EXAMPLE CALCULATIONS

This section presents example calculations used for each test determination. Wherever applicable, calculations from the appropriate regulations are used in making the test determinations. In other instances, calculations are based on generally accepted scientific and engineering principles.

A. CONVERSION FACTORS AND CONSTANTS

The following conversion factors and constants are used throughout the calculations:

Volume:
1 cubic meter = 35.31 cubic feet
1 cubic foot = 28.32 liters

Mass:
1 pound = 453.59 grams
1 pound = 7000.0 grains
1 kilogram = 2.2046 pounds

Length:
1 meter = 3.281 feet

Constants:
Standard conditions are 68°F, 29.92 in. Hg, when using English units.
Standard conditions are 20°C, 101.3 KPa (760 mm Hg), when using metric units.
1 lb-mol occupies 385 cubic feet at **standard conditions**.
1 kg-mol occupies 24.04 cubic meters at **standard conditions**.

B. CALCULATIONS

Constituent Input Rates:

Constituent input rates (metals, chlorine/chloride, ash, etc.) for each run are calculated by multiplying the feed rate of each input material times the constituent concentration for that material. The total constituent input rate is calculated by summing the constituent input rate from each input material. Depending upon the form of laboratory results (mass concentration, weight percent, or volumetric measurement) the appropriate formula shown below is used:

Mass Concentration Results:

$$Constituent\ Input\ Rate\,(mass/time) = \sum_i \left([C]_i \times \frac{1kg}{1\times 10^6\,mg} \times \dot{m}_i \right)$$

where:

$[C]_i$ = Concentration of constituent C in material *i* (mg/kg)

$\dot{m}_i$ = Mass feed rate of material *i* (mass/time)

Weight Percent Results:

$$Constituent\ Input\ Rate\,(mass/time) = \sum_i \left([C]_i \times \dot{m}_i \right)$$

where:

$[C]_i$ = Concentration of constituent C in material *i* (wt %)

$\dot{m}_i$ = Mass feed rate of material *i* (mass/time)

Stack Gas Sampling:

The following equations are used for all stack gas sampling determinations. These calculations are given in the referenced sampling methods and in 40 CFR 60.

Stack Gas Velocity:

$$v_s = K_p \times C_p \times \left(\sqrt{\Delta p}\right)_{avg} \times \sqrt{\frac{T_{s(avg)}}{P_s \times M_s}}$$

where:

v_s = Average stack gas velocity (m/sec) or (ft/sec)

K_p = Pitot tube constant

$$34.97\frac{m}{\sec}\sqrt{\left[\frac{(g/g-mol)(mm\,Hg)}{(^\circ K)(mm\,H_2O)}\right]}\ or\ 85.49\frac{ft}{\sec}\sqrt{\left[\frac{(lb/lb-mol)(in.Hg)}{(^\circ R)(in.H_2O)}\right]}$$

C_p = Pitot tibe coefficient, dimensionless

Δp = Velocity head of stack gas (mm H_2O) or (in. H_2O)

T_s = Absolute stack gas temperature (K) or (R)

P_s = Absolute stack gas pressure (mm Hg) or (in. Hg)

M_s = Molecular weight of stack gas, wet basis (g/g-mol) or (lb/lb-mol)

Stack Gas Molecular Weight:

$$M_d = 0.440 \times [CO_2] + 0.320 \times [O_2] + 0.280 \times [N_2 + CO]$$

where:

M_d = Molecular weight of stack gas, dry basis (g/g-mol) or (lb/lb-mol)

$[CO_2]$ = Concentration of carbon dioxide in stack gas (vol%, dry)

$[O_2]$ = Concentration of oxygen in stack gas (vol%, dry)

$[N_2 + CO]$ = Concentration of nitrogen plus carbon monoxide in stack gas (vol%, dry)

$$M_s = M_d \times (1 - B_{ws}) + 18.0 \times B_{ws}$$

where:

