Interim results from ORNL's OptiNO_X Study

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Crosscut Lean Exhaust Emissions Reduction Simulation (CLEERS) Workshop

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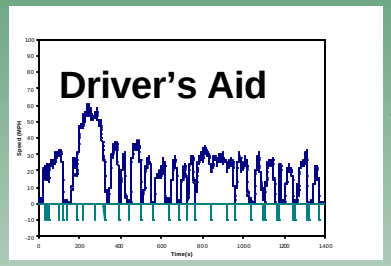
What is the OptiNOx Project?

- **Goal: Examine the effects of regeneration conditions on NO_X Adsorber / DPF system performance.**
  - **Vehicle Based**
  - **Transient Cycles**
  - **Full-size prototype devices**
  - **Laboratory regeneration system (not suitable for production vehicles)**

A system was devised to meter gases from cylinders into the exhaust to simulate on-board regeneration systems.



Timing

Control Electronics

(Not ECU)

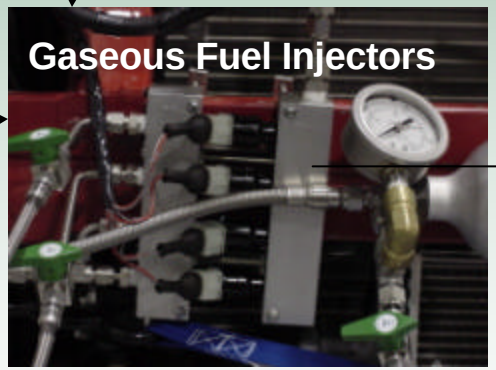
RPM

Load

PWM Drive

CO, H_2, 10% C_2H_4 in CO

Gas Flow



72.5% CO, 25% H_2, 2.5% C_2H_4

Vehicle Exhaust

Several exhaust configurations are being studied.

- **Lightoff catalyst, CDPF, NO_X Adsorber 1 (DVECSE system)**
- **Lightoff catalyst, CDPF, NO_X Adsorber 2**

- **CDPF, NO_X Adsorber 1**
- **CDPF, NO_X Adsorber 2**

- **Several regeneration conditions (richness, duration, schedule) for each exhaust configuration.**

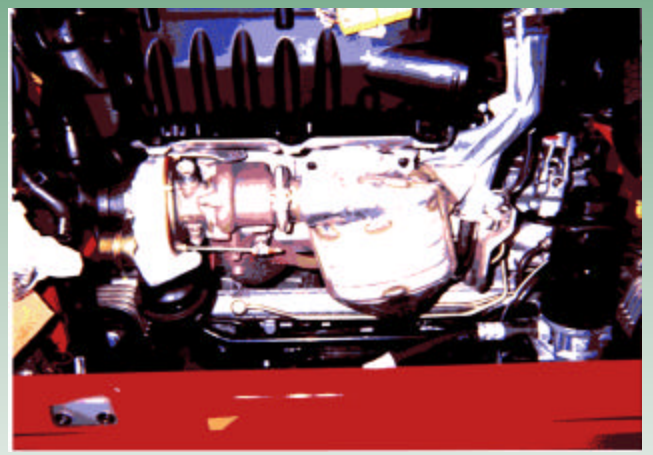
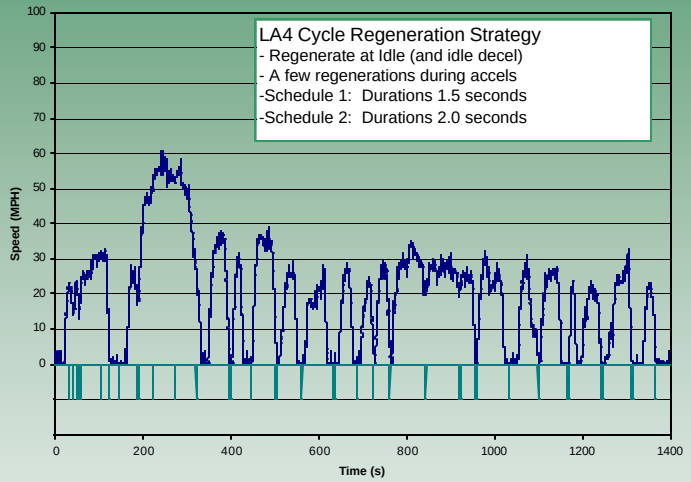


Photo of close-coupled lightoff catalyst. CDPF and NO_X Adsorbers in "under floor" location.

