate, and dilute chemical balance

Exhaust gas molar flow rate $\dot{n}_{\text{exh}}$ [mol/s] may be calculated based on the measured intake air molar flow rate, $\dot{n}_{\text{int}}$, the measured diluted exhaust gas molar flow rate, $\dot{n}_{\text{dexh}}$, and the values calculated using the chemical balance in point 3.4.3.. Note that the chemical balance must be based on diluted exhaust gas concentrations. For continuous-flow calculations, solve for the chemical balance in point 3.4.3. at the same frequency that $\dot{n}_{\text{int}}$ and $\dot{n}_{\text{dexh}}$ are updated and recorded. This calculated $\dot{n}_{\text{dexh}}$ may be used for the PM dilution ratio verification, the calculation of dilution air molar flow rate in the background correction in point 3.6.1. and the calculation of mass of emissions in point 3.5.1. for species that are measured in the raw exhaust gas.

Based on diluted exhaust gas and intake air molar flow rate, exhaust gas molar flow rate, $\dot{n}_{\text{exh}}$ [mol/s] shall be calculated as follows:

$$\dot{n}_{\text{exh}} = (x_{\text{raw/exhdry}} - x_{\text{int/exhdry}}) \cdot (1 - x_{\text{H2Oexh}}) \cdot \dot{n}_{\text{dexh}} + \dot{n}_{\text{int}} \tag{7-114}$$

where

$\dot{n}_{\text{exh}}$ = raw exhaust gas molar flow rate from which emissions are measured [mol/s];

$x_{\text{int/exhdry}}$ = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust gas [mol/mol];

$x_{\text{raw/exhdry}}$ = amount of undiluted exhaust gas, without excess air, per mole of dry (raw or diluted) exhaust gas [mol/mol];

x_{H2Oexh} = amount of water in exhaust gas per mole of exhaust gas [mol/mol];

$\dot{n}_{\text{dexh}}$ = diluted exhaust gas molar flow rate from which emissions are measured [mol/s];

$\dot{n}_{\text{int}}$ = intake air molar flow rate including humidity in intake air [mol/s].

3.6. Diluted gaseous emissions

3.6.1. Emission mass calculation and background correction

The calculation of gaseous emissions mass m_{gas} [g/test] as a function of molar emissions flow rates shall be calculated as follows:

(a) Continuous sampling, varying flow rate, shall be calculated by means of equation (7-106):

$$m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \sum_{i=1}^{\text{N}} \dot{n}_{\text{exh}i} \cdot x_{\text{gas}i}$$

[see equation (7-106)]

Where:

$M\text{gas}$ = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}i}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gas}i}$ = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

Continuous sampling, constant flow rate, shall be calculated by means of equation (7-107):

$$m_{\text{gas}} = M_{\text{gas}} \cdot \dot{n}_{\text{exh}} \cdot \bar{x}_{\text{gas}} \cdot \Delta t$$

[see equation (7-107)]

Where:

$M\text{gas}$ = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{\text{gas}}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(b) Batch sampling, regardless the flow rate is varying or constant, shall be calculated by means of equation (7-108):

$$m_{\mathrm{gas}} = \frac{1}{f} \cdot M_{\mathrm{gas}} \cdot \bar{x}_{\mathrm{gas}} \cdot \sum_{i=1}^{\mathrm{N}} \dot{n}_{\mathrm{exh}i}$$

[see equation (7-108)]

Where:

Mgas = generic emission molar mass [g/mol]

$\dot{n}_{\mathrm{exh}i}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{\mathrm{gas}}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(c) In case of diluted exhaust gas calculated values for mass of the pollutants shall be corrected by subtracting the mass of background emissions, due to dilution air:

(i) Firstly, the molar flow rate of dilution air $\dot{n}_{\mathrm{airdil}}$ [mol/s] shall be determined over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust gas flow and the flow-weighted mean fraction of dilution air in diluted exhaust gas, $\bar{x}_{\mathrm{dil/exh}}$;

(ii) The total flow of dilution air n_{airdil} [mol] shall be multiplied by the mean concentration of background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of n_{airdil} and the mean concentration of a background emission is the total amount of a background emission;

(iii) If the result is a molar quantity, it shall be converted to a mass of the background emission m_{bkgnd} [g] by multiplying it by emission molar mass, M_{gas} [g/mol];

(iv) Total background mass shall be subtracted from total mass to correct for background emissions;

(v) The total flow of dilution air may be determined by a direct flow measurement. In this case, the total mass of background shall be calculated, using the dilution air flow, n_{airdil}. The background mass shall be subtracted from the total mass. The result shall be used in brake-specific emission calculations;

(vi) The total flow of dilution air may be determined from the total flow of diluted exhaust gas and a chemical balance of the fuel, intake air, and exhaust gas as described in point 3.4. In this case, the total mass of background shall be calculated, using the total flow of diluted exhaust gas, n_{dexh}. Then this result shall be multiplied by the flow-weighted mean fraction of dilution air in diluted exhaust gas, $\bar{x}_{\text{dil/exh}}$.

Considering the two cases (v) and (vi), equations (7-115) and (7-116) shall be used:

$$m_{\text{bkgnd}} = M_{\text{gas}} \cdot x_{\text{gasdil}} \cdot n_{\text{airdil}} \quad \text{or} \quad m_{\text{bkgnd}} = M_{\text{gas}} \cdot \bar{x}_{\text{dil/exh}} \cdot \bar{x}_{\text{bkgnd}} \cdot n_{\text{dexh}} \qquad (7\text{-}115)$$

$$m_{\text{gascor}} = m_{\text{gas}} - m_{\text{bkgnd}} \qquad (7\text{-}116)$$

where:

m_{gas} = total mass of the gaseous emission [g]

m_{bkgnd} = total background masses [g]

m_{gascor} = mass of gas corrected for background emissions [g]

M_{gas} = molecular mass of generic gaseous emission [g/mol]

x_{gasdil} = gaseous emission concentration in dilution air [mol/mol]

n_{airdil} = dilution air molar flow [mol]

$\bar{x}_{\text{dil/exh}}$ = flow-weighted mean fraction of dilution air in diluted exhaust gas [mol/mol]

$\bar{x}_{\text{bkgnd}}$ = gas fraction of background [mol/mol]

n_{dexh} = total flow of diluted exhaust gas [mol]

3.6.2. Dry-to wet concentration conversion

The same relations for raw gases (point 3.5.2.) shall be used for dry-to-wet conversion on diluted samples. For dilution air a humidity measurement shall be performed with the aim to calculate its water vapour fraction $x_{\text{H2Odildry}}$ [mol/mol] by means of equation (7-96):

$$x_{\text{H2Odildry}} = \frac{x_{\text{H2Odil}}}{1 - x_{\text{H2Odil}}} \qquad \text{[(see equation (7-96)]}$$

Where:

x_{H2Odil} = water molar fraction in the dilution air flow [mol/mol]

3.6.3. Exhaust gas molar flow rate

(a) Calculation via chemical balance;

The molar flow rate $\dot{n}_{\text{exh}}$ [mol/s] can be calculated based on fuel mass flow rate $\dot{m}_{\text{fuel}}$ by means of equation (7-113):

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_{\text{C}} \cdot \left(1 + x_{\text{H2Oexhdry}}\right)}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \qquad \text{(see equation 7-113)}$$

Where:

$\dot{n}_{\text{exh}}$ = raw exhaust gas molar flow rate from which emissions are measured

$\dot{m}_{\text{fuel}}$ = fuel flow rate including humidity in intake air [g/s]

w_{C} = carbon mass fraction for the given fuel [g/g]

$x_{\text{H2Oexhdry}}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_{C} = molecular mass of carbon 12,0107 g/mol

x_{Ccombdry} = amount of carbon from fuel in the exhaust gas per mole of dry exhaust gas [mol/mol]

(b) Measurement

The exhaust gas molar flow rate may be measured by means of three systems:

(i) PDP molar flow rate. Based upon the speed at which the Positive Displacement Pump (PDP) operates for a test interval, the corresponding slope a_1, and intercept, a_0 [-], as calculated with the calibration procedure set out in Appendix 1, shall be used to calculate molar flow rate $\dot{n}$ [mol/s] by means of equation (7-117):

$$\dot{n} = f_{\text{n,PDP}} \cdot \frac{p_{\text{in}} \cdot V_{\text{rev}}}{R \cdot T_{\text{in}}} \qquad (7\text{-}117)$$

with:

$$V_{\text{rev}} = \frac{a_1}{f_{\text{n,PDP}}} \cdot \sqrt{\frac{p_{\text{out}} - p_{\text{in}}}{p_{\text{in}}}} + a_0 \qquad (7\text{-}118)$$

where:

a_1 = calibration coefficient [m^3/s]

a_0 = calibration coefficient [m^3/rev]

p_{in}, p_{out} = inlet/outlet pressure [Pa]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