M_s = Molecular weight of stack gas, wet basis (g/g-mol) or (lb/lb-mol)

M_d = Molecular weight of stack gas, dry basis (g/g-mol) or (lb/lb-mol)

B_{ws} = Water vapor fraction in stack gas by volume, dimensionless

Stack Gas Volumetric Flow Rate:

$$Q_{sd} = 60 \times (1 - B_{ws}) \times v_s \times A \times \frac{T_{std}}{T_{s(avg)}} \times \frac{P_s}{P_{std}}$$

where:

Q_{sd} = Stack gas volumetric flow rate (dscm/min) or (dscfm)

B_{ws} = Water vapor fraction in stack gas by volume, dimensionless

v_s = Average stack gas velocity (m/sec) or (ft/sec)

A = Cross-sectional area of stack (m^2) or (ft^2)

T_{std} = Standard absolute temperature (293 K) or (528 R)

T_s = Absolute stack temperature (K) or (R)

P_s = Absolute stack pressure (mm Hg) or (in. Hg)

P_{std} = Standard absolute pressure (760 mm Hg) or (29.92 in. Hg)

Stack Gas Moisture:

$$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

where:

B_{ws} = Water vapor fraction in stack gas by volume, dimensionless

$V_{wc(std)}$ = Volume of water vapor condensed, corrected to standard conditions (scm) or (scf)

$V_{wsg(std)}$ = Volume of water vapor collected in silica gel, corrected to standard conditions (scm) or (scf)

$V_{m(std)}$ = Gas sample volume (dscm) or (dscf)

$$V_{wc(std)} = \frac{(V_f - V_i) \times \rho_w \times R \times T_{std}}{P_{std} \times M_w}$$

$$V_{wsg(std)} = \frac{(W_f - W_i) \times R \times T_{std}}{P_{std} \times M_w}$$

where:

V_f = Final volume of condenser water (ml)

V_i = Initial volume of condenser water (ml)

ρ_w = Density of water (0.9982 g/ml) or (0.002201 lb/ml)

W_f = Final weight of silica gel (g)

W_i = Initial weight of silica gel (g)

R = Ideal gas constant $0.06236 \frac{(mm\,Hg)(m^3)}{(g-mol)(^\circ K)}$ or $21.85 \frac{(in.Hg)(ft^3)}{(lb-mol)(^\circ R)}$

T_{std} = Standard absolute temperature (293 K) or (528 R)

P_{std} = Standard absolute pressure (760 mm Hg) or (29.92 in. Hg)

M_w = Molecular weight of water (18.0 g/g-mol) or (18.0 lb/lb-mol)

<u>Sample Gas Sample Volume:</u>

$$V_{m(std)} = V_m \times Y \times \left(\frac{T_{std}}{T_m} \right) \times \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}} \right]$$

where:

$V_{m(std)}$ = Gas sample volume (dscm) or (dscf)

V_m = Dry gas volume measured at dry gas meter (dcm) or (dcf)

Y = Dry gas meter calibration factor, dimensionless

T_m = Absolute temperature at dry gas meter (K) or (R)

T_{std} = Standard absolute temperature (293 K) or (528 R)

P_{std} = Standard absolute pressure (760 mm Hg) or (29.92 in. Hg)

P_{bar} = Barometric pressure at the sampling site (mm Hg) or (in. Hg)

ΔH = Average pressure differential across the orifice meter (mm H_2O) or (in. H_2O)

Isokinetic Variation:

$$I(\%) = \frac{T_s \times V_{m(std)} \times P_{std}}{T_{std} \times v_s \times 60 \times \theta \times A_n \times P_s \times (1 - B_{ws})} \times 100\%$$

where:

T_{std} = Standard absolute temperature (293 K) or (528 R)

T_s = Absolute stack temperature (K) or (R)

P_s = Absolute stack pressure (mm Hg) or (in. Hg)

P_{std} = Standard absolute pressure (760 mm Hg) or (29.92 in. Hg)

$V_{m(std)}$ = Gas sample volume (dscm) or (dscf)

B_{ws} = Water vapor fraction in stack gas by volume, dimensionless

v_s = Average stack gas velocity (m/sec) or (ft/sec)

θ = Total sampling time (min)

A_n = Cross-sectional area of sample nozzle (m^2) or (ft^2)

60 = sec/min.