First 9 cases: 3 Regeneration Schedules, 3 richness levels. (Lightoff Catalyst, CDPF, NO_X Adsorber 1

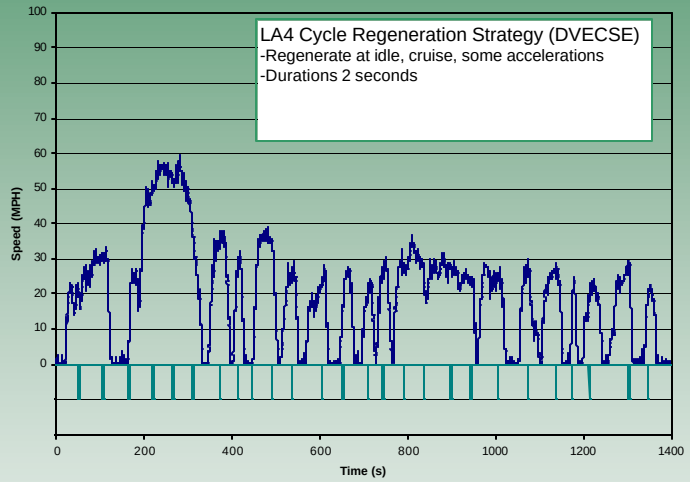
- **Regeneration Schedules**
  - **Idle regeneration, rich duration 1.5 seconds**
  - **Idle regeneration, rich duration 2.0 seconds**
  - **Original DVECSE regeneration schedule**
- **“Richness”**
  - **3 syngas calibrations, all rich of stoichiometry**
- **Triplicate warm-start LA4 cycles at each condition.**

Regeneration schedules were determined experimentally.



Schedule 1: Idle regeneration, 1.5 second duration

Schedule 2: Idle regeneration, 2.0 second duration



Schedule 3: DVECSE Regeneration schedule. Nominally 60 second lean period, 2 second duration.

Today's discussion focuses on interim data from the project.

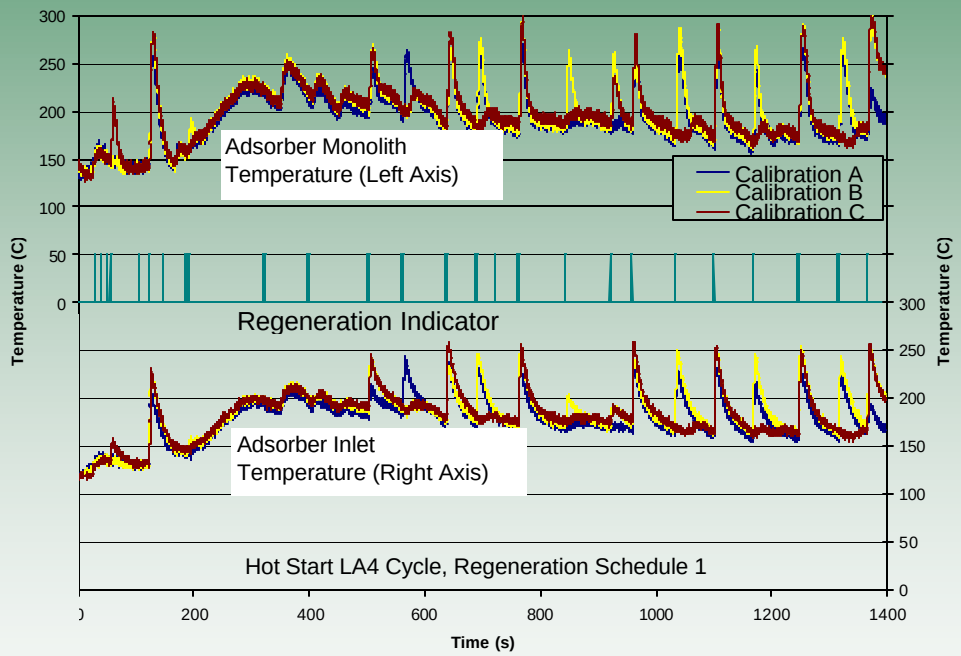
- **Data shown are from the 3rd of 3 consecutive cycles conducted at each condition.**
- **All data are for hot start LA4 cycles conducted using DECSE 3 PPM sulfur fuel.**