V_{rev} = PDP pumped volume [m^3/rev]

$f_{\mathrm{n.,PDP}}$ = PDP speed [rev/s]

(ii) SSV molar flow rate. Based on the C_{d} versus $\mathrm{R_e}^{\#}$ equation determined according to Appendix 1, the Sub-Sonic Venturi (SSV) molar flow rate during an emission test $\dot{n}$ [mol/s] shall be calculated by means of equation (7-119):

$$\dot{n} = C_{\mathrm{d}} \cdot C_{\mathrm{f}} \cdot \frac{A_{\mathrm{t}} \cdot p_{\mathrm{in}}}{\sqrt{Z \cdot M_{\mathrm{mix}} \cdot R \cdot T_{\mathrm{in}}}} \tag{7-119}$$

Where:

p_{in} = inlet pressure [Pa]

A_{t} = Venturi throat cross-sectional area [m^2]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

Z = compressibility factor

M_{mix} = molar mass of diluted exhaust gas [kg/mol]

C_{d} = discharge coefficient of the SSV [-]

C_{f} = flow coefficient of the SSV [-]

(iii) CFV molar flow rate. To calculate the molar flow rate through one venturi or one combination of venturis, its respective mean C_{d} and other constants, determined according to Appendix 1, shall be used. The calculation of its molar flow rate $\dot{n}$ [mol/s] during an emission test shall be calculated by means of equation (7-120):

$$\dot{n} = C_{\mathrm{d}} \cdot C_{\mathrm{f}} \cdot \frac{A_{\mathrm{t}} \cdot p_{\mathrm{in}}}{\sqrt{Z \cdot M_{\mathrm{mix}} \cdot R \cdot T_{\mathrm{in}}}} \tag{7-120}$$

Where:

p_{in} = inlet pressure [Pa]

A_{t} = Venturi throat cross-sectional area [m^2]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

Z = compressibility factor

M_{mix} = molar mass of diluted exhaust gas [kg/mol]

C_{d} = discharge coefficient of the CFV [-]

C_{f} = flow coefficient of the CFV [-]

3.7. Determination of particulates

3.7.1. Sampling

(a) Sampling from a varying flow rate:

If a batch sample from a changing exhaust gas flow rate is collected, a sample proportional to the changing exhaust gas flow rate shall be extracted. The flow rate shall be integrated over a test interval to determine the total flow. The mean PM concentration $\bar{M}_{\mathrm{PM}}$ (which is already in units of mass per mole of sample) shall be multiplied by the total flow to obtain the total mass of PM m_{PM} [g] by means of equation (7-121):

$$m_{\mathrm{PM}} = \bar{M}_{\mathrm{PM}} \cdot \sum_{i=1}^{\mathrm{N}} \left(\dot{n}_i \cdot \Delta t_i \right) \tag{7-121}$$

Where:

$\dot{n}_i$ = instantaneous exhaust gas molar flow rate [mol/s]

$\bar{M}_{\mathrm{PM}}$ = mean PM concentration [g/mol]

Δt_i = sampling interval [s]

(b) Sampling from a constant flow rate

If a batch sample from a constant exhaust gas flow rate is collected, the mean molar flow rate from which the sample is extracted shall be determined. The mean PM concentration shall be multiplied by the total flow to obtain the total mass of PM m_{PM}[g] by means of equation (7-122):

$$m_{\mathrm{PM}} = \bar{M}_{\mathrm{PM}} \cdot \dot{n} \cdot \Delta t \tag{7-122}$$

where:

$\dot{n}$ = exhaust gas molar flow rate [mol/s]

$\bar{M}_{\mathrm{PM}}$ = mean PM concentration [g/mol]

Δt = time duration of test interval [s]

For sampling with a constant dilution ratio (*DR*), m_{PM} [g] shall be calculated by means of equation (7-123):

$$m_{\mathrm{PM}} = m_{\mathrm{PMdil}} \cdot DR \tag{7-123}$$

where:

m_{PMdil} = PM mass in dilution air [g]

DR = dilution ratio [-] defined as the ratio between the mass of the emission m and the mass of diluted exhaust gas $m_{\mathrm{dil/exh}}$ ($DR = m/m_{\mathrm{dil/exh}}$).

The dilution ratio *DR* can be expressed as a function of $x_{\mathrm{dil/exh}}$ [equation (7-124)]:

$$DR = \frac{1}{1 - x_{\mathrm{dil/exh}}} \tag{7-124}$$

3.7.2. Background correction

The same approach as that of point 3.6.1. shall be applied to correct the mass of PM for the background. Multiplying $\bar{M}_{\mathrm{PMbkgnd}}$ by the total flow of dilution air, the total background mass of PM (m_{PMbkgnd} [g]) is obtained. Subtraction of total background mass from total mass gives background corrected mass of particulates m_{PMcor} [g] [equation (7-125)]:

$$m_{\mathrm{PMcor}} = m_{\mathrm{PMuncor}} - \bar{M}_{\mathrm{PMbkgnd}} \cdot n_{\mathrm{airdil}} \tag{7-125}$$

where:

m_{PMuncor} = uncorrected PM mass [g]

$\overline{M}_{\mathrm{PMbkgnd}}$ = mean PM concentration in dilution air [g/mol]

n_{airdil} = dilution air molar flow [mol]

3.8. Cycle work and specific emissions

3.8.1. Gaseous emissions

3.8.1.1. 2.3.1. Transient (NRTC and LSI-NRTC) test cycles and RMC

Reference is made to points 3.5.1. and 3.6.1. for raw and diluted exhaust gas respectively. The resulting values for power P_i [kW] shall be integrated over a test interval. The total work W_{act} [kWh] shall be calculated by means of equation (7-126):

$$W_{\mathrm{act}} = \sum_{i=1}^{\mathrm{N}} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^{\mathrm{N}} \left(n_i \cdot T_i \right) \qquad \text{(7-126)}$$

Where:

P_i = instantaneous engine power [kW]

n_i = instantaneous engine speed [rpm]

T_i = instantaneous engine torque [N·m]

W_{act} = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

Where auxiliaries were fitted in accordance with Appendix 2 of Annex VI there shall be no adjustment to the instantaneous engine torque in equation (7-126). Where, according to points 6.3.2. or 6.3.3. of Annex VI to this regulation necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value of T_i used in equation (7-126) shall be adjusted by means of equation (7-127):

$$T_i = T_{i,\mathrm{meas}} + T_{i,\mathrm{AUX}} \qquad \text{(7-127)}$$

Where:

$T_{i,\mathrm{meas}}$ = measured value of instantaneous engine torque

$T_{i,\mathrm{AUX}}$ = corresponding value of torque required to drive auxiliaries determined according to point 7.7.2.3.2. of Annex VI to this regulation.

The specific emissions e_{gas} [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{\mathrm{gas}} = \frac{m_{\mathrm{gas}}}{W_{\mathrm{act}}} \qquad (7\text{-}128)$$

where:

m_{gas} = total mass of emission [g/test]

W_{act} = cycle work [kWh]

In case of the NRTC, for gaseous emissions other than CO_2 the final test result e_{gas} [g/kWh] shall be a weighted average from cold-start run and hot-start run calculated by means of equation (7-129):

$$e_{\mathrm{gas}} = \frac{(0.1 \cdot m_{\mathrm{cold}}) + (0.9 \cdot m_{\mathrm{hot}})}{(0.1 \cdot W_{\mathrm{actcold}}) + (0.9 \cdot W_{\mathrm{acthot}})} \qquad (7\text{-}129)$$

Where:

m_{cold} is the gas mass emissions of the cold-start NRTC [g]

$W_{\mathrm{act,\ cold}}$ is the actual cycle work of the cold-start NRTC [kWh]

m_{hot} is the gas mass emissions of the hot-start NRTC [g]

$W_{\mathrm{act,\ hot}}$ is the actual cycle work of the hot-start NRTC [kWh]

In case of the NRTC, for CO_2 the final test result e_{CO2} [g/kWh] shall be calculated from the hot-start NRTC calculated by means of equation (7-130):

$$e_{\mathrm{CO2,hot}} = \frac{m_{\mathrm{CO2,hot}}}{W_{\mathrm{act,hot}}} \qquad (7\text{-}130)$$

Where:

