(q) *Additional required records for natural gas-fueled vehicles.* Composition, including all carbon containing compounds; e.g. CO_2, of the natural gas-fuel used during the test. C_1 and C_2 compounds shall be individually reported. C_3 and heavier hydrocarbons and C_6 and heavier compounds may be reported as a group.

(r) *Additional required records for liquefied petroleum gas-fueled vehicles.* Composition of the liquefied petroleum gas-fuel used during the test. Each hydrocarbon compound present, through C_4 compounds, shall be individually reported. C_5 and heavier hydrocarbons may be reported as a group.

[54 FR 14553, Apr. 11, 1989, as amended at 59 FR 48515, Sept. 21, 1994; 60 FR 34357, June 30, 1995]

§86.544–90 Calculations; exhaust emissions.

The final reported test results, with oxides of nitrogen being optional for model years prior to 2006 and required for 2006 and later model years, shall be computed by use of the following formula: (The results of all emission tests shall be rounded, in accordance with ASTM E29–93a (incorporated by reference in §86.1), to the number of places to the right of the decimal point indicated by expressing the applicable standard to three significant figures.)

$$(a) Y_{wm} = 0.43\left(\frac{Y_{ct} + Y_s}{D_{ct} + D_s}\right) + 0.57\left(\frac{Y_{ht} + Y_s}{D_{ht} + D_s}\right)$$

Where:

(1) Y_{wm} = Weighted mass emissions of CO_2Or of each pollutant (*i.e.*, HC, CO, or NO_X) in grams per vehicle kilometer and if appropriate, the weighted carbon mass equivalent of total hydrocarbon equivalent, in grams per vehicle kilometer.

(2) Y_{ct} = Mass emissions as calculated from the "transient" phase of the cold-start test, in grams per test phase.

(3) Y_{ht} = Mass emissions as calculated from the "transient" phase of the hot-start test, in grams per test phase.

(4) Y_s = Mass emissions as calculated from the "stabilized" phase of the cold-start test, in grams per test phase.

(5) D_{ct} = The measured driving distance from the "transient" phase of the cold-start test, in kilometers.

(6) D_{ht} = The measured driving distance from the "transient" phase of the hot-start test, in kilometers.

(7) D_s = The measured driving distance from the "stabilized" phase of the cold-start test, in kilometers.

(b) The mass of each pollutant for each phase of both the cold-start test and the hot-start test is determined from the following:

(1) Hydrocarbon mass:

$HC_{mass} = V_{mix} \times Density_{HC} \times (HC_{conc}/1{,}000{,}000)$

(2) Oxides of nitrogen mass:

$NOx_{mass} = V_{mix} \times Density_{NO2} \times K_H \times (NOx_{conc}/1{,}000{,}000)$

(3) Carbon monoxide mass:

$CO_{mass} = V_{mix} \times Density_{CO} \times (CO_{conc}/1{,}000{,}000)$

(4) Carbon dioxide mass:

$CO_{2mass} = V_{mix} \times Density_{CO2} \times (CO_{2conc}/100)$

(5) Methanol mass:

$CH_3OH_{mass} = V_{mix} \times Density_{CH3OH} \times (CH_3OH_{conc}/1{,}000{,}000)$

(6) Formaldehyde mass:

$HCHO_{mass} = V_{mix} \times Density_{HCHO} \times (HCHO_{conc}/1{,}000{,}000)$

(7) Total hydrocarbon equivalent:

(i) $THCE = HC_{mass} + 13.8756/32.042 \times (CH_3OH)_{mass} + 13.8756/30.0262 \times (HCHO)_{mass}$

(c) Meaning of symbols:

(1)(i) HC_{mass} = Hydrocarbon emissions, in grams per test phase.

(ii) $Density_{HC}$=Density of HC in exhaust gas.

