WHEN YOU NEED TO BE SURE

CyFlex® Knowledge Article

Step-by-Step EGR Calculations

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Assume we are measuring CO_2 in the intake charge and burning an overall lean mixture of Cummins standard air and diesel fuel with a molar hydrogen to carbon ratio of β, usually assumed to be equal to 1.80 or 1.85.

1. Determine $y_{CO_2,air,dry}$, the CO_2 concentration in the dry combustion air. It can either be measured directly on a dry basis or assumed equal to a mole fraction of 0.00033 per the TSFE definition of Cummins standard air.

2. Calculate *a*, the number of moles of dry combustion air per mole of fuel carbon. If the dry air to fuel ratio is being measured, use

$$a = \left.\frac{A}{F}\right|_{dry} \times \frac{(M_C + \beta M_H)}{M_{air}} \qquad \text{ss.1}$$

   where M_C = 12.011 is the molecular weight of carbon, M_H = 1.008 is the molecular weight of hydrogen, and M_{air} = 28.9646 is the molecular weight of dry air.

   If the wet air to fuel ratio is being measured, use

$$a = \left.\frac{A}{F}\right|_{wet} \times \frac{(M_C + \beta M_H)}{\left(M_{air} + \frac{P_{vap}}{P_{bar}} M_{H_2O}\right)} \qquad \text{ss.2}$$

   where M_{H2O} = 18.016 is the molecular weight of water, P_{vap} is the measured vapor pressure and P_{bar} is the measured barometric pressure.

   If the exhaust gas CO_2 concentration is being measured on a dry basis, use

$$a = \frac{1 + y_{CO_2,exh,dry}\beta / 4}{y_{CO_2,exh,dry} - y_{CO_2,air,dry}} \qquad \text{ss.3}$$

3. Calculate b, the number of moles of water vapor in the combustion air per mole of fuel carbon using

$$b = a\frac{P_{vap}}{P_{bar} - P_{vap}} \qquad \text{ss.4}$$

4. Calculate the combustion air water vapor concentration using

$$y_{H_2O,air,wet} = \frac{P_{vap}}{P_{bar}} \qquad \text{ss.5}$$

5. Calculate the exhaust gas water vapor concentration using

$$y_{H_2O,exh,wet} = \frac{b + \beta/2}{a + b + \beta/4} \qquad \text{ss.6}$$

6. If the exhaust gas CO_2 concentration is not being measured, calculate it using

$$y_{CO_2,exh,dry} = \frac{a\, y_{CO_2,air,dry} + 1}{a - \beta / 4} \quad \text{ss.7}$$

7. Calculate M_{exh}, the molecular weight of the exhaust gas using the following set of equations

$$y_{CO_2,exh,wet} = \frac{a\, y_{CO_2,air,dry} + 1}{a + b + \beta / 4} \quad \text{ss.8}$$

$$y_{O_2,exh,wet} = \frac{a\, y_{O_2,air,dry} - \beta / 4 - 1}{a + b + \beta / 4} \quad \text{ss.9}$$

$$y_{N_2,exh,wet} = \frac{a\, y_{N_2,air,dry}}{a + b + \beta / 4} \quad \text{ss.10}$$

$$y_{A,exh,wet} = \frac{a\, y_{A,air,dry}}{a + b + \beta / 4} \quad \text{ss.11}$$

$$M_{exh} = y_{CO_2,exh,wet} \mathrm{M}_{\mathrm{CO_2}} + y_{H_2O,exh,wet} \mathrm{M}_{\mathrm{H_2O}} + y_{O_2,exh,wet} \mathrm{M}_{\mathrm{O_2}} + y_{N_2,exh,wet} \mathrm{M}_{\mathrm{N_2}} + y_{A,exh,wet} \mathrm{M}_{\mathrm{A}} \quad \text{ss.12}$$

where by the TSFE definition of dry "Cummins standard" combustion air (http://www.ctc.cummins.com/ctc-fe/tsfe/teams/stdcal/aircomp.htm) $y_{O_2,air,dry}$ = 0.20946, $Y_{N_2,air,dry}$ = 0.78087, $y_{A,air,dry}$ = 0.00934, and $y_{CO_2,air,dry}$ = 0.00033 and the molecular weights are M_{CO2} = 44.010, M_{H2O} = 18.016, M_{O2} = 31.999, M_{N2} = 28.013, and M_A = 39.948.

8. Calculate $M_{air,wet}$, the molecular weight of the combustion air using

$$M_{air,wet} = \frac{P_{vap}}{P_{bar}} M_{H_2O} + \frac{P_{bar} - P_{vap}}{P_{bar}} M_{air} \quad \text{ss.13}$$

9. Calculate r, the number of moles of exhaust gas per mole of combustion air in the intake charge using

$$r = \frac{\left(y_{CO_2,\mathrm{int},dry} - y_{CO_2,air,dry}\right)\left(1 - y_{H_2O,air,wet}\right)}{\left(y_{CO_2,exh,dry} - y_{CO_2,\mathrm{int},dry}\right)\left(1 - y_{H_2O,exh,wet}\right)} \quad \text{ss.14}$$