$m_{\mathrm{CO2,\ hot}}$ is the CO_2 mass emissions of the hot-start NRTC [g]

$W_{\mathrm{act,\ hot}}$ is the actual cycle work of the hot-start NRTC [kWh]

3.8.1.2. Discrete-mode NRSC

The specific emissions e_{gas} [g/kWh] shall be calculated by means of equation (7-131):

$$e_{\text{gas}} = \frac{\sum_{i=1}^{N_{\text{mode}}} \left(\dot{m}_{\text{gas}i} \cdot WF_i\right)}{\sum_{i=1}^{N_{\text{mode}}} \left(P_i \cdot WF_i\right)} \qquad (7\text{-}131)$$

where:

$\dot{m}_{\text{gas},i}$ = mean emission mass flow rate for the mode i [g/h]

P_i = engine power for the mode i [kW] with $P_i = P_{\max i} + P_{\text{aux}i}$ (see points 6.3. and 7.7.1.3. of Annex VI)

WF_i = weighting factor for the mode i [-]

3.8.2. Particulate emissions

3.8.2.1. 2.3.1. Transient (NRTC and LSI-NRTC) test cycles and RMC

The particulate specific emissions shall be calculated by transforming equation (7-128) into equation (7-132) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{\text{PM}} = \frac{m_{\text{PM}}}{W_{\text{act}}} \qquad (7\text{-}132)$$

Where:

m_{PM} = total mass of particulates emission, calculated according to point 3.7.1. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold-start NRTC and hot-start NRTC) shall be calculated as shown in point 3.8.1.1..

3.8.2.2. Discrete-mode NRSC

The particulate specific emission e_{PM} [g/kWh] shall be calculated in the following way:

4.8.2.2.1. For the single-filter method by means of equation (7-133):

$$e_{\text{PM}} = \frac{\dot{m}_{\text{PM}}}{\sum_{i=1}^{N} \left(P_i \cdot WF_i\right)} \qquad (7\text{-}133)$$

Where:

P_i = engine power for the mode *i* [kW] with $P_i = P_{\text{max}i} + P_{\text{aux}i}$ (see points 6.3. and 7.7.1.3. of Annex VI)

WF_i = weighting factor for the mode *i* [-]

$\dot{m}_{\text{PM}}$ = particulate mass flow rate [g/h]

4.8.2.2.2. For the multiple-filter method by means of equation (7-134):

$$e_{\text{PM}} = \frac{\sum_{i=1}^{N} \left(\dot{m}_{\text{PM}i} \cdot WF_i \right)}{\sum_{i=1}^{N} \left(P_i \cdot WF_i \right)} \tag{7-134}$$

Where:

P_i = engine power for the mode *i* [kW] with $P_i = P_{\text{max}i} + P_{\text{aux}i}$ (see points 6.3. and 7.7.1.3. of Annex VI)

WF_i = weighting factor for the mode *i* [-]

$\dot{m}_{\text{PM}i}$ = particulate mass flow rate at mode *i* [g/h]

For the single-filter method, the effective weighting factor, $WF_{\text{eff}i}$, for each mode shall be calculated by means of equation (7-135):

$$WF_{\text{eff}i} = \frac{m_{\text{smpldexh}i} \cdot \overline{\dot{m}_{\text{eqdexhwet}}}}{m_{\text{smpldex}} \cdot \dot{m}_{\text{eqdexhwet}i}} \tag{7-135}$$

Where:

$m_{\text{smpldexh}i}$ = mass of the diluted exhaust gas sample passed through the particulate sampling filters at mode *i* [kg]

m_{smpldexh} = mass of the diluted exhaust gas sample passed through the particulate sampling filters [kg]

$\dot{m}_{\text{eqdexhwet}i}$ = equivalent diluted exhaust gas mass flow rate at mode *i* [kg/s]

$\overline{\dot{m}_{\text{eqdexhwet}}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

The value of the effective weighting factors shall be within ± 0,005 (absolute value) of the weighting factors listed in Appendix 1 of Annex XVII.

3.8.3. Adjustment for emission controls that are regenerated on an infrequent (periodic) basis

In case of engines, other than those of category RLL, equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis (see point 6.6.2. of Annex VI), the specific emissions of gaseous and particulate pollutants calculated according to points 3.8.1. and 3.8.2. shall be corrected with either the applicable multiplicative adjustment factor or with the applicable additive adjustment factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$). In the case of the discrete-mode NRSC, where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result.

3.8.4. Adjustment for deterioration factor

The specific emissions of gaseous and particulate pollutants calculated according to points 3.8.1. and 3.8.2., where applicable inclusive of the infrequent regeneration adjustment factor according to point 3.8.3., shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex III.

3.9. Diluted Exhaust Flow (CVS) Calibration and Related Calculations

This section describes the calculations for calibrating various flow meters. Point 3.9.1. first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining points describe the calibration calculations that are specific to certain types of flow meters.

3.9.1. Reference meter conversions

The calibration equations in this section use molar flow rate, $\dot{n}_{\mathrm{ref}}$, as a reference quantity. If the adopted reference meter outputs a flow rate in a different quantity, such as standard volume rate, $\dot{V}_{\mathrm{stdref}}$, actual volume rate, $\dot{V}_{\mathrm{actdref}}$, or mass rate, $\dot{m}_{\mathrm{ref}}$, the reference meter output shall be converted to a molar flow rate by means of equations (7-136), (7-137) and (7-138), noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, they should be kept as constant as practical for each individual set point during a flow meter calibration:

$$\dot{n}_{\mathrm{ref}} = \frac{\dot{V}_{\mathrm{stdref}} \cdot p_{\mathrm{std}}}{T_{\mathrm{std}} \cdot R} = \frac{\dot{V}_{\mathrm{actref}} \cdot p_{\mathrm{act}}}{T_{\mathrm{act}} \cdot R} = \frac{\dot{m}_{\mathrm{ref}}}{M_{\mathrm{mix}}} \qquad (7\text{-}136)$$

where:

$\dot{n}_{\mathrm{ref}}$	=	reference molar flow rate [mol/s]
$\dot{V}_{\mathrm{stdref}}$	=	reference volume flow rate, corrected to a standard pressure and a standard temperature [m^3/s]
$\dot{V}_{\mathrm{actref}}$	=	reference volume flow rate, at the actual pressure and temperature [m^3/s]
$\dot{m}_{\mathrm{ref}}$	=	reference mass flow [g/s]
p_{std}	=	standard pressure [Pa]
p_{act}	=	actual pressure of the gas [Pa]
T_{std}	=	standard temperature [K]
T_{act}	=	actual temperature of the gas [K]
R	=	molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$
M_{mix}	=	molar mass of the gas [g/mol]

3.9.2. PDP calibration calculations

For each restrictor position, the following values shall be calculated from the mean values determined in point 8.1.8.4. of Annex VI, as follows:

(a) PDP volume pumped per revolution, V_{rev} ($\mathrm{m^3/rev}$):

$$V_{\mathrm{rev}} = \frac{\bar{\dot{n}}_{\mathrm{ref}} \cdot R \cdot \bar{T}_{\mathrm{in}}}{\bar{p}_{\mathrm{in}} \cdot \bar{f}_{n\mathrm{PDP}}} \qquad (7\text{-}137)$$

where:

$\bar{\dot{n}}_{\mathrm{ref}}$ = mean value of reference molar flow rate [mol/s]

R = molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

$\bar{T}_{\mathrm{in}}$ = mean inlet temperature [K]

$\bar{p}_{\mathrm{in}}$ = mean inlet pressure [Pa]

$\bar{f}_{n\mathrm{PDP}}$ = mean rotational speed [rev/s]

(b) PDP slip correction factor, K_{s} [s/rev]:

$$K_{\mathrm{s}} = \frac{1}{\bar{f}_{n\mathrm{PDP}}} \cdot \sqrt{\frac{\bar{p}_{\mathrm{out}} - \bar{p}_{\mathrm{in}}}{\bar{p}_{\mathrm{out}}}} \qquad (7\text{-}138)$$

Where:

$\bar{\dot{n}}_{\mathrm{ref}}$ = mean reference molar flow rate [mol/s]

$\bar{T}_{\mathrm{in}}$ = mean inlet temperature [K]

$\bar{p}_{\mathrm{in}}$ = mean inlet pressure [Pa]

$\bar{p}_{\mathrm{out}}$ = mean outlet pressure [Pa]

$\bar{f}_{n\mathrm{PDP}}$ = mean PDP revolution speed [rev/s]

R = molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

(c) A least-squares regression of PDP volume pumped per revolution, V_{rev}, versus PDP slip correction factor, K_{s}, shall be performed by calculating slope, a_1, and intercept, a_0, as described in Appendix 4;

(d) The procedure in subparagraphs (a) to (c) of this point shall be repeated for every speed that PDP is operated;

(e) Table 7.4. illustrates these calculations for different values of $\overline{f}_{n\mathrm{PDP}}$:

Table 7.4.

