CI engine assignment

Exhaust gas recirculation (EGR) is an efficient method to reduce NOx emissions from diesel engines and together with a diesel particulate filter (DPF) the emissions from diesel engines have become very clean. However, as emission regulations have become stricter, even extensive use of EGR has proven to be insufficient to meet the regulations. A more efficient method to reduce NOx emissions to desired levels is Selective Catalytic Reduction (SCR), which we will investigate in this year's CI exercise.

SCR has the potential to reduce NOx completely and real reductions of 90-95% are not unusual under favorable conditions. However, there is a risk that other unwanted compounds are emitted such as nitrous oxides (N2O) and ammonia (NH3). The urea injection should therefore be controlled carefully.

In this year's exercise we will focus on the effect of SCR used with a modern diesel engine. Unfortunately, we have to use some old measurements because our only FTIR gas analyzer was available and the new one did not arrive early enough to be used in the course. You are welcome anytime to ask about the experimental setup or drop by to look at it.

The test engine is a 1.4 liter PSA diesel engine from a Citroen C2. It is equipped with turbocharger, high-pressure common rail direct injection system and EGR (which will be turned off during this exercise) and a standalone SCR-unit.

Measurements were made for varied engine loads, engine speeds and SCR modes, as shown below. Exhaust gas sampled between the SCR and the ammonia slip catalyst in order to investigate the SCR performance only.

<table>
<tr><th>Engine Speed (rpm)</th><th>SCR</th><th>Torque [Nm]</th></tr>
<tr><td rowspan="2">1500</td><td>Off</td><td rowspan="4">15, 30, 60 … max load</td></tr>
<tr><td>On</td></tr>
<tr><td rowspan="2">3000</td><td>Off</td></tr>
<tr><td>On</td></tr>
<tr><td rowspan="2">2000</td><td>Off</td><td rowspan="4">15, 30, 60 … max load</td></tr>
<tr><td>On</td></tr>
<tr><td rowspan="2">3500</td><td>Off</td></tr>
<tr><td>On</td></tr>
<tr><td rowspan="2">2500</td><td>Off</td><td rowspan="4">15, 30, 60 … max load</td></tr>
<tr><td>On</td></tr>
<tr><td rowspan="2">4000</td><td>Off</td></tr>
<tr><td>On</td></tr>
</table>

Assignment Tasks

This assignment does not need to be shaped as an academic report but more like a short test report. It should only contain plots showing the effect of relevant parameter variations. The only (but important) writing should be a discussion of the trends you observe in the plots.

Map the engine performance and emissions with SCR turned off and with SCR controlled by the SCR controller. Engine maps, also called mussel diagrams, are actually contour plots with engine speed and BMEP along x and y axis respectively. It is an important engine discipline to make nice and smooth contour plots. Examples are shown in Spencers book in chapter 11.

The tasks are to create and show contour plots of:

- The excess air ratio (lambda)
- Brake specific performances of BSFC (fuel consumption), emissions of BSNO, BSNO2, BSNOx and exhaust temperature with SCR turned off (no AdBlue injection). All brake specific values should have the unit g/kWh.
- BSAdBlueC (AdBlue consumption), BSNO, BSNO2, BSNOx and BSNH3 with SCR turned on.
- The reduction in percentage of BSNOx due to SCR
- The SCR efficiency, which means how efficient AdBlue is utilized to reduce NOx. Assume that 100 % SCR efficiency would mean that one mole of urea reduces two moles of NOx regardless of the NO/NO2 ratio.
- Temperature out of the SCR and an estimation of exhaust gas velocity in the SCR.

Have a discussion of the following:

- Explain the tendencies of the NOx reduction and compare with NH3 slip, temperature and gas velocity (thus residence time in the catalyst).
- Discuss the performance of the SCR system in terms of NOx and NH3 emissions at different engine operation modes. Compare for example with Euro 6 limits for trucks https://www.dieselnet.com/standards/eu/hd.php. Is a NH3 slip catalyst needed to meet the 10 ppm limit?
- Discuss the cost of AdBlue consumption compared to diesel.
- Discuss effects on SCR performance by the AdBlue dosing, exhaust gas velocity and temperature. Suggest how the performance could be improved.

Help:

I have uploaded a code (`ContourExample.m`) that shows how contour plots can be made even with relatively crude data and a technical paper (`Hirata2005.pdf`) is describing SCR systems using urea.

Brake Specific emissions (typically BSHC, BSCO, BSNOx) and Brake Specific Fuel Consumption BSFC is used to specify mass of emissions or fuel consumption per energy output. Units are almost always g/kWh.

Remember that kWh is a measure of energy not power (like kW or W). It may be confusing and people are often mistaking these two.

A safe way to do the calculation is simply by dividing the mass flow in g/h with the brake power in kW. Then the units become correct. See also Spencers book (eq. 15.57).

Emission analyzers measures in volume fractions (in % or ppm) and assuming ideal gas law this is the same as mole fractions.

You may assume that exhaust gas have a mean molecular mass of 28.6 g/mol. It varies slightly with lambda and fuel type but it is insignificant compared to many other uncertainties.

Specs:

Engine:

The engine is from a Citroen C2. It is made by Ford/PSA and is named DLD-414.

Vd: 1398cm^3

Power: 50kW@4500rpm

Torque: 150Nm@2000rpm.

SCR catalyst diameter/ length: 155/150 mm

Urea Injection:

AdBlue is the commercial name of urea used for many vehicle SCR systems. The SCR system used in present experiments is a standalone system with an automated AdBlue dosing system. AdBlue is only injected if the catalyst temperature is sufficient for reduction to happen. The injected mass flow of AdBlue, $\dot{m}_{AdBlue}$, can be estimated from the collected date by equation 1, where t_{inj} is duration of one injection and P_{inj} is the period between injections.

$$\dot{m}_{AdBlue} = 1.2\,\frac{t_{inj}}{P_{inj}}\,\left[\frac{g}{s}\right] \tag{1}$$

AdBlue is an aqueous solution of 32.5 % urea by mass. Urea has the formula $(NH_2)_2CO$ and it may be assumed that one mole of urea decomposes into two moles of ammonia (NH_3).

Equation 1 will return a NaN when there is no injection because both t_{inj} and P_{inj} are zero. You can just replace the NaNs with zeros in your code.

Diesel:

Assumed formula: $C_{12}H_{26}$

Density: 840 g/L

Lower heating value: 42500 kJ/kg

AF ratio: 14.7