EMISSION CALCULATIONS

EXHAUST FLOW

Exhaust Flow Using EPA Method 2 (Pitot Tube)

Equations 1-1a, 1-1b, and 1-1c show the calculations for computing exhaust flow at stack conditions using a pitot tube.

$$Qa = V \times A \qquad (1\text{-}1a)$$

$$V = 5128.8 \times Kp \times \frac{\sum_{i=1}^{n} \sqrt{\Delta P_i}}{n} \times \sqrt{\frac{Ts}{Ps \times MW}} \qquad (1\text{-}1b)$$

$$Ps = Pb + (Pg \times 0.0735) \qquad (1\text{-}1c)$$

where

Qa	Exhaust stack flow rate (ft^3/min at stack conditions)
V	Exhaust stack velocity (ft/min at stack conditions)
A	Cross sectional area of the exhaust stack at measurement point (ft^2)
Kp	Pitot tube factor
$<P_i$	Measured differential pressure across the pitot tube each test point (in. H_2O)
n	Mathematical system representing the total number of measured test points
Ts	Exhaust stack temperature (degrees Rankine)
Ps	Absolute exhaust stack pressure (in. Hg)
MW	Molecular weight of the exhaust gas from EPA Method 3a and 4 (lbs/mole)
Pb	Atmospheric pressure (in. Hg)
Pg	Exhaust stack static/gauge pressure (in. H_2O)

Equation 1-2 describes how flow rate can be converted to a dry basis at EPA standard conditions.

$$Qd = Qa \times 1059 \times \frac{Ps}{Ts} \times Fd \qquad (1\text{-}2)$$

where

Qd	Exhaust stack flow rate on a dry basis (SCFH at EPA standard conditions)
Qa	Exhaust stack flow rate (ft^3/min at stack conditions)
Ps	Absolute exhaust stack pressure (in. Hg)
Ts	Exhaust stack temperature (degrees Rankine)
Fd	Dry fraction of stack gas from EPA Method 4

Exhaust Flow Using EPA Method 19 (F-Factor Technique)

Equations 1-3a and 1-3b show the calculations for computing exhaust flow on a dry basis at standard conditions using the measured oxygen or carbon dioxide concentration.

O_2 F-Factor

$$Qd = Qf \times F_{Btu} \times 10^{-6} \times F_{O_2} \times \left(\frac{20.9\%}{20.9\% - O_2\%_{measured}} \right) \quad \text{(1-3a)}$$

CO_2 F-Factor

$$Qd = Qf \times F_{Btu} \times 10^{-6} \times F_{CO_2} \times \left(\frac{100\%}{CO_2\%_{measured}} \right) \quad \text{(3-3b)}$$

where

Qd	Exhaust stack flow rate on a dry basis (SCFH at EPA standard conditions)
Qf	Fuel flow rate of the engine (SCFH natural gas)
F_{Btu}	Higher heating value (HHV) of gas (Btu/SCF)
F_{O2}	O_2 F-Factor from EPA Method 19 = 8710 dry SCF/MMBtu exhaust
F_{CO2}	CO_2 F-Factor from EPA Method 19 = 1040 dry SCF/MMBtu exhaust
$O_2\%_{measured}$	Measured concentration of O_2 in the exhaust (%)
$CO_2\%_{measured}$	Measured concentration of CO_2 in the exhaust (%)

Exhaust Flow Using Measured Horsepower

Equations 1-4a and 1-4b describe the calculations to calculate exhaust flow using the measured horsepower of the engine (Method 19 variation).

O_2 F-Factor

$$Qd = HP_{measured} \times BSFC \times 10^{-6} \times F_{O_2} \times \left(\frac{20.9\%}{20.9\% - O_2\%_{measured}} \right) \quad \text{(1-4a)}$$

CO_2 F-Factor

$$Qd = HP_{measured} \times BSFC \times 10^{-6} \times F_{CO_2} \times \left(\frac{100\%}{CO_2\%_{measured}} \right) \quad \text{(1-4b)}$$

where

Qd	Exhaust stack flow rate on a dry basis (SCFH at EPA standard conditions)
$HP_{measured}$	Measured horsepower from engine (BHP)