Example of PDP calibration data

$\overline{f}_{n\text{PDP}}$ [rev/min]	$\overline{f}_{n\text{PDP}}$ [rev/s]	a_1 [m^3/min]	a_1 [m^3/s]	a_0 [m^3/rev]
755,0	12,58	50,43	0,8405	0,056
987,6	16,46	49,86	0,831	-0,013
1254,5	20,9	48,54	0,809	0,028
1401,3	23,355	47,30	0,7883	-0,061

(f) For each speed at which the PDP is operated, the corresponding slope, a_1, and intercept, a_0, shall be used to calculate flow rate during emission testing as described in point 3.6.3.(b).

3.9.3. Venturi governing equations and permissible assumptions

This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio, r (i.e., r_{SSV} versus r_{CFV}). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In point 3.9.3.(d), other assumptions that may be made are described. If the assumption of an ideal gas for the measured flow is not allowed, the governing equations include a first-order correction for the behaviour of a real gas; namely, the compressibility factor, Z. If good engineering judgment dictates using a value other than $Z = 1$, an appropriate equation of state to determine values of Z as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed based on good engineering judgment. It shall be noted that the equation for the flow coefficient, C_{f}, is based on the ideal gas assumption that the isentropic exponent, γ, is equal to the ratio of specific heats, c_p/c_V. If good engineering judgment dictates using a real gas isentropic exponent, an appropriate equation of state to determine values of γ as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed. Molar flow rate, $\dot{n}$ [mol/s], shall be calculated by means of equation (7-139):

$$\dot{n} = C_{\text{d}} \cdot C_{\text{f}} \cdot \frac{A_{\text{t}} \cdot p_{\text{in}}}{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}} \qquad (7\text{-}139)$$

Where:

C_{d} = Discharge coefficient, as determined in point 3.9.3.(a) [-]

C_f = Flow coefficient, as determined in point 3.9.3.(b) [-]

A_t = Venturi throat cross-sectional area [m^2]

p_{in} = Venturi inlet absolute static pressure [Pa]

Z = Compressibility factor [-]

M_{mix} = Molar mass of gas mixture [kg/mol]

R = Molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

T_{in} = Venturi inlet absolute temperature [K]

(a) Using the data collected in point 8.1.8.4. of Annex VI, C_d is calculated by means of equation (7-140):

$$C_d = \dot{n}_{ref} \cdot \frac{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}{C_f \cdot A_t \cdot p_{in}} \quad (7\text{-}140)$$

Where:

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

Other symbols as per equation (7-139).

(b) C_f shall be determined using one of the following methods:

(i) For CFV flow meters only, C_{fCFV} is derived from Table 7.5. based on values for β (ratio of venturi throat to inlet diameters) and γ (ratio of specific heats of the gas mixture), using linear interpolation to find intermediate values:

Table 7.5.

C_{fCFV} versus β and γ for CFV flow meters

C_{fCFV}		
β	γ_{exh} =1,385	γ_{dexh} =γ_{air}=1,399
0,000	0,6822	0,6846
0,400	0,6857	0,6881
0,500	0,6910	0,6934
0,550	0,6953	0,6977
0,600	0,7011	0,7036
0,625	0,7047	0,7072
0,650	0,7089	0,7114
0,675	0,7137	0,7163
0,700	0,7193	0,7219
0,720	0,7245	0,7271
0,740	0,7303	0,7329
0,760	0,7368	0,7395
0,770	0,7404	0,7431
0,780	0,7442	0,7470
0,790	0,7483	0,7511
0,800	0,7527	0,7555
0,810	0,7573	0,7602
0,820	0,7624	0,7652
0,830	0,7677	0,7707
0,840	0,7735	0,7765
0,850	0,7798	0,7828

(ii) For any CFV or SSV flow meter, equation (7-141) may be used to calculate C_f:

$$C_{\mathrm{f}} = \left[\frac{2 \cdot \gamma \cdot \left(r^{\frac{\gamma-1}{\gamma}} - 1 \right) \cdot}{(\gamma - 1) \cdot \left(\beta^4 - r^{\frac{-2}{\gamma}} \right)} \right]^{\frac{1}{2}} \tag{7-141}$$

Where:

γ = isentropic exponent [-]. For an ideal gas, this is the ratio of specific heats of the gas mixture, c_p/c_V

r = pressure ratio, as determined in paragraph (c)(3) of this point

β = ratio of venturi throat to inlet diameters

(c) The pressure ratio r shall be calculated as follows:

(i) For SSV systems only, r_{SSV} shall be calculated by means of equation (7-142):

$$r_{\mathrm{SSV}} = 1 - \frac{\Delta p_{\mathrm{SSV}}}{p_{\mathrm{in}}} \tag{7-142}$$

Where:

Δp_{SSV} = differential static pressure; venturi inlet minus venturi throat [Pa]

(ii) For CFV systems only, r_{CFV} shall be calculated iteratively by means of equation (7-143):

$$r_{\mathrm{CFV}}^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma - 1}{2} \right) \cdot \beta^4 \cdot r_{\mathrm{CFV}}^{\frac{2}{\gamma}} = \frac{\gamma + 1}{2} \tag{7-143}$$

(d) Any of the following simplifying assumptions of the governing equations may be made, or good engineering judgment may be used to develop more appropriate values for testing:

(i) For emission testing over the full ranges of raw exhaust gas, diluted exhaust gas and dilution air, the gas mixture may be assumed to behave as an ideal gas: $Z = 1$;

(ii) For the full range of raw exhaust gas a constant ratio of specific heats of γ = 1,385 may be assumed;

(iii) For the full range of diluted exhaust gas and air (e.g., calibration air or dilution air), a constant ratio of specific heats of γ = 1,399 may be assumed;

(iv) For the full range of diluted exhaust gas and air, the molar mass of the mixture, M_{mix} [g/mol], may be considered as a function only of the amount of water in the dilution air or calibration air, x_{H2O}, determined as described in point 3.3.2. and shall be calculated by means of equation (7-144):

$$M_{\text{mix}} = M_{\text{air}} \cdot (1 - x_{\text{H2O}}) + M_{\text{H2O}} \cdot (x_{\text{H2O}}) \qquad (7\text{-}144)$$

Where:

M_{air} = 28,96559 g/mol

M_{H2O} = 18,01528 g/mol

x_{H2O} = amount of water in the dilution or calibration air [mol/mol]

(v) For the full range of diluted exhaust gas and air, a constant molar mass of the mixture, M_{mix}, may be assumed for all calibration and all testing as long as assumed molar mass differs no more than ± 1 % from the estimated minimum and maximum molar mass during calibration and testing. This assumption may be made if sufficient control of the amount of water in calibration air and in dilution air is ensured, or if sufficient water is removed from both calibration air and dilution air. Table 7.6. provides for examples of permissible ranges of dilution air dew point versus calibration air dew point:

Table 7.6.

Examples of dilution air and calibration air dew points at which a constant M_{mix} may be assumed

If calibration T_{dew} (°C) is...	the following constant M_{mix} (g/mol) is assumed	for the following ranges of T_{dew} (°C) during emission tests [(a)]
dry	28,96559	dry to 18
0	28,89263	dry to 21
5	28,86148	dry to 22
10	28,81911	dry to 24
15	28,76224	dry to 26

20	28,68685	-8 to 28
25	28,58806	12 to 31
30	28,46005	23 to 34
[a] Range valid for all calibration and emission testing over the atmospheric pressure range (80,000 to 103,325) kPa.		

3.9.4. SSV calibration

(a) Molar based approach. To calibrate an SSV flow meter the following steps shall be performed:

(i) The Reynolds number, $Re^{\#}$, for each reference molar flow rate, shall be calculated using the throat diameter of the venturi, d_{t} [equation (7-145)]. Because the dynamic viscosity, μ, is needed to compute $Re^{\#}$, a specific viscosity model may be used to determine μ for calibration gas (usually air), using good engineering judgment [equation (7-146)]. Alternatively, the Sutherland three-coefficient viscosity model may be used to approximate μ (see Table 7.7.):

$$Re^{\#} = \frac{4 \cdot M_{\mathrm{mix}} \cdot \dot{n}_{\mathrm{ref}}}{\pi \cdot d_{\mathrm{t}} \cdot \mu} \qquad \text{(7-145)}$$

Where:

d_{t} = diameter of the SSV throat [m]

M_{mix} = mixture molar mass [kg/mol]

$\dot{n}_{\mathrm{ref}}$ = reference molar flow rate [mol/s]

and, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \left(\frac{T_{\mathrm{in}}}{T_0} \right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T_{\mathrm{in}} + S} \right) \qquad \text{(7-146)}$$

Where:

μ = Dynamic viscosity of calibration gas [kg /(m•s)]

μ_0 = Sutherland reference viscosity [kg /(m·s)]

S = Sutherland constant [K]

T_0 = Sutherland reference temperature [K]

T_{in} = Absolute temperature at the venturi inlet [K]

Table 7.7.

