Conversion factors

$ppm_{methane} := 1 \qquad ppm_{NOx} := 1 \qquad ppm_{C1} := 1$

Ratio between Hydrogen and Carbon atoms in fuel

$HC_{ratio} := 1.75$

assumed value although the gasoline is mixed with ethanol

Molecular weights

$MW_{CO} := 28.01\,\frac{gm}{mol} \qquad MW_{CO2} := 44.01\,\frac{gm}{mol} \qquad MW_{NO2} := 46.01\,\frac{gm}{mol}$

$MW_{O2} := 32\,\frac{gm}{mol} \qquad MW_{C} := 12.01\,\frac{gm}{mol} \qquad MW_{H} := 1.008\,\frac{gm}{mol}$

$MW_{fuel} := \left(MW_C + HC_{ratio} \cdot MW_H\right) = 0.014\,\frac{kg}{mol}$

Total molecular weight of fuel

Calculating NO2 correction factor to account for humidity

$H_{specific} := 3.0343\,\frac{gm}{kg}$

Specific humidity of air at intake (units are grams of moisture per kg of air)

$K_H := \frac{1}{1 - 0.0329 \cdot \left(H_{specific} - 10.71\right)} = 0.74$

Correction factor for effects of humidity on NO2 formation

Measured engine performance parameters at four operating points

$N_m := \begin{pmatrix} 4550 \\ 5250 \\ 5950 \\ 7000 \end{pmatrix} \cdot \frac{1}{min}$

Measured engine speed

$T_m := \begin{pmatrix} 20.4 \\ 28 \\ 45.5 \\ 82 \end{pmatrix} \cdot ft \cdot lbf$

Measured engine torque

$dm_f := \begin{pmatrix} 0.014 \\ 0.0215 \\ 0.048 \\ 0.136 \end{pmatrix} \cdot \frac{kg}{15 \cdot s}$

Measured mass flow rate of fuel

$i := 1, 2 .. 4$

$P_{m_i} := 2 \cdot \pi \cdot N_{m_i} \cdot T_{m_i}$ $\quad P_m = \begin{pmatrix} 13.179 \\ 20.871 \\ 38.438 \\ 81.497 \end{pmatrix} \cdot kW$

Calculated power (consistent with recorded value in excel spreadsheet)

Measured dry emmisions at four operating points

$CO_{dry} := \begin{pmatrix} 0.28 \\ 2 \\ 2.287 \\ 6.97 \end{pmatrix} \cdot \%$

Carbon monoxide dry emissions

$CO_{2dry} := \begin{pmatrix} 10.26 \\ 9.72 \\ 10.32 \\ 6.26 \end{pmatrix} \cdot \%$

Carbon dioxide dry emissions

$HC_{dry} := \begin{pmatrix} 706 \\ 483 \\ 222 \\ 3450 \end{pmatrix} \cdot ppm_{methane}$

Hydro-carbon dry emissions

$NO_{xdry} := \begin{pmatrix} 51 \\ 101 \\ 181 \\ 249 \end{pmatrix} \cdot ppm_{NOx}$

NOx dry emissions

$O_{2dry} := \begin{pmatrix} 6.5 \\ 6.02 \\ 2.57 \\ 6.29 \end{pmatrix} \cdot \%$

Oxygen dry emissions

The correction factor K is the factor used to adjust the dry percentages of each emission which do not include water into the wet percentages which do include water. In order to accomplish this one must calculate the percentage of H2 in the emissions.

$$H_{2dry} := \frac{0.5 \cdot HC_{ratio} \cdot CO_{dry} \cdot \left(CO_{dry} + CO_{2dry}\right)}{CO_{dry} + 3 \cdot CO_{2dry}} = \begin{pmatrix} 4.153 \\ 4.14 \\ 3.88 \\ 5.01 \end{pmatrix} \cdot \%$$

$$K_{cf} := \frac{1}{1 + \left[0.005 \cdot \left(CO_{dry} + CO_{2dry}\right) \cdot HC_{ratio} - 0.01 \cdot H_{2dry}\right] \cdot 100} = \begin{pmatrix} 0.952 \\ 0.942 \\ 0.933 \\ 0.938 \end{pmatrix}$$

Calculated wet emmisions at four operating points

$$CO_{wet_i} := K_{cf_i} \cdot CO_{dry_i} \qquad CO_{wet} = \begin{pmatrix} 0.266 \\ 1.885 \\ 2.134 \\ 6.541 \end{pmatrix} \cdot \%$$

Carbon monoxide wet emissions

$$CO_{2wet_i} := K_{cf_i} \cdot CO_{2dry_i} \qquad CO_{2wet} = \begin{pmatrix} 9.765 \\ 9.16 \\ 9.631 \\ 5.874 \end{pmatrix} \cdot \%$$

Carbon dioxide wet emissions

$$HC_{wet_i} := K_{cf_i} \cdot HC_{dry_i} \qquad HC_{wet} = \begin{pmatrix} 671.939 \\ 455.167 \\ 207.185 \\ 3.237 \times 10^3 \end{pmatrix} \cdot ppm_{methane}$$