(A) *For gasoline-fuel;* $Density_{HC}$=576.8 g/m^3-carbon atom (16.33 g/ft^3-carbon atom), assuming an average carbon to hydrogen ratio of 1:1.85, at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(B) *For natural gas and liquefied petroleum gas-fuel;* $Density_{HC}$=41.57(12.011+H/C(1.008)) g/m^3-carbon atom (1.1771(12.011+H/C(1.008)) g/ft^3-carbon atom) where H/C is the hydrogen to carbon ratio of the hydrocarbon components of test fuel, at 20 °C (68 °F) and 101.3 kPa (760mm Hg) pressure.

(iii)(A) HC_{conc} = Hydrocarbon concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent, *i.e.*, equivalent propane×3.

(B) $HC_{conc} = HC_e - HC_d(1 - (1/DF))$

Where:

(iv)(A) HC_e = Hydrocarbon concentrations of the dilute exhaust sample as measured, in ppm carbon equivalent (propane ppm×3).

(B) $HC_e = FIDHC_e - (r)C_{CH3OHe}$

(v) FID HC_e=Concentration of hydrocarbon (plus methanol if methanol-fueled motorcycle is tested) in dilute exhaust as measured by the FID ppm carbon equivalent.

(vi) r = FID response to methanol.

(vii) C_{CH30He} = Concentration of methanol in dilute exhaust as determined from the dilute exhaust methanol sample, ppm carbon.

(viii)(A) HC_d = Hydrocarbon concentration of the dilution air as measured, ppm carbon equivalent.

(B) $HC_d = FID\ HC_d - (r)C_{CH30Hd}$

(ix) FID HC_d=Concentration of hydrocarbon (plus methanol if methanol-fueled motorcycle is tested) in dilution air as measured by the FID, ppm carbon equivalent.

(x) C_{CH3OHd} = Concentration of methanol in dilution air as determined from dilution air methanol sample, ppm carbon.

(2)(i) NOx_{mass} = Oxides of nitrogen emissions, grams per test phase.

(ii) $Density_{N02}$ = Density of oxides of nitrogen in the exhaust gas, assuming they are in the form of nitrogen dioxide, 1913 g/m^3 (54.16 g/ft^3), at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(iii)(A) NOx_{conc} = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, ppm.

(B) $NOx_{conc} = NOx_e - NOx_d(1 - (1/DF))$

Where:

(iv) NOx_e = Oxides of nitrogen concentration of the dilute exhaust sample as measured, ppm.

(v) NOx_d = Oxides of nitrogen concentration of the dilution air as measured, ppm.

(3)(i) CO_{mass} = Carbon monoxide emissions, in grams per test phase.

(ii) $Density_{CO}$ = Density of carbon monoxide, 1164 g/m^3 (32.97 g/ft^3), at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(iii)(A) CO_{conc} = Carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and CO_2 extraction, ppm.

(B) $CO_{conc} = CO_e - CO_d(1 - (1/DF))$

Where:

(iv)(A) CO_e = Carbon monoxide concentration of the dilute exhaust sample volume corrected for water vapor and carbon dioxide extraction, in ppm.

(B) $CO_e = (1 - 0.01925CO_{2e} - 0.000323R)CO_{em}$ for gasoline-fueled vehicles with hydrogen to carbon ratio of 1.85:1

(C) $CO_e=[1 - (0.01+0.005HCR)\ CO_{2e} - 0.000323R]CO_{em}$ for methanol-fueled, natural gas-fueled or liquefied petroleum gas-fueled motorcycles, where HCR is hydrogen to carbon ratio as measured for the fuel used.

(v) CO_{em} = Carbon monoxide concentration of the dilute exhaust sample as measured, ppm

(vi) CO_{2e} = Carbon dioxide concentration of the dilute exhaust sample, pct.

(vii) R = Relative humidity of the dilution air, pct (*see* § 86.542(n)).

(viii)(A) CO_d = Carbon monoxide concentration of the dilution air corrected for water vapor extraction, ppm.