Regeneration calibrations and schedules focused on near-idle conditions.

- **Regenerate at idle, whenever possible.**
  - **O_2 flow at a minimum**
  - **Prevents excessive heating of exhaust system**
  - **Mimics high EGR, throttling on a fully integrated system**
- **Idle conditions can occur during clutch-in decelerations or zero speed conditions.**
- **Regenerate during low-RPM cruise and acceleration conditions only as necessary to reduce fuel penalty and driveability impacts.**

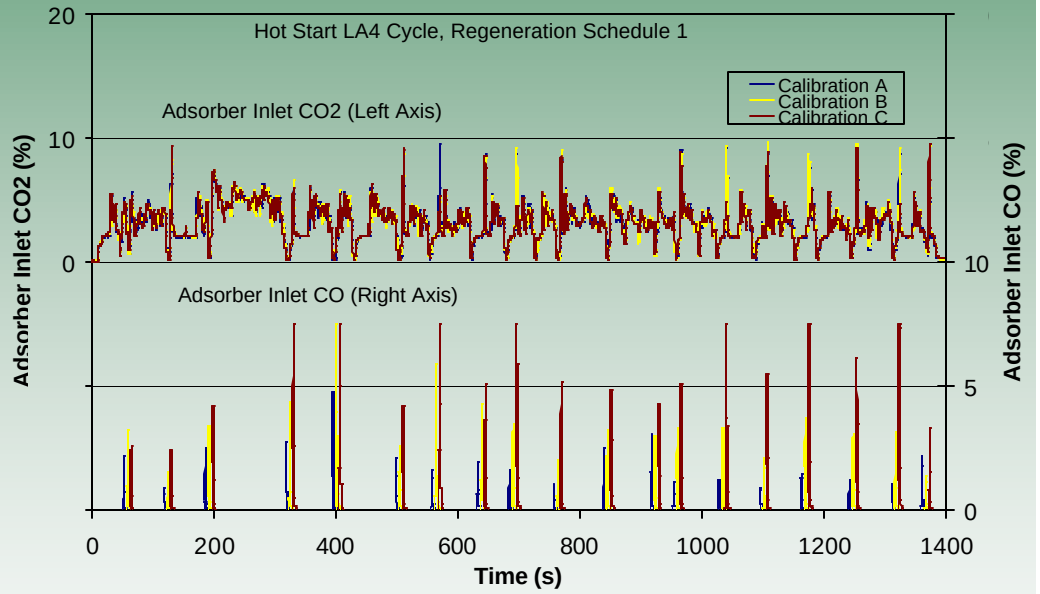
Exhaust temperatures for schedule 1 were very low.

- **Upstream catalyst and DPF do not indicate significant exotherms present during regeneration.**
- **NO_X adsorber 1 monolith temperatures remain at less than 300 C during regeneration, averaging less than 200 C during lean periods.**