Sutherland three-coefficient viscosity model parameters

Gas[(a)]	μ_0	T_0	S	Temp range within ±2 % error	Pressure limit
	kg /(m·s)	K	K	K	kPa
Air	$1{,}716 \times 10^{-5}$	273	111	170 to 1900	≤ 1800
CO_2	$1{,}370 \times 10^{-5}$	273	222	190 to 1700	≤ 3600
H_2O	$1{,}12 \times 10^{-5}$	350	1,064	360 to 1500	≤ 10000
O_2	$1{,}919 \times 10^{-5}$	273	139	190 to 2000	≤ 2500
N_2	$1{,}663 \times 10^{-5}$	273	107	100 to 1500	≤ 1600

(a) Tabulated parameters only for the pure gases, as listed, shall be used. Parameters to calculate viscosities of gas mixtures shall not be combined.

(ii) An equation for C_d versus $Re^{\#}$ shall be created, using paired values of ($Re^{\#}$, C_d). C_d is calculated according to equation (7-140), with C_f obtained from equation (7-141), or any mathematical expression may be used, including a polynomial or a power series. Equation (7-147) is an example of a commonly used mathematical expression for relating C_d and $Re^{\#}$;

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}} \qquad (7\text{-}147)$$

(iii) A least-squares regression analysis shall be performed to determine the best-fit coefficients to the equation and calculate the equation's regression statistics, the standard estimate error *SEE* and the coefficient of determination r^2, in accordance with Appendix 3;

(iv) If the equation meets the criteria of $SEE < 0{,}5\ \%\ n_{\text{ref max}}$ (or $\dot{m}_{\text{refmax}}$) and $r^2 \geq 0{,}995$, the equation may be used to determine C_d for emission tests, as described in point 3.6.3.(b);

(v) If the *SEE* and r^2 criteria are not met, good engineering judgment may be used to omit calibration data points to meet the regression statistics. At least seven calibration data points shall be used to meet the criteria;

(vi) If omitting points does not resolve outliers, corrective action shall be taken. For example, another mathematical expression for the C_d versus $Re^{\#}$ equation shall be selected, leaks are to be checked, or the calibration process has to be repeated. If the process shall be repeated, tighter tolerances shall be applied to measurements and more time for flows to stabilize shall be allowed;

(vii) Once the equation meets the regression criteria, the equation may be used only to determine flow rates that are within the range of the reference flow rates used to meet the C_d versus $Re^{\#}$ equation's regression criteria.

3.9.5. CFV calibration

(a) Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow meters that consist of multiple venturis, either calibration of each venturi independently to determine a separate discharge coefficient, C_d, for each venturi, or calibration of each combination of venturis as one venture may be performed. In the case where a combination of venturis is calibrated, the sum of the active venturi throat areas is used as A_t, the square root of the sum of the squares of the active venturi throat diameters as d_t, and the ratio of the venturi throat to inlet diameters as the ratio of the venturi throat to inlet diameters as the ratio of the square root of the sum of the active venture throat diameters (d_t) to the diameter of the common entrance to all of the venturis (D). To determine the C_d for a single venturi or a single combination of venturis, the following steps shall be performed:

(i) With the data collected at each calibration set point an individual C_d for each point shall be calculated using equation (7-140);

(ii) The mean and standard deviation of all the C_d values shall be calculated in accordance with equations (7-155) and (7-156);

(iii) If the standard deviation of all the C_d values is less than or equal to 0,3 % of the mean C_d, then the mean C_d shall be used in equation (7-120), and the CFV shall be used only down to the lowest r measured during calibration;

$$r = 1 - \left(\Delta p / p_{in}\right) \tag{7-148}$$

(iv) If the standard deviation of all the C_d values exceeds 0,3 % of the mean C_d, the C_d values corresponding to the data point collected at the lowest r measured during calibration shall be omitted;

(v) If the number of remaining data points is less than seven, corrective action shall be taken by checking calibration data or repeating the calibration process. If the calibration process is repeated, checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilize, is recommended;

(vi) If the number of remaining C_d values is seven or greater, the mean and standard deviation of the remaining C_d values shall be recalculated;

(vii) If the standard deviation of the remaining C_d values is less than or equal to 0,3 % of the mean of the remaining C_d, that mean C_d shall be used in equation (7-120) and the CFV values only down to the lowest r associated with the remaining C_d shall be used;

(viii) If the standard deviation of the remaining C_d still exceeds 0,3 % of the mean of the remaining C_d values, the steps set out in paragraph (e) (4) to (8) of this point shall be repeated.

Appendix 1

Drift Correction

1. Scope and frequency

The calculations in this Appendix shall be performed to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, the test interval's gas analyzer responses shall be corrected for drift according to this Appendix. The drift-corrected gas analyzer responses shall be used in all subsequent emission calculations. The acceptable threshold for gas analyzer drift over a test interval is specified in point 8.2.2.2. of Annex VI.

2. Correction principles

The calculations in this Appendix utilize a gas analyzer's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyzer's responses that were recorded during a test interval. The correction is based on an analyzer's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validation and correction for drift shall be performed as follows:

3. Drift validation

After applying all the other corrections–except drift correction–to all the gas analyzer signals, brake-specific emissions shall be calculated in accordance with point 3.8.. Then all gas analyzer signals shall be corrected for drift according to this Appendix. Brake-specific emissions shall be recalculated using all of the drift-corrected gas analyzer signals. The brake-specific emission results shall be validated and reported before and after drift correction according to point 8.2.2.2. of Annex VI.

4. Drift correction

All gas analyzer signals shall be corrected as follows:

(a) Each recorded concentration, x_i, shall be corrected for continuous sampling or for batch sampling, $\bar{x}$;

(b) Correction for drift shall be calculated by means of equation (7-149):

$$x_{i\text{driftcor}} = x_{\text{refzero}} + \left(x_{\text{refspan}} - x_{\text{refzero}}\right)\frac{2x_i - \left(x_{\text{prezero}} + x_{\text{postzero}}\right)}{\left(x_{\text{prespan}} + x_{\text{postspan}}\right) - \left(x_{\text{prezero}} + x_{\text{postzero}}\right)} \qquad (7\text{-}149)$$

Where:

$x_{i\text{driftcor}}$ = concentration corrected for drift [µmol/mol]

x_{refzero} = reference concentration of the zero gas, which is usually zero unless known to be otherwise [µmol/mol]

x_{refspan} = reference concentration of the span gas [µmol/mol]

x_{prespan} = pre-test interval gas analyzer response to the span gas concentration [µmol/mol]

x_{postspan} = post-test interval gas analyzer response to the span gas concentration [µmol/mol]

x_i or $\overline{x}$ = concentration recorded, i.e. measured, during test, before drift correction [µmol/mol]

x_{prezero} = pre-test interval gas analyzer response to the zero gas concentration [µmol/mol]

x_{postzero} = post-test interval gas analyzer response to the zero gas concentration [µmol/mol]

(c) For any pre-test interval concentrations, concentrations determined most recently before the test interval shall be used. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals;

(d) For any post-test interval concentrations, concentrations determined most recently after the test interval shall be used. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals;

(e) If any pre-test interval analyzer response to the span gas concentration, x_{prespan}, is not recorded, x_{prespan} shall be set equal to the reference concentration of the span gas: $x_{\mathrm{prespan}} = x_{\mathrm{refspan}}$;

(f) If any pre-test interval analyzer response to the zero gas concentration, x_{prezero}, is not recorded, x_{prezero} shall be set equal to the reference concentration of the zero gas: $x_{\mathrm{prezero}} = x_{\mathrm{refzero}}$;

(g) Usually the reference concentration of the zero gas, $\mathrm{x}_{\mathrm{refzero}}$, is zero: $\mathrm{x}_{\mathrm{refzero}} = 0$ µmol/mol. However, in some cases it might be known that $\mathrm{x}_{\mathrm{refzero}}$ has a non-zero concentration. For example, if a CO_2 analyzer is zeroed using ambient air, the default ambient air concentration of CO_2, which is 375 µmol/mol, may be used. In this case, $\mathrm{x}_{\mathrm{refzero}} = 375$ µmol/mol. When an analyzer is zeroed using a non-zero $\mathrm{x}_{\mathrm{refzero}}$, the analyzer shall be set to output the actual xrefzero concentration. For example, if $\mathrm{x}_{\mathrm{refzero}} = 375$ µmol/mol, the analyzer shall be set to output a value of 375 µmol/mol when the zero gas is flowing to the analyzer.