BSFC	Brake specific fuel consumption of engine at operating condition (Btu/BHP-hr)
F_{O2}	O_2 F-Factor from EPA Method 19 = 8710 dry SCF/MMBtu exhaust
F_{CO2}	CO_2 F-Factor from EPA Method 19 = 1040 dry SCF/MMBtu exhaust
$O_2\%_{measured}$	Measured concentration of O_2 in the exhaust (%)
$CO_2\%_{measured}$	Measured concentration of CO_2 in the exhaust (%)

EXHAUST CONCENTRATIONS AT WET AND DRY CONDITIONS

Wet and Dry Basis Concentrations

Equations 1-5a and 1-5b show the calculations required to convert between wet and dry concentrations.

$$E_{dry} = E_{wet} \times \left(\frac{100\%}{100\% - Fw} \right) \quad (1\text{-}5a)$$

$$E_{wet} = E_{dry} \times \left(\frac{Fd}{100\%} \right) \quad (1\text{-}5b)$$

where

E_{dry}	Emission concentration on a dry basis (ppmv, dry)
E_{wet}	Emission concentration on a wet basis (ppmv, wet)
Fw	Wet fraction of exhaust gas (% by volume)
Fd	Dry fraction of exhaust gas (% by volume). Note: Fd = 100% - Fw

Moisture Content

Equation 1-6 describes the calculation for determining moisture content using specific humidity. However, it is only applicable for engines with natural gas fuel and no water injection.

$$Fw = (H \times 161) + \left(\frac{20.9\% - O_2\%_{measured}}{1.099} \right) \quad (1\text{-}6)$$

where

Fw	Wet fraction of exhaust gas (% by volume)
H	Specific humidity in ambient air from wet/dry bulb and psychrometric table (lbs water / lb dry air)
$O_2\%_{measured}$	Measured concentration of O_2 in the exhaust, dry basis (%).

MASS EMISSION RATES

Equation 3-7 describes the conversion from emission concentration to mass emission rates (lbs / hour).

$$E_{mass} = Fe \times E_{conc} \times d_E \qquad (1\text{-}7)$$

where

E_{mass}	Mass emission rate of exhaust (lb/hr)
Fe	Exhaust stack flow rate (ft^3/hr)
E_{conc}	Concentration of emission by volume (ppmv)
d_E	Gas density factor for converting volume to mass
	1 mole of ideal gas = 385.5 scf at 68F, 1 atm
	d_{NOx} = 46 lbs/mole / 385scf/mole = 11.94 x 10^{-8} lbs/scf-ppmv
	d_{CO} = 28 lbs/mole / 385scf/mole = 7.26 x 10^{-8} lbs/scf-ppmv
	$d_{THC\ as\ C1}$ = 16 lbs/mole / 385scf/mole = 4.15 x 10^{-8} lbs/scf-ppmv

Equation 1-8 describes the conversion from mass emission rate (lbs per hour) to tons per year.
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$$E_{tpy} = \frac{E_{mass} \times RunHours}{2{,}000} \qquad (1\text{-}8)$$

where

E_{tpy}	Mass emission rate of exhaust in tons per year (tons/yr)
E_{mass}	Mass emission rate of exhaust (lb/hr)
RunHours	Actual or potential run-hours for the engine in a given year (hr)

HORSEPOWER SPECIFIC MASS EMISSION RATES

Equation 1-9 converts mass emission rates to horsepower specific emission rates.

$$E_{hpmass} = \frac{E_{mass} \times 454}{BHP} \qquad (1\text{-}9)$$

where

E_{hpmass}	Horsepower specific emission rate of exhaust (gm/BHP-hr)
E_{mass}	Mass emission rate of exhaust (lb/hr)
BHP	Brake horsepower produced by the engine (horsepower)

HORSEPOWER CALCULATIONS

Horsepower From Kilowatts (Generator Application)

Equation 1-10 can be used to calculate the brake horsepower from generators.

$$BHP = \left(\frac{KW \times PF}{EFF \times 0.7457} \right) + PHP \qquad (1\text{-}10)$$

where

BHP	Brake horsepower produced by the engine (horsepower)
KW	Electrical power produced by the generator (kilowatts)
PF	Power factor of electricity produce (typically about 1.0)
EFF	Efficiency of generator (typically 0.92)
PHP	Parasitic horsepower load used to drive auxiliary equipment attached to the engine (e.g. oil pumps, fans, etc.) (horsepower)

