OH absorption spectroscopy to investigate light-load HCCI combustion

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HCCI Advantages:
- Fuel economy and light-load efficiency
  - No throttling losses
  - Load can be controlled by adjusting the amount of fuel injected
    - Very low equivalence ratios are possible (down to ~0.1)
- Low NOx and soot emissions
  - Low temperature combustion (compared to Diesel operation)
  - No rich flame combustion

Disadvantages:
- Difficult to control start of combustion
- High CO and uHC emission at low load

Motivation:
- OH is a necessary agent for the CO → CO2 oxidation reaction which is the main heat release mechanism in the combustion process
- As equivalence ratio decreases (< 0.1)
  - Temperature rise is very low (1200-1300K)
  - OH concentration becomes too low for complete combustion
- What is the low-load limit for this type of engine?

We know:
1. The lower limit for lean/light-load HCCI operation is the temperature limit for complete combustion
2. We can measure the completeness of combustion by observing how much OH appears/remains in the cylinder
3. The limit has been developed based on chemical kinetic analysis—we want to measure it directly

The Plan:
- Make a quantitative measurement of OH concentration and temperature
- Measure changes in [OH] during the cycle as equivalence ratio is lowered

Beer-Lambert Law:
Transmission = 1 – Absorption = \frac{I_{\text{trans}}}{I_0} = \exp(-k_{\text{PXL}} \lambda)

Use this relation to calculate output spectrum as a function of wavelength, \( I_{\text{trans}}(\lambda) \)

- We know:
  - \( I_0 \)
  - Pressure
  - Path length
- Absorption coefficient is calculated by computer programs which generate \( k_{\text{PXL}}(\lambda, T, P) \) for OH molecules

Simulated Spectrum:

Fast Kinetics Acquisition (cont’d):
Image onto sub-area → Shift previous image down

Note:
1. Features around 281 and 310 nm (OH absorption lines)
2. More absorption at larger concentrations

Preliminary results:

Fast Kinetics Acquisition:
Problem:
- Need to acquire consecutive sets of data quickly (crank angle resolution)
- At 600 RPM, 1 degree = 0.2778 msec
- A camera shutter can’t move fast enough to capture individual images at this rate

Process:
- Illuminate a sub-area of the CCD camera
- Shift the image/charge to another part of the CCD
- An image is then sampled in time according to how fast the CCD can shift the pixels (shift time << shutter time)

What’s Next?
- Demonstrate technique and explore noise characteristics
- Investigate effect of equivalence ratio (temperature and [OH]), and see how it relates to combustion efficiency
- Improve techniques for measuring [OH]