Appendix 2

Carbon Flow Check

1. Introduction

All but a tiny part of the carbon in the exhaust gas comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO_2. This is the basis for a system verification check based on CO_2 measurements. In the case of SI engines without control of excess air ratio λ or SI engines operating outside the range $0,97 \leq \lambda \leq 1,03$, the procedure shall additionally include measurement of HC and CO.

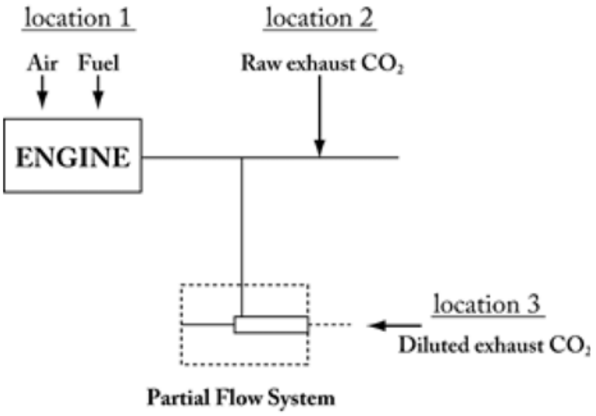
The flow of carbon into the exhaust gas measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO_2 (or CO_2, HC and CO) concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure 7.1. shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given in the following points.

Figure 7.1.

Measuring points for carbon flow check



2. Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine $q_{m\mathrm{Cf}}$ [kg/s] for a fuel $\mathrm{CH}_{\alpha}\mathrm{O}_{\varepsilon}$ shall be calculated by means of equation (7-150):

$$q_{m\mathrm{Cf}} = \frac{12.011}{12.011 + \alpha + 15.9994 \cdot \varepsilon} \cdot q_{m\mathrm{f}} \qquad (7\text{-}150)$$

Where:

$q_{m\mathrm{f}}$ = fuel mass flow rate [kg/s]

3. Carbon flow rate in the raw exhaust gas (location 2)

3.1. Based on CO_2

The carbon mass flow rate in the exhaust pipe of the engine $q_{m\mathrm{Ce}}$ [kg/s] shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate by means of equation (7-151):

$$q_{m\mathrm{Ce}} = \left(\frac{c_{\mathrm{CO2,r}} - c_{\mathrm{CO2,a}}}{100} \right) \cdot q_{m\mathrm{ew}} \cdot \frac{12.011}{M_{\mathrm{e}}} \qquad (7\text{-}151)$$

where:

$c_{\mathrm{CO2,r}}$ = wet CO_2 concentration in the raw exhaust gas [%]

$c_{\mathrm{CO2,a}}$ = wet CO_2 concentration in the ambient air [%]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on wet basis [kg/s]

M_{e} = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis it shall be converted to a wet basis in accordance with point 2.1.3. or point 3.5.2..

3.2. Based on CO_2, HC and CO

As an alternative to performing the calculation solely based upon CO_2 in point 3.1., the carbon mass flow rate in the exhaust pipe of the engine $q_{m\mathrm{Ce}}$ [kg/s] shall be determined from the raw CO_2, HC and CO concentration and the exhaust gas mass flow rate by means of equation (7-152):

$$q_{mCe} = \left(\frac{c_{CO2,r} - c_{CO2,a}}{100} + \frac{c_{THC(C1),r} - c_{THC(C1),a}}{100} + \frac{c_{CO,r} - c_{CO,a}}{100}\right) \cdot q_{mew} \frac{12.011}{M_e}$$

(7-152)

Where:

$c_{\mathrm{CO2,r}}$ = wet CO_2 concentration in the raw exhaust gas [%]

$c_{\mathrm{CO2,a}}$ = wet CO_2 concentration in the ambient air [%]

$c_{\mathrm{THC(C1),r}}$ = THC(C1) concentration in the raw exhaust gas [%]

$c_{\mathrm{THC(C1),a}}$ = THC(C1) concentration in the ambient air [%]

$c_{\mathrm{CO,r}}$ = wet CO concentration in the raw exhaust gas [%]

$c_{\mathrm{CO,a}}$ = wet CO concentration in the ambient air [%]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on wet basis [kg/s]

M_{e} = molar mass of exhaust gas [g/mol]

If CO_2 or CO are measured on a dry basis they shall be converted to a wet basis in accordance with point 2.1.3. or point 3.5.2..

4. Carbon flow rate in the dilution system (location 3)

4.1. Based on CO_2

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate in an equivalent dilution system $q_{m\mathrm{Cp}}$ [kg/s] (with equivalent meaning equivalent to a full flow system where the total flow is diluted) shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate; the new equation (7-153) is identical to equation (7-151), being only supplemented by the dilution factor $q_{m\mathrm{dew}}/q_{m\mathrm{p}}$.

$$q_{m\mathrm{Cp}} = \left(\frac{c_{\mathrm{CO2,d}} - c_{\mathrm{CO2,a}}}{100}\right) \cdot q_{m\mathrm{ew}} \cdot \frac{12.011}{M_{\mathrm{e}}} \cdot \frac{q_{m\mathrm{dew}}}{q_{m\mathrm{p}}}$$

(7-153)

Where:

$c_{\mathrm{CO2,d}}$ = wet CO_2 concentration in the diluted exhaust gas at the outlet of the dilution tunnel [%]

$c_{\mathrm{CO2,a}}$ = wet CO_2 concentration in the ambient air [%]

$q_{m\mathrm{dew}}$ = diluted sample flow in the partial flow dilution system [kg/s]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on wet basis [kg/s]

q_{mp} = sample flow of exhaust gas into partial flow dilution system [kg/s]

M_e = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis it shall be converted to a wet basis in accordance with point 2.1.3. or point 3.5.2..

4.2. Based on CO_2, HC and CO

For the partial flow dilution system, the splitting ratio also needs to be taken into account. As an alternative to performing the calculation solely based upon CO_2 in point 4.1., the carbon flow rate in an equivalent dilution system q_{mCp} [kg/s] (with equivalent meaning equivalent to a full flow system where the total flow is diluted) shall be determined from the dilute CO_2, HC and CO concentrations, the exhaust gas mass flow rate and the sample flow rate; the new equation (7-154) is identical to equation (7-152), being only supplemented by the dilution factor q_{mdew} / q_{mp} .

$$q_{mCe} = \left(\frac{c_{CO2,d} - c_{CO2,a}}{100} + \frac{c_{THC(C1),d} - c_{THC(C1),a}}{100} + \frac{c_{CO,d} - c_{CO,a}}{100}\right) \cdot q_{mew} \frac{12.011}{M_e} \cdot \frac{q_{mdew}}{q_{mp}} \tag{7-154}$$

Where:

$c_{CO2,d}$ = wet CO_2 concentration in the diluted exhaust gas at the outlet of the dilution tunnel [%]

$c_{CO2,a}$ = wet CO_2 concentration in the ambient air [%]

$c_{THC(C1),d}$ = THC(C1) concentration in the diluted exhaust gas at the outlet of the dilution tunnel [%]

$c_{THC(C1),a}$ = THC(C1) concentration in the ambient air [%]

$c_{CO,d}$ = wet CO concentration in the diluted exhaust gas at the outlet of the dilution tunnel [%]

$c_{CO,a}$ = wet CO concentration in the ambient air [%]

q_{mdew} = diluted sample flow in the partial flow dilution system [kg/s]

q_{mew} = exhaust gas mass flow rate on wet basis [kg/s]

q_{mp} = sample flow of exhaust gas into partial flow dilution system [kg/s]

M_e = molar mass of exhaust gas [g/mol]

If CO_2 or CO are measured on a dry basis they shall be converted to a wet basis in accordance with point 2.1.3. or point 3.5.2. of this Annex.

5. Calculation of the molar mass of the exhaust gas

The molar mass of the exhaust gas shall be calculated by means of equation (7-13) (see point 2.1.5.2.of this Annex).