Horsepower from Equipment Analyzer (Compressor Application)

Using pressure transducers to measure crank-referenced pressures an each compressor end, equation 1-11 can calculate a compressor's brake horsepower.

$$BHP = \left(\frac{IHP}{0.95} \right) + PHP \qquad (1\text{-}11)$$

where

BHP	Brake horsepower produced by the engine (horsepower)
IHP	Indicated horsepower – the actual horsepower consumed by the compressors
PHP	Parasitic horsepower load used to drive auxiliary equipment attached to the engine (e.g. oil pumps, fans, etc.) (horsepower)

Horsepower from Fuel Flow Rate and BSFC

As shown in Equations 1-12a and 1-12b, engine horsepower can be calculated using the fuel flow rate and the brake specific fuel consumption (BSFC)

$$BHP = \frac{Qf \times LHV}{BSFC} \qquad (1\text{-}12a)$$

$$LHV = HHV \times 0.91 \qquad (1\text{-}12b)$$

where

BHP	Brake horsepower produced by the engine (horsepower)
Qf	Fuel flow rate computed from engine fuel meter (scfh)
LHV	Lower Heating Value of fuel gas (Btu/scf)
HHV	Higher Heating Value of fuel gas (Btu/scf)
BSFC	Brake Specific Fuel Consumption is the heat rate or efficiency of fuel conversion to horsepower

Horsepower from Measured Exhaust Flow Rate and BSFC

As shown in Equation 1-13, brake horsepower can be calculated using empirically derived exhaust flow measurements and brake specific fuel consumption (BSFC). Equation 3-2 shows the calculation.

$$BHP = \left(\frac{Qe}{O_2 FFactor \times BSFC} \right) \times \left(\frac{20.9\% - O_2\%}{20.9\%} \right) \times 10^6 \qquad (1\text{-}13)$$

where

BHP	Brake horsepower produced by the engine (horsepower)
Qe	Exhaust flow rate computed from pitot tube data or F-factor data (dscfh)
O_2 F-factor	O_2 F-Factor from EPA Method 19
BSFC	Brake Specific Fuel Consumption is the heat rate or efficiency of fuel conversion to horsepower
O_2%	Percent oxygen measured in exhaust flow (dry basis)

Horsepower from Fuel Pressure or Governor Control Valve Position

Brake horsepower can be estimated using fuel pressure (Equation 1-14a) or governor position (Equation 1-14b). If the torque is known, brake horsepower can be computed using Equation 1-14c.

$$BHP = \left(\frac{FMP_{actual}}{FMP_{rated}} \right) \times BHP_{rated} \qquad (1\text{-}14a)$$

$$BHP = \left(\frac{FCV_{actual}}{FCV_{rated}} \right) \times BHP_{rated} \qquad (1\text{-}14b)$$

$$BHP = BHP_{rated} \times \left(\frac{Speed_{actual}}{Speed_{rated}} \right) \times \left(\frac{Torque_{actual}}{Torque_{rated}} \right) \qquad (1\text{-}14c)$$

where

BHP	Brake horsepower produced by the engine (horsepower)
BHP_{rated}	Rated brake horsepower of the engine (horsepower)

FMP_{rated}	Fuel manifold pressure typically observed at full load (in. Hg or psi)
FMP_{actual}	Actual fuel manifold pressure (in. Hg or psi)
FCV_{rated}	Position of the fuel control valve typically observed at full load (% open)
FCV_{actual}	Actual position of fuel control valve during the test (% open)
$Speed_{rated}$	Rated or maximum speed of the engine (rpm)
$Speed_{actua}l$	Actual speed of the engine (rpm)
$Torque_{rated}$	Maximum allowable torque rating – typically 100%
$Torque_{actual}$	Observed torque of the engine (%)

CATALYTIC CONVERTOR EFFICIENCY

The reduction efficiency of a catalytic converter can be computed using Equation 1-15.

$$EFF = \left(1 - \frac{C_{outlet}}{C_{inlet}}\right) \times 100 \qquad (1\text{-}15)$$

where

EFF	The reduction efficiency of the catalytic converter (%)
C_{outlet}	Concentration of exhaust (NOx, CO, etc) leaving the catalyst after the outlet (ppmv)
C_{inlet}	Concentration of exhaust (NOx, CO, etc) entering the catalyst at the inlet (ppmv)