Stack Gas Emission Concentration Corrections:

Numerous stack gas emission results are required to be corrected (or normalized) to a specified oxygen concentration in order to account for dilution effects. The following calculations are used to perform those corrections:

Correction to 7% oxygen:

$$C_{(corr)} = C_{(unc)} \times \frac{21-7}{21-Y}$$

where:

$C_{(corr)}$ = Corrected sample concentration.

$C_{(unc)}$ = Uncorrected sample concentration

Y = Stack gas oxygen concentration (vol %, dry).

Particulate Matter:

Particulate emissions are determined in accordance with EPA Method 5 and the calculations presented in 40 CFR 60 Appendix A. The final emission rate and stack gas concentration equations are as follows:

$$E_P\,(lb/hr) = \frac{M_P}{V_{m(std)}} \times Q_{sd} \times \frac{1g}{1000\,mg} \times \frac{1lb}{453.59\,g} \times \frac{60\min}{hr}$$

where:

E_P = Stack gas emission rate of particulate matter (lb/hr)

M_P = Mass of particulate matter collected in the M5 sample (mg)

$V_{m(std)}$ = Gas sample volume (dscf)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

$$C_P\,(gr/dscf) = \frac{M_P}{V_{m(std)}} \times \frac{1g}{1000\,mg} \times \frac{1lb}{453.59\,g} \times \frac{7000\,gr}{lb}$$

where:

C_P = Measured stack gas particulate matter concentration (gr/dscf)

M_P = Mass of particulate matter collected in the M5 sample (mg)

$V_{m(std)}$ = Gas sample volume (dscf)

$$C_P\,(mg/dscm) = \frac{M_P}{V_{m(std)}} \times \frac{35.31dscf}{dscm}$$

where:

C_P = Measured stack gas particulate matter concentration (mg/dscm)

M_P = Mass of particulate matter collected in the M5 sample (mg)

$V_{m(std)}$ = Gas sample volume (dscf)

Note: Oxygen corrections are made using the formulas given at the beginning of this document.

Hydrogen Chloride and Chlorine:

Stack gas samples are collected in acidic and alkaline impingers to capture gaseous chlorides. The chloride captured in the acidic impingers is assumed to be associated with hydrogen chloride emissions. The chloride captured in the alkaline impingers is assumed to be associated with chlorine emissions. Overall control efficiency for any halogen is calculated by taking the ratio of the total stack gas emission rate for the halogen to the total input of the corresponding halogen.

$$E_{HCl}\,(lb/hr) = \frac{\left[Cl^-\right]_a \times Q_{sd}}{V_{m(std)}} \times \frac{1g}{1000\,mg} \times \frac{1lb}{453.59\,g} \times \frac{60\min}{hr} \times \frac{36.46\,lb\,HCl}{35.45\,lb\,Cl}$$

where:

E_{HCl} = Emission rate of hydrogen chloride (lb/hr)

$\left[Cl^-\right]_a$ = Chloride in acidic impingers (mg)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

$V_{m(std)}$ = Gas sample volume (dscf)

$$E_{Cl_2}\ (lb/hr) = \frac{\left[Cl^-\right]_b \times Q_{sd}}{V_{m(std)}} \times \frac{1g}{1000\,mg} \times \frac{1lb}{453.59\,g} \times \frac{60\min}{hr}$$

where:

E_{Cl_2} = Emission rate of chlorine (lb/hr)

$\left[Cl^-\right]_b$ = Chloride in alkaline impingers (mg)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

$V_{m(std)}$ = Gas sample volume (dscf)