Alternatively, the following exhaust gas molar masses may be used:

M_e (diesel) = 28,9 g/mol

M_e (LPG) = 28,6 g/mol

M_e (Natural gas/biomethane) = 28,3 g/mol

M_e (Petrol) = 29,0 g/mol

Appendix 3

Statistics

1. Arithmetic mean

The arithmetic mean, $\overline{y}$, shall be calculated by means of equation (7-155):

$$\overline{y} = \frac{\sum_{i=1}^{N} y_i}{N} \qquad (7\text{-}155)$$

2. Standard deviation

The standard deviation for a non-biased (*e.g.*, *N*–1) sample, σ, shall be calculated by means of equation (7-156):

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{N} (y_i - \overline{y})^2}{(N-1)}} \qquad (7\text{-}156)$$

3. Root mean square

The root mean square, rms_y, shall be calculated by means of equation (7-157):

$$rms_y = \sqrt{\frac{1}{N}\sum_{i=1}^{N} y_i^2} \qquad (7\text{-}157)$$

4. t-test

It shall be determined if the data passes a t-test by means of the following equations and Table 7.8.:

(a) For an unpaired *t*-test, the *t* statistic and its number of degrees of freedom, *v*, shall be calculated by means of equations (7-158) and (7-159):

$$t = \frac{\left|\overline{y}_{\mathrm{ref}} - \overline{y}\right|}{\sqrt{\frac{\sigma_{\mathrm{ref}}^2}{N_{\mathrm{ref}}} + \frac{\sigma_y^2}{N}}} \qquad (7\text{-}158)$$

$$v = \frac{\left(\frac{\sigma_{\mathrm{ref}}^2}{N_{\mathrm{ref}}} + \frac{\sigma_y^2}{N}\right)^2}{\frac{\left(\sigma_{\mathrm{ref}}^2 / N_{\mathrm{ref}}\right)^2}{N_{\mathrm{ref}} - 1} + \frac{\left(\sigma_y^2 / N\right)^2}{N - 1}} \qquad (7\text{-}159)$$

(b) For a paired *t*-test, the *t* statistic and its number of degrees of freedom, *ν,* shall be calculated by means of equation (7-160), noting that the ε_i are the errors (*e.g.*, differences) between each pair of $y_{\mathrm{ref}i}$ and y_i:

$$t = \frac{|\bar{\varepsilon}| \cdot \sqrt{\mathrm{N}}}{\sigma_\varepsilon} \qquad \nu = \mathrm{N} - 1 \qquad (7\text{-}160)$$

(c) Table 7.8. shall be used to compare *t* to the t_{crit} values tabulated versus the number of degrees of freedom. If t is less than t_{crit}, then *t* passes the *t*-test.

Table 7.8.

Critical *t* values versus number of degrees of freedom, ν

ν	Confidence	
	90 %	95 %
1	6,314	12,706
2	2,920	4,303
3	2,353	3,182
4	2,132	2,776
5	2,015	2,571
6	1,943	2,447
7	1,895	2,365
8	1,860	2,306
9	1,833	2,262
10	1,812	2,228
11	1,796	2,201
12	1,782	2,179
13	1,771	2,160
14	1,761	2,145
15	1,753	2,131
16	1,746	2,120
18	1,734	2,101
20	1,725	2,086
22	1,717	2,074
24	1,711	2,064
26	1,706	2,056
28	1,701	2,048
30	1,697	2,042
35	1,690	2,030
40	1,684	2,021
50	1,676	2,009
70	1,667	1,994
100	1,660	1,984
1000+	1,645	1,960

Linear interpolation shall be used to establish values not shown here.

5. F-test

The *F* statistic shall be calculated by means of equation (7-161):

$$F_y = \frac{\sigma_y^2}{\sigma_{\mathrm{ref}}^2} \qquad (7\text{-}161)$$

(a) For a 90 % confidence F-test, Table 7.9. is used to compare F to the F_{crit90} values tabulated versus (N−1) and (N_{ref}−1). If F is less than F_{crit90}, then F passes the F-test at 90 % confidence;

(b) For a 95 % confidence F-test, Table 7.10. is used to compare F to the F_{crit95} values tabulated versus (N−1) and (N_{ref}−1). If F is less than F_{crit95}, then F passes the F-test at 95 % confidence.

6. Slope

The least-squares regression slope, $a_{1\mathrm{y}}$, shall be calculated by means of equation (7-162):

$$a_{1y} = \frac{\sum_{i=1}^{\mathrm{N}} (y_i - \overline{y}) \cdot (y_{\mathrm{ref}i} - \overline{y}_{\mathrm{ref}})}{\sum_{i=1}^{\mathrm{N}} (y_{\mathrm{ref}i} - \overline{y}_{\mathrm{ref}})^2}$$

(7-162)

7. Intercept

The least-squares regression intercept, $a_{0\mathrm{y}}$, shall be calculated by means of equation (7-163):

$$a_{0y} = \overline{y} - \left(a_{1y} \cdot \overline{y}_{\mathrm{ref}}\right) \qquad (7\text{-}163)$$

8. Standard estimate of error

The standard estimate of error, *SEE,* shall be calculated by means of equation (7-164):

$$SEE_y = \sqrt{\frac{\sum_{i=1}^{\mathrm{N}} \left[y_i - a_{0y} - \left(a_{1y} \cdot y_{\mathrm{ref}i}\right)\right]^2}{\mathrm{N} - 2}} \qquad (7\text{-}164)$$

9. Coefficient of determination

The coefficient of determination, r^2, shall be calculated by means of equation (7-165):

$$r_y^2 = 1 - \frac{\sum_{i=1}^{\mathrm{N}} \left[y_i - a_{0y} - \left(a_{1y} \cdot y_{\mathrm{ref}i}\right)\right]^2}{\sum_{i=1}^{\mathrm{N}} \left[y_i - \overline{y}\right]^2}$$

(7-165)

Appendix 4

1980 INTERNATIONAL GRAVITY FORMULA

The acceleration of Earth's gravity, a_g, varies depending on the location and a_g shall be calculated for a respective latitude, by means of equation (7-1666):

$$a_g = 9.7803267715\left[1 + 5.2790414\times10^{-3}\sin^2\theta + 2.32718\times10^{-5}\sin^4\theta + 1.262\times10^{-7}\sin^6\theta + 7\times10^{-10}\sin^8\theta\right]$$

(7-166)

Where:

θ = Degrees north or south latitude

Appendix 5

Particle number calculation

1. Determination of particle numbers

1.1. Time alignment

For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedure in point 8.2.1.2. of Annex VI. The transformation time of the particle number sampling and measurement system shall be determined in accordance with point 2.1.3.7. of Appendix 1 of Annex VI.

1.2. Determination of particle numbers for transient (NRTC and LSI-NRTC) test cycles and RMC with a partial flow dilution system

Where particle numbers are sampled using a partial flow dilution system according to the specifications set out in point 9.2.3. of Annex VI, the number of particles emitted over the test cycle shall be calculated by means of equation (7-167):

$$N = \frac{m_{edf}}{1.293} \cdot k \cdot \overline{c_s} \cdot \overline{f_r} \cdot 10^6 \quad (7\text{-}167)$$

Where:

N is the number of particles emitted over the test cycle, [#/test],

m_{edf} is the mass of equivalent diluted exhaust gas over the cycle, determined by means of equation (7-45) (point 2.3.1.1.2.), [kg/test],

k is the 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 equation (7-167),

$\overline{c_s}$ is the average concentration of particles from the diluted exhaust gas corrected to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\overline{c_s} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad (7\text{-}168)$$

Where:

$c_{s,I}$ is a discrete measurement of particle concentration in the diluted exhaust gas from the particle counter, corrected for coincidence and to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken over the duration of the test.