(B) $CO_d = (1 - 0.000323R)CO_{dm}$

Where:

(ix) CO_{dm} = Carbon monoxide concentration of the dilution air sample as measured, ppm.

NOTE: If a CO instrument which meets the criteria specified in § 86.511 is used and the conditioning column has been deleted, CO_{em} can be substituted directly for CO_e and CO_{dm} must be substituted directly for CO_d.

(4)(i) CO_{2mass} = Carbon dioxide emissions, grams per test phase.

(ii) $Density_{C02}$ = Density of carbon dioxide, 1830 g/m^3 (51.81 g/ft^3), at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(iii)(A) CO_{2conc} = carbon dioxide concentration of the dilute exhaust sample corrected for background, in percent.

(B) $CO_{2conc} = CO_{2e} - CO_{2d}(1 - 1/DF)$

Where:

(iv) CO_{2d} = Carbon dioxide concentration of the dilution air as measured, in percent.

(5)(i) CH_3OH_{mass} = Methanol emissions corrected for background, grams per test phase.

(ii) $Density_{CH3OH}$ = Density of methanol is 1332 g/m^3 (37.71 g/ft^3), at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(iii)(A) CH_3OH_{conc} = Methanol concentration of the dilute exhaust corrected for background, ppm.

(B) $CH_3OH_{conc} = C_{CH3OHe} - C_{CH3OHd}(1 - (1/DF))$

Where:

(iv)(A) C_{CH3OHe}=Methanol concentration in the dilute exhaust, ppm.

(B)

$$C_{CH3OHe} = \frac{3.813 \times 10^{-2} \times T_{EM}\left[\left(C_{S1} \times AV_{S1}\right) + \left(C_{S2} \times AV_{S2}\right)\right]}{P_B \times V_{EM}}$$

(v)(A) C_{CH3OHd}=Methanol concentration in the dilution air, ppm.

(B)

$$C_{CH3OHd} = \frac{3.813 \times 10^{-2} \times T_{DM}\left[\left(C_{D1} \times AV_{D1}\right) + \left(C_{D2} \times AV_{D2}\right)\right]}{P_B \times V_{DM}}$$

(vi) T_{EM}=Temperature of methanol sample withdrawn from dilute exhaust, °R.

(vii) T_{DM}=Temperature of methanol sample withdrawn from dilution air, °R.

(viii) P_B=Barometric pressure during test, mm Hg.

(ix) V_{EM}=Volume of methanol sample withdrawn from dilute exhaust, ft^3.

(x) V_{DM}=Volume of methanol sample withdrawn from dilution air, ft^3.

(xi) C_s=GC concentration of sample drawn from dilute exhaust, μg/ml.

(xii) C_D=GC concentration of sample drawn from dilution air, μg/ml.

(xiii) AV_s=Volume of absorbing reagent (deionized water) in impinger through which methanol sample from dilute exhaust is drawn, ml.

(xiv) AV_D=Volume of absorbing reagent (deionized water) in impinger through which methanol sample from dilution air is drawn, ml.

(xv) 1=first impinger.

(xvi) 2=second impinger.

(6)(i) $HCHO_{mass}$ = Formaldehyde emissions corrected for background, grams per test phase.

(ii) $Density_{HCHO}$ = Density of formaldehyde is 1249 g/m^3 (35.36 g/ft^3), at 20 °C (68 °F) and 101.3 kPa (760 mm Hg) pressure.

(iii)(A) $HCHO_{conc}$ = Formaldehyde concentration of the dilute exhaust corrected for background, ppm.

(B) $HCHO_{conc} = C_{HCHOe} - C_{HCHOd}\,(1 - (1/DF))$

Where:

(iv)(A) C_{HCHOe} = Formaldehyde concentration in dilute exhaust, ppm.

(B)

$$C_{HCHO_e} = \frac{4.069 \times 10^{-2} \times C_{FDE} \times V_{AE} \times Q \times T_{EF}}{V_{SE} \times P_B}$$

(v)(A) C_{HCHOd} = Formaldehyde concentration in dilution air, ppm.