Hydro-carbon wet emissions

$$NO_{xwet_i} := K_{cf_i} \cdot NO_{xdry_i} \qquad NO_{xwet} = \begin{pmatrix} 48.54 \\ 95.18 \\ 168.921 \\ 233.657 \end{pmatrix} \cdot ppm_{NOx}$$

NOx wet emissions

$$O_{2wet_i} := K_{cf_i} \cdot O_{2dry_i} \qquad O_{2wet} = \begin{pmatrix} 6.186 \\ 5.673 \\ 2.398 \\ 5.902 \end{pmatrix} \cdot \%$$

Oxygen wet emissions

Calculate mass emissions

$$TC_i := \left(CO_{wet_i} + CO_{2wet_i} + \frac{HC_{wet_i}}{10^6} \right) \qquad TC = \begin{pmatrix} 10.099 \\ 11.09 \\ 11.786 \\ 12.739 \end{pmatrix} \cdot \%$$

$$CO_{mass_i} := \frac{MW_{CO}}{MW_{fuel}} \cdot \frac{dm_{f_i}}{TC_i} \cdot CO_{wet_i} \qquad CO_{mass} = \begin{pmatrix} 180.306 \\ 1.783 \times 10^3 \\ 4.242 \times 10^3 \\ 3.408 \times 10^4 \end{pmatrix} \cdot \frac{gm}{hr}$$

$$CO_{2mass_i} := \frac{MW_{CO2}}{MW_{fuel}} \cdot \frac{dm_{f_i}}{TC_i} \cdot CO_{2wet_i} \qquad CO_{2mass} = \begin{pmatrix} 1.038 \times 10^4 \\ 1.362 \times 10^4 \\ 3.008 \times 10^4 \\ 4.809 \times 10^4 \end{pmatrix} \cdot \frac{gm}{hr}$$

$$HC_{mass_i} := \frac{dm_{f_i}}{TC_i} \cdot \frac{HC_{wet_i}}{10^6} \qquad HC_{mass} = \begin{pmatrix} 22.357 \\ 21.178 \\ 20.25 \\ 829.525 \end{pmatrix} \cdot \frac{gm}{hr}$$

$$NO_{xmass_i} := \frac{MW_{NO2}}{MW_{fuel}} \cdot \frac{dm_{f_i}}{TC_i} \cdot \frac{NO_{xwet_i}}{10^6} \cdot K_H \qquad NO_{xmass} = \begin{pmatrix} 3.989 \\ 10.939 \\ 40.784 \\ 147.891 \end{pmatrix} \cdot \frac{gm}{hr}$$

$$O_{2mass_i} := \frac{MW_{O2}}{MW_{fuel}} \cdot \frac{dm_{f_i}}{TC_i} \cdot O_{2wet_i} \qquad O_{2mass} = \begin{pmatrix} 4.782 \\ 6.132 \\ 5.446 \\ 35.136 \end{pmatrix} \cdot \frac{kg}{hr}$$

Calculate the brake specific emission values

$$bs_{CO_i} := \frac{CO_{mass_i}}{P_{m_i}} \qquad bs_{CO} = \begin{pmatrix} 0.014 \\ 0.085 \\ 0.11 \\ 0.418 \end{pmatrix} \cdot \frac{kg}{hr \cdot kW}$$

Brake specific carbon monoxide emission

$$bs_{CO2_i} := \frac{CO_{2mass_i}}{P_{m_i}} \qquad bs_{CO2} = \begin{pmatrix} 0.788 \\ 0.652 \\ 0.783 \\ 0.59 \end{pmatrix} \cdot \frac{kg}{hr \cdot kW}$$

Brake specific carbon dioxide emission

$$bs_{HC_i} := \frac{HC_{mass_i}}{P_{m_i}} \qquad bs_{HC} = \begin{pmatrix} 1.696 \times 10^{-3} \\ 1.015 \times 10^{-3} \\ 5.268 \times 10^{-4} \\ 0.01 \end{pmatrix} \cdot \frac{kg}{hr \cdot kW}$$

Brake specific hydrocarbon emission

$$bs_{NOx_i} := \frac{NO_{xmass_i}}{P_{m_i}} \qquad bs_{NOx} = \begin{pmatrix} 3.027 \times 10^{-4} \\ 5.241 \times 10^{-4} \\ 1.061 \times 10^{-3} \\ 1.815 \times 10^{-3} \end{pmatrix} \cdot \frac{kg}{hr \cdot kW}$$

Brake specific NOx emission

$$bs_{O2_i} := \frac{O_{2mass_i}}{P_{m_i}} \qquad bs_{O2} = \begin{pmatrix} 0.363 \\ 0.294 \\ 0.142 \\ 0.431 \end{pmatrix} \cdot \frac{kg}{hr \cdot kW}$$

Brake specific oxygen emission

Discussion/Reflection: In this problem it was interesting to see how many different pieces of equipment went into monitoring an engine. However, if I think about it there is a lot of phenomena that is going on in such a device. It is nice to see how we can use multi-diciplinary engineering (mechanical, electrical, computer) to optimize performance and still make progress in what is a relatively old technology.