1.3. Determination of particle numbers for transient (NRTC and LSI-NRTC) test cycles and RMC with a full flow dilution system

Where particle numbers are sampled using a full flow dilution system according to the specifications set out in point 9.2.2. of Annex VI, the number of particles emitted over the test cycle shall be calculated by means of equation (7-169):

$$N = \frac{m_{edf}}{1.293} \, .k\, .\overline{c_s}\, .\overline{f_r}\, .10^6 \qquad (7\text{-}169)$$

Where:

N is the number of particles emitted over the test cycle, [#/test],

m_{ed} is the total diluted exhaust gas flow over the cycle calculated according to any one of the methods described in points 2.2.4.1. to 2.2.4.3., of Annex VII, kg/test,

k is the 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 equation (7-169),

$\overline{c_s}$ is the average corrected concentration of particles from the diluted exhaust gas corrected to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\overline{c} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad (7\text{-}170)$$

Where:

$c_{s,I}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken over the duration of the test

1.4. Determination of particle numbers for discrete-mode NRSC with a partial flow dilution system

Where particle numbers are sampled using a partial flow dilution system according to the specifications set out in point 9.2.3. of Annex VI, the rate of emission of particles during each individual discrete-mode shall be calculated by means of equation (7-171) using the average values for the mode:

$$\dot{N} = \frac{q_{medf}}{1.293} \times k \times \overline{c_s} \times \overline{f_r} \times 10^6 \times 3600 \qquad (7\text{-}171)$$

Where:

$\dot{N}$ is the rate of emission of particles during the individual discrete-mode, [#/h],

q_{medf} is the equivalent diluted exhaust mass flow rate on a wet basis during the individual discrete-mode, determined in accordance with equation (7-51) (point 2.3.2.1.), [kg/s],

k is the 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 equation (1-171),

$\overline{c}_s$ is the average concentration of particles from the diluted exhaust gas during the individual discrete-mode corrected to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\overline{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad (7\text{-}172)$$

Where:

$c_{s,I}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken during the individual discrete-mode sampling period

1.5. Determination of particle numbers for discrete-mode cycles with a full flow dilution system

Where particle numbers are sampled using a full flow dilution system according to the specifications set out in point 9.2.2. of Annex VI, the rate of emission of particles during each individual discrete-mode shall be calculated by means of equation (7-173) using the average values for the mode:

$$\dot{N} = \frac{q_{mdew}}{1.293} \times k \times \bar{c_s} \times \bar{f_r} \times 10^6 \times 3600 \qquad (7\text{-}173)$$

Where:

$\dot{N}$ is the rate of emission of particles during the individual discrete-mode, [#/h],

q_{mdew} is the total diluted exhaust mass flow rate on a wet basis during the individual discrete-mode, [kg/s],

k is the 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 equation (7-173),

$\bar{c}_s$ is the average concentration of particles from the diluted exhaust gas during the individual discrete-mode corrected to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\bar{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad (7\text{-}174)$$

Where:

$c_{s,I}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273,2 K and 101,33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken during the individual discrete-mode sampling period.

2. Test result

2.1. Calculation of the specific emissions for transient (NRTC and LSI-NRTC) test cycles and RMC

For each applicable individual RMC, hot-start NRTC and cold-start NRTC the specific emissions in number of particles/kWh shall be calculated by means of equation (7-175):

$$e = \frac{N}{W_{act}} \qquad (7\text{-}175)$$

Where:

N is the number of particles emitted over the applicable RMC, hot-start run of the NRTC or cold-start NRTC,

W_{act} is the actual cycle work in accordance with point 7.8.3.4. of Annex VI, [kWh].

For an RMC, in case of an engine with infrequent (periodic) exhaust after treatment system regeneration (see point 6.6.2. of Annex VI), the specific emissions shall be corrected with either the applicable multiplicative adjustment factor or with the applicable adjustment additive factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{\mathrm{ru,m}}$ or $k_{\mathrm{ru,a}}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{\mathrm{rd,m}}$ or $k_{\mathrm{rd,a}}$).

For an RMC the final result shall also be adjusted with the applicable multiplicative or additive deterioration factor established according to the requirements of Annex III.

2.1.1. Weighted average NRTC test result

For the NRTC, the final test result shall be a weighted average from cold-start run and hot-start run (including infrequent regeneration where relevant) shall be calculated by means of equation (7-176) or (7-177):

(a) In the case of multiplicative regeneration adjustment, or engines without infrequently regenerating exhaust after-treatment system

$$e = k_r \left(\frac{(0.1 \times N_{cold}) + (0.9 \times N_{hot})}{(0.1 \times W_{act,cold}) + (0.9 \times W_{act.hot})} \right) \qquad (7\text{-}176)$$

In the case of additive regeneration adjustment

$$e = k_r + \left(\frac{(0.1 \times N_{cold}) + (0.9 \times N_{hot})}{(0.1 \times W_{act,cold}) + (0.9 \times W_{act.hot})} \right) \qquad (7\text{-}177)$$

Where:

N_{cold} is the total number of particles emitted over the NRTC cold-start run of the NRTC,

N_{hot} is the total number of particles emitted over the NRTC hot-start run of the NRTC,

$W_{act,cold}$ is the actual cycle work over the cold-start NRTC in accordance with point 7.8.3.4. of Annex VI, [kWh],

$W_{act, hot}$ is the actual cycle work over the hot-start NRTC in accordance with point 7.8.3.4. of Annex VI, [kWh],

k_r is the regeneration adjustment, according to point 6.6.2. of Annex VI, or in the case of engines without infrequently regenerating exhaust after-treatment system $k_r = 1$

In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{\mathrm{ru,m}}$ or $k_{\mathrm{ru,a}}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{\mathrm{rd,m}}$ or $k_{\mathrm{rd,a}}$).

The result, where applicable inclusive of infrequent regeneration adjustment factor, shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex III.

2.2. Calculation of the specific emissions for discrete-mode NRSC tests

The specific emissions e [#/kWh] shall be calculated by means of equation (7-178):

$$e = \frac{\sum_{i=1}^{N_{\mathrm{mode}}} (\dot{N}_i \cdot WF_i)}{\sum_{i=1}^{N_{\mathrm{mode}}} (P_i \cdot WF_i)} \qquad (7\text{-}178)$$

Where:

P_i is the engine power for the mode i [kW] with $P_i = P_{\max i} + P_{\mathrm{aux}i}$

(see points 6.3. and 7.7.1.3. of Annex VI)

WF_i is the weighting factor for the mode i [-]

$\dot{N}_i$ is the mean emission number flow rate for the mode i [#/h] from equation (7-171) or (7-173) depending upon the dilution method

In case of an engine with infrequent (periodic) exhaust after-treatment system regeneration (see point 6.6.2. of Annex VI), the specific emissions shall be corrected with either the applicable multiplicative adjustment factor or with the applicable adjustment additive factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$). Where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result at equation (7-178).

The result, where applicable inclusive of infrequent regeneration adjustment factor, shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex III.

2.3. Rounding of final results

The final NRTC and weighted average NRTC test results shall be rounded in one step to three significant figures in accordance with ASTM E 29–06B. No rounding of intermediate values leading to the final brake specific emission result is permissible.

2.4. Determination of particle number background

2.4.1. At the engine manufacturer’s request, dilution tunnel background particle number concentrations may be sampled, prior to or after the test, from a point downstream of the particle and hydrocarbon filters into the particle number measurement system, to determine the tunnel background particle concentrations.

2.4.2. Subtraction of particle number tunnel background concentrations shall not be allowed for type approval, but may be used at the manufacturer’s request, with the prior approval of the approval authority , for conformity of production testing, if it can be demonstrated that tunnel background contribution is significant, which can then be subtracted from the values measured in the diluted exhaust gas.

Appendix 6

Ammonia emission calculation

1. Calculation of the mean concentration for transient (NRTC and LSI-NRTC) test cycles and RMC

The mean NH_3 concentration in the exhaust gas over the test cycle cNH3 [ppm] shall be determined by integrating the instantaneous values over the cycle. Equation (7-179) shall be applied:

$$cNH3 = \frac{1}{n}\sum_{i=1}^{i=n} c_{\mathrm{NH3,i}} \qquad (7\text{-}179)$$

Where:

cNH3,i is the instantaneous NH3 concentration in the exhaust gas [ppm]

n is the number of measurements

For the NRTC, the final test result shall be calculated by means of equation (7-180):

$$cNH3 = (0.1 \times cNH3,cold) + (0.9 \times cNH3,hot) \qquad (7\text{-}180)$$

Where:

cNH3,cold is the mean NH3 concentration of the cold-start NRTC [ppm]

cNH3,hot is the mean NH3 concentration of the hot-start NRTC [ppm]

2. Calculation of the mean concentration for discrete-mode NRSC

The mean NH_3 concentration in the exhaust gas over the test cycle cNH3 [ppm] shall be determined by measuring the mean concentration for each mode and weighting the result in accordance with the weighting factors applicable to the test cycle. Equation (7-181) shall be applied:

$$cNH3 = \sum_{i=1}^{N_{mode}} \bar{c}_{\mathrm{NH3,i}} \cdot WF_i \qquad (7\text{-}181)$$

Where:

$\bar{c}$NH3,i is the mean NH3 concentration in the exhaust gas for mode i [ppm]

Nmode is the number of modes in the test cycle

WFi is the weighting factor for the mode i [-]