Total HCl and Cl_2 as HCl Equivalents:

$$C_{HCl(eq)} = \frac{\left(\left[Cl^-\right]_a + \left[Cl^-\right]_b\right) \times \frac{36.46\,mg\ HCl}{35.45\,mg\ Cl}}{V_{m(std)}} \times \frac{35.31\ ft^3}{m^3} \times \frac{1\,kg\ HCl}{1\times10^6\ mg\ HCl} \times \frac{1\,kg-mol\ HCl}{36.46\,kg\ HCl} \times \frac{24.04\,dscm}{kg-mol} \times \left(1\times10^6\ ppm\right)$$

where:

$C_{HCl(eq)}$ = Concentration of HCl and Cl_2 as HCl equivalents (ppmv)

$\left[Cl^-\right]_a$ = Chloride in acidic impingers (mg)

$\left[Cl^-\right]_b$ = Chloride in alkaline impingers (mg)

$V_{m(std)}$ = Gas sample volume (dscf)

Note: Oxygen corrections are made using the formulas given at the beginning of this document.

Metals:

For each metal, the amount found in each sample component is added, and the total amount is used in all calculations:

$$E_{m(i)}\,(lb/hr) = \frac{\sum M_{m(i)} \times Q_{sd}}{V_{m(std)}} \times \frac{1g}{1\times10^6\ \mu g} \times \frac{1lb}{453.59\,g} \times \frac{60\min}{hr}$$

where:

$E_{m(i)}$ = Emission rate of metal i (lb/hr)

$M_{m(i)}$ = Mass of metal i collected in sampling train components (ug)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

$V_{m(std)}$ = Gas sample volume (dscf)

$$C_{m(i)}\ (\mu g / dscm) = \frac{\sum M_{m(i)}}{V_{m(std)}} \times \frac{35.31 dscf}{dscm}$$

where:

$C_{m(i)}$ = Concentration of metal i (ug/dscm)

$M_{m(i)}$ = Mass of metal i collected in sampling train components (ug)

$V_{m(std)}$ = Gas sample volume (dscf)

Note: Oxygen corrections are made using the formulas given at the beginning of this document.

Volatile Organic Compound Emission Rates (Using Sorbent Tubes):

For each volatile organic compound, the amounts found in all sorbent tube sets used in a run are added together. The amount of gas sampled through all analyzed tube sets used in the run is also added together. Emission rates are calculated as follows:

$$E_{v(i)}\,(g/\sec) = \frac{\sum M_{v(i)}}{\sum V_{v(std)}} \times \frac{1000\,liters}{m^3} \times Q_{sd} \times \frac{1m^3}{35.31\,ft^3} \times \frac{1g}{1\times 10^9\,ng} \times \frac{1\min}{60\sec}$$

where:

$E_{v(i)}$ = Emission rate of volatile organic compound *i* (g/sec)

$M_{v(i)}$ = Mass of volatile organic compound *i* found in VOST train components (ng)

$V_{v(std)}$ = Sorbent tube set gas sample volume (liters, dry standard)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

Semi-Volatile Organic Compound Emission Rates (Including PAHs, PCBs, and Organochlorine Pesticides):

For each semi-volatile organic compound, the total amount found in the entire sample was divided by the gas sample volume, and multiplied by the stack gas volumetric flow rate to yield the semi-volatile organic compound emission rate, as follows:

$$E_{sv(i)}\,(g/\sec) = \frac{\sum M_{sv(i)}}{V_{m(std)}} \times Q_{sd} \times \frac{1g}{1\times10^{6}\,\mu g} \times \frac{1\min}{60\sec}$$

where:

$E_{sv(i)}$ = Emission rate of semi-volatile compound *i* (g/sec)
$M_{sv(i)}$ = Mass of semi-volatile organic compound *i* found on sampling train components (μg)
$V_{m(std)}$ = Gas sample volume (dscf)
Q_{sd} = Stack gas volumetric flow rate (dscfm)

Destruction and Removal Efficiency:

Destruction and removal efficiency (DRE) for POHCs is calculated using the formula given in 40 CFR 264.343(a)(1).

$$DRE\,(\%) = \frac{(W_{in} - W_{out})}{W_{in}} \times 100\%$$

where:

W_{in} = Mass feed rate of POHC into the incinerator
W_{out} = Mass emission rate of POHC present in the exhaust emissions prior to release to the atmosphere

For preservation of significant figures, the equation is transformed to the following:

$$DRE\,(\%) = \left(1 - \frac{W_{out}}{W_{in}}\right) \times 100\%$$

PCDD/PCDF Emission Rate and Stack Gas Concentration:

Total emissions of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are calculated by summing the emissions of the tetra- through octa- chlorinated PCDDs and PCDFs. Emission rates of the PCDDs and PCDFs are calculated by summing the total mass of the tetra- through octa- chlorinated PCDDs and PCDFs found in the entire stack gas sample, dividing by the gas sample volume, and multiplying by the stack gas flow rate. Stack gas PCDD/PCDF concentration is calculated by dividing the total mass of PCDDs and PCDFs in the stack gas sample by the gas sample volume. Values are corrected to an equivalent 7% oxygen, dry basis. Calculations used for PCDD/PCDF determinations are as follows:

$$E_{DF}\,(g/\sec) = E_D + E_F$$

where:

E_{DF} = Total PCDD/PCDF emission rate (g/sec)

E_D = Total tetra- through octa- chlorinated PCDD emission rate (g/sec)

E_F = Total tetra- through octa- chlorinated PCDF emission rate (g/sec)

$$E_D\,(g/\sec) = \frac{\sum_{i=4}^{8} M_{D(i)}}{V_{m(std)}} \times Q_{sd} \times \frac{1g}{1\times10^9\,ng} \times \frac{1\min}{60\sec}$$

$$E_F\,(g/\sec) = \frac{\sum_{i=4}^{8} M_{F(i)}}{V_{m(std)}} \times Q_{sd} \times \frac{1g}{1\times10^9\,ng} \times \frac{1\min}{60\sec}$$

where:

$M_{D(i)}$ = Mass of CDD on sample in congener group *i* (ng)

$M_{F(i)}$ = Mass of CDF on sample in congener group *i* (ng)

i = Number of chlorine atoms in congener group (i.e., *i* = 4 represents tetra- CDD/CDF)

$V_{m(std)}$ = Gas sample volume (dscf)

Q_{sd} = Stack gas volumetric flow rate (dscfm)

$$C_{DF(corr)} = C_{D(corr)} + C_{F(corr)}$$

where:

$C_{DF(corr)}$ = Total stack gas concentration of PCDDs and PCDFs (ng/dscm, corrected to 7% O_2, dry)

$C_{D(corr)}$ = Stack gas concentration of tetra- through octa- chlorinated PCDDs (ng/dscm, corrected to 7% O_2, dry)

$C_{F(corr)}$ = Stack gas concentration of tetra- through octa- chlorinated PCDFs (ng/dscm, corrected to 7% O_2, dry)

$$C_{D(corr)} = \frac{\sum_{i=4}^{8} M_{D(i)}}{V_{m(std)}} \times \frac{35.31\,ft^3}{m^3} \times \frac{14}{21-Y}$$

$$C_{F(corr)} = \frac{\sum_{i=4}^{8} M_{F(i)}}{V_{m(std)}} \times \frac{35.31\,ft^3}{m^3} \times \frac{14}{21-Y}$$

where:

$M_{D(i)}$ = Mass of CDD on sample in congener group *i* (ng)

$M_{F(i)}$ = Mass of CDF on sample in congener group *i* (ng)

i = Number of chlorine atoms in congener group (i.e., *i* = 4 represents tetra- CDD/CDF)

$V_{m(std)}$ = Gas sample volume (dscf)

Y = Stack gas oxygen concentration (vol %, dry).