10. Calculate the EGR percent by mass in the intake charge using

$$\%EGR = 100 \left(\frac{r\, M_{exh}}{M_{air,wet} + r\, M_{exh}} \right) \quad \text{ss.15}$$

11. Calculate the oxygen concentration in the intake charge using

$$y_{O_2,mix,wet} = \frac{y_{O_2,air,dry}\ (1-\frac{P_{vap}}{P_{bar}}) + r\ y_{O_2,exh,wet}}{1+r}$$ ss.16

Example EGR Calculation

Assume:

$\left.\frac{A}{F}\right|_{wet}$ = 25.00

β = *1.85*

$y_{CO_2,air,dry}$ = 0.033%

$y_{CO_2,\text{int},dry}$ = 2.090%

P_{bar} = 29.92 in_hg

P_{vap} = 0.510 in_hg

$$\begin{aligned} a &= \left.\frac{A}{F}\right|_{wet} \times \frac{(M_C + \beta M_H)}{\left(M_{air} + \frac{P_{vap}}{P_{bar}} M_{H_2O}\right)} \\ &= 25.00 \times \frac{(12.011 + 1.85 \times 1.008)}{\left(28.9646 + \frac{0.510}{29.92} \times 18.016\right)} \\ &= 11.849 \end{aligned}$$

$$\begin{aligned} b &= a \frac{P_{vap}}{P_{bar} - P_{vap}} \\ &= 11.849 \times \frac{0.510}{29.92 - 0.510} \\ &= 0.20547 \end{aligned}$$

$$y_{H_2O,air,wet} = \frac{P_{vap}}{P_{bar}} = \frac{0.510}{29.92} = 0.017045$$

$$y_{H_2O,exh,wet} = \frac{\beta/2+b}{a+b+\beta/4} = \frac{1.85/2+0.20547}{11.8487+0.20547+1.85/4} = 0.090317$$

$$y_{CO_2,exh,dry} = \frac{a\,y_{CO_2,air,dry}+1}{a-\beta/4} = \frac{11.8487\times 0.00033+1}{11.8487-1.85/4} = 0.088170$$

$$y_{CO_2,exh,wet} = \frac{a\,y_{CO_2,air,dry}+1}{a+b+\beta/4} = \frac{11.8487\times 0.00033+1}{11.8487+0.20547+1.85/4} = 0.080206$$

$$y_{O_2,exh,wet} = \frac{a\,y_{O_2,air,dry}-\beta/4-1}{a+b+\beta/4} = \frac{11.8487\times 0.20946-1.85/4-1}{11.8487+0.20547+1.85/4} = 0.081438$$

$$y_{N_2,exh,wet} = \frac{a\,y_{N_2,air,dry}}{a+b+\beta/4} = \frac{11.8487\times 0.78087}{11.8487+0.20547+1.85/4} = 0.73920$$

$$y_{A,exh,wet} = \frac{a\, y_{A,air,dry}}{a + b + \beta / 4} = \frac{11.8487 \times 0.00934}{11.8487 + 0.20547 + 1.85/4} = 0.0088416$$

$$\begin{aligned} M_{exh} &= y_{CO_2,exh,wet}\mathrm{M}_{\mathrm{CO_2}} + y_{H_2O,exh,wet}\mathrm{M}_{\mathrm{H_2O}} + y_{O_2,exh,wet}\mathrm{M}_{\mathrm{O_2}} \\ &\quad + y_{N_2,exh,wet}\mathrm{M}_{\mathrm{N_2}} + y_{A,exh,wet}\mathrm{M}_{\mathrm{A}} \\ &= 0.080206 \times 44.010 + 0.090317 \times 18.016 + 0.081438 \times 31.999 \\ &\quad + 0.73920 \times 28.013 + 0.0088416 \times 39.948 \\ &= 28.8233 \end{aligned}$$

$$M_{air,wet} = \frac{P_{vap}}{P_{bar}} M_{H_2O} + \frac{P_{bar} - P_{vap}}{P_{bar}} M_{air} = \frac{0.510}{29.92} \times 18.016 + \frac{29.92 - 0.510}{29.92} 28.9646 = 28.7780$$

$$r = \frac{\left(y_{CO_2,mix,dry} - y_{CO_2,air,dry}\right)\left(1 - y_{H_2O,air,wet}\right)}{\left(y_{CO_2,exh,dry} - y_{CO_2,mix,dry}\right)\left(1 - y_{H_2O,exh,wet}\right)} = \frac{(0.0209 - 0.00033)(1 - 0.017455)}{(0.088170 - 0.0209)(1 - 0.090317)} = 0.33042$$

$$\%EGR = 100\left(\frac{r\, M_{exh}}{M_{air,wet} + r\, M_{exh}}\right) = 100 \times \left(\frac{0.33042 \times 28.8233}{28.7780 + 0.33042 \times 28.8233}\right) = 24.8650$$

$$y_{O_2,mix,wet} = \frac{y_{O_2,air,dry}\ (1 - \frac{P_{vap}}{P_{bar}}) + r\ y_{O_2,exh,wet}}{1 + r} = \frac{0.20946 \times (1 - \frac{0.510}{29.92}) + 0.33042 \times 0.081438}{1 + 0.33042} = 0.17498$$