(B)

$$C_{HCHOd} = \frac{4.069 \times 10^{-2} \times C_{FDA} \times V_{AA} \times Q \times T_{DF}}{V_{SA} \times P_B}$$

(vi) C_{FDE} = Concentration of DNPH derivative of formaldehyde from dilute exhaust sample in sampling solution, µg/ml.

(vii) V_{AE} = Volume of sampling solution for dilute exhaust formaldehyde sample, ml.

(viii)(A) Q = Ratio of molecular weights of formaldehyde to its DNPH derivative.

(B) Q = 0.1429

(ix) T_{EF} = Temperature of formaldehyde sample withdrawn from dilute exhaust, °R.

(x) V_{SE} = Volume of formaldehyde sample withdrawn from dilute exhaust, ft^3.

(xi) P_B = Barometric pressure during test, mm Hg.

(xii) C_{FDA} = Concentration of DNPH derivative of formaldehyde from dilution air sample in sampling solution, µg/ml.

(xiii) V_{AA} = Volume of sampling solution for dilution air formaldehyde sample, ml.

(xiv) T_{DF} = Temperature of formaldehyde sample withdrawn from dilution air, °R.

(xv) V_{SA} = Volume of formaldehyde sample withdrawn from dilution air, ft^3.

(7)(i) DF = $13.4/[CO_{2e} + (HC_e = CO_e)10^{-4}]$ for gasoline-fueled vehicles.

(ii) For methanol-fueled, natural gas-fueled or liquefied petroleum gas-fueled motorcycles, where fuel composition is $C_x H_y O_z$ as measured, or calculated, for the fuel used (for natural gas and liquefied petroleum gas-fuel, Z=0):

$$DF = \frac{(100)\dfrac{x}{(x + y/2 + 3.76)(x + y/2 - z/2)}}{CO_{2e} + \left(HC_e + CO_e + CH_3OH_e = HCHO_e\right) \times 10^{-4}}$$

(iii)(A) V_{mix} = Total dilute exhaust volume in cubic meters per test phase corrected to standard conditions (293 °K (528 °R) and 101.3 kPa (760 mm Hg)).

(B)

$$V_{mix} = \frac{V_o \times N \times \left(P_B - P_i\right) \times 293}{101.3 \times T_p}$$

Where:

(iv) V_o = Volume of gas pumped by the positive displacement pump, in cubic meters per revolution. This volume is dependent on the pressure differential across the positive displacement pump. (See calibration techniques in § 86.519.)

(v) N = Number of revolutions of the positive displacement pump during the test phase while samples are being collected.

(vi) P_B = Barometric pressure, kPa.

(vii) P_i = Pressure depression below atmospheric measured at the inlet to the positive displacement pump, kPa.

(viii) T_p = Average temperature of dilute exhaust entering positive displacement pump during test while samples are being collected, °K.

(ix)(A) K_h = Humidity correction factor.

(B) $K_h = 1/[1 - 0.0329(H - 10.71)]$

Where:

(x)(A) H = Absolute humidity in grams of water per kilogram of dry air.

(B) $H = [(6.211)R_a \times P_d]/[P_B - (P_d \times R_a/100)]$

(xi) R_a = Relative humidity of the ambient air, pct.

(xii) P_d = Saturated vapor pressure, in kPa at the ambient dry bulb temperature.

(xiii) P_B = Barometric pressure, kPa.

(d) Sample calculation of mass emission values for gasoline-fueled vehicles with engine displacements equal to or greater than 170 cc (10.4 cu. in.):

(1) For the "transient" phase of the cold-start test, assume V_o = 0.0077934 m^3 per rev; N = 12,115; R = 20.5 pct; R_a = 20.5 pct; P_B = 99.05 kPa; P_d = 3.382 kPa; P_i = 9.851 kPa; T_p = 309.8 °K; HC_e = 249.75 ppm carbon equivalent; NOx_e = 38.30 ppm; CO_{em} = 311.23 ppm; CO_{2e} = 0.415 percent; HC_d = 4.90 ppm; NOx_d = 0.30 ppm; CO_{dm} = 8.13 ppm; CO_{2d} = 0.037 pct; D_{ct} = 5.650 km.

Then:

(i) V_{mix} = [(0.0077934)(12,115)(99.05–9.851)(293.15)]/ [(101.325)(309.8)] = 78.651 m^3 per test phase.

(ii) H = [(6.211)(20.5)(3.382)]/[(99.05) − (3.382)(20.5/100)] = 4.378 grams H_2O per kg dry air.

(iii) K_h = 1/[1 − 0.0329(4.378 − 10.71)] = 0 8276

(iv) CO_e = [1 − 0.01925(0.415) − 0.000323 (20.5)](311.23) = 306.68 ppm.

(v) CO_d = [1 − 0.000323(20.5)](8.13) = 8.08 ppm.

(vi) DF = 13.4/[0.415 + (249.75 + 306.68)10^{-4}] = 28.472

(vii) HC_{conc} = 249.75 − 4.90(1 − 1/28.472) = 245.02 ppm.

(viii) HC_{mass} = (78.651) (576.8) (245.02) 10^{-6} = 11.114 grams per test phase.

(ix) NOx_{conc} = 38.30 − 0.30(1 − 1/28.472) = 38.01 ppm.

(x) NOx_{mass} = (78.651)(1913)(38.01)(0.8276) × 10^{-6} = 4.733 grams per test phase.

(xi) CO_{conc} = 306.68 − 8.08 (1 − 1/28.472) = 298.88 ppm.

(xii) CO_{mass} = (78.651) (1164) (298.88) (10^{-6}) = 27.362 grams per test phase.

(xiii) CO_{2conc} = 0.415 − 0.037 (1 − 1/28.472) = 0.3793 percent.

(xiv) CO_{2mass} = (78.651)(1843)(0.3793)/100 = 549.81 grams per test phase.

(2) For the "stabilized" portion of the cold-start test, assume that similar calculations resulted in HC_{mass} = 7.184 grams per test phase; NOx_{mass} = 2.154 grams per test phase; CO_{mass} = 64.541 grams per test phase; and CO_{2mass} = 529.52 grams per test phase. D_s = 6.070 km.

(3) For the "transient" portion of the hot-start test, assume that similar calculations resulted in HC_{mass} = 6.122 grams per test phase; NOx_{mass} = 7.056 grams per test phase; CO_{mass} = 34.964 grams per test phase; and CO_{2mass} = 480.93 grams per test phase. D_{ht} = 5.660 km.

(4) For a 1978 motorcycle with an engine displacement equal to or greater than 170 cc (10.4 cu. in):

(i) HC_{wm} = 0.43 [(11.114 + 7.184)/(5.650 + 6.070)] + 0.57 [(6.122 + 7.184)/(5.660 + 6.070)] = 1.318 grams per vehicle kilometer.

(ii) NOx_{wm} = 0.43 [(4.733 = 2.154)/(5.650 = 6.070)] = 0.57 [(7.056 = 2.154)/(5.660 = 6.070)] = 0.700 gram per vehicle kilometer.

(iii) CO_{wm} = 0.43 [(27.362 + 64.541)/(5.650 + 6.070)] + 0.57 [(34.964 + 64.541)/(5.660 + 6.070)] = 8.207 grams per vehicle kilometer.

(iv) CO_{2wm} = 0.43 [(549.81 + 529.52)/(5.650 + 6.070)] + 0.57 [(480.93 + 529.52)/(5.660 + 6.070)] = 88.701 grams per vehicle kilometer.

[54 FR 14553, Apr. 11, 1989, as amended at 59 FR 48515, Sept. 21, 1994; 60 FR 34358, June 30, 1995; 69 FR 2441, Jan. 15, 2004]