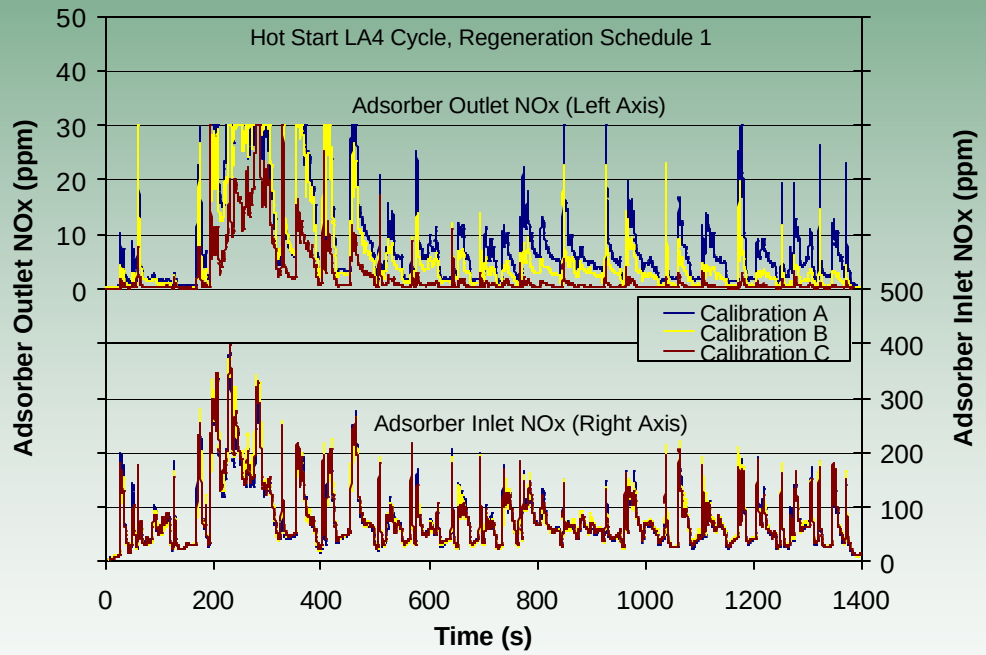
CO and CO2 concentrations show the synthesis gas was combusting.

- **CO levels offset in time to show variation in levels.**
- **CO_2 doesn't change as richness increases.**
- **UEGO shows O_2 "depleted."**
- **Syngas combustion is limited and is probably not complete.**
- **CO levels are probably not indicative of those at complete combustion.**



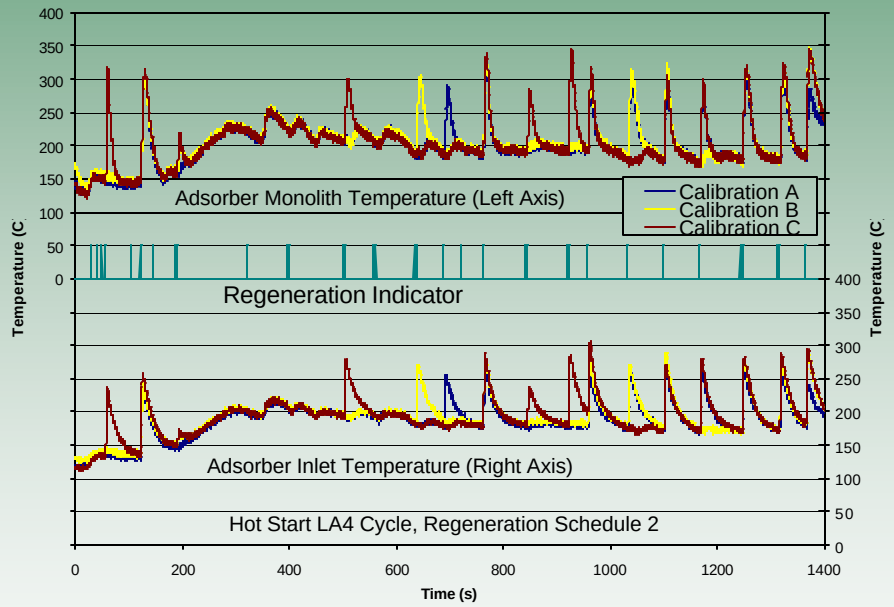
Despite the relatively low operating temperature, this setup produced very good NO_X reduction.

- **Cycle Average Efficiencies:**
  - **Cal A: 90%**
  - **Cal B: 94%**
  - **Cal C: 98%**
- **Obvious problem area on "hill 2" of the FTP.**
- **Large NO_X slips during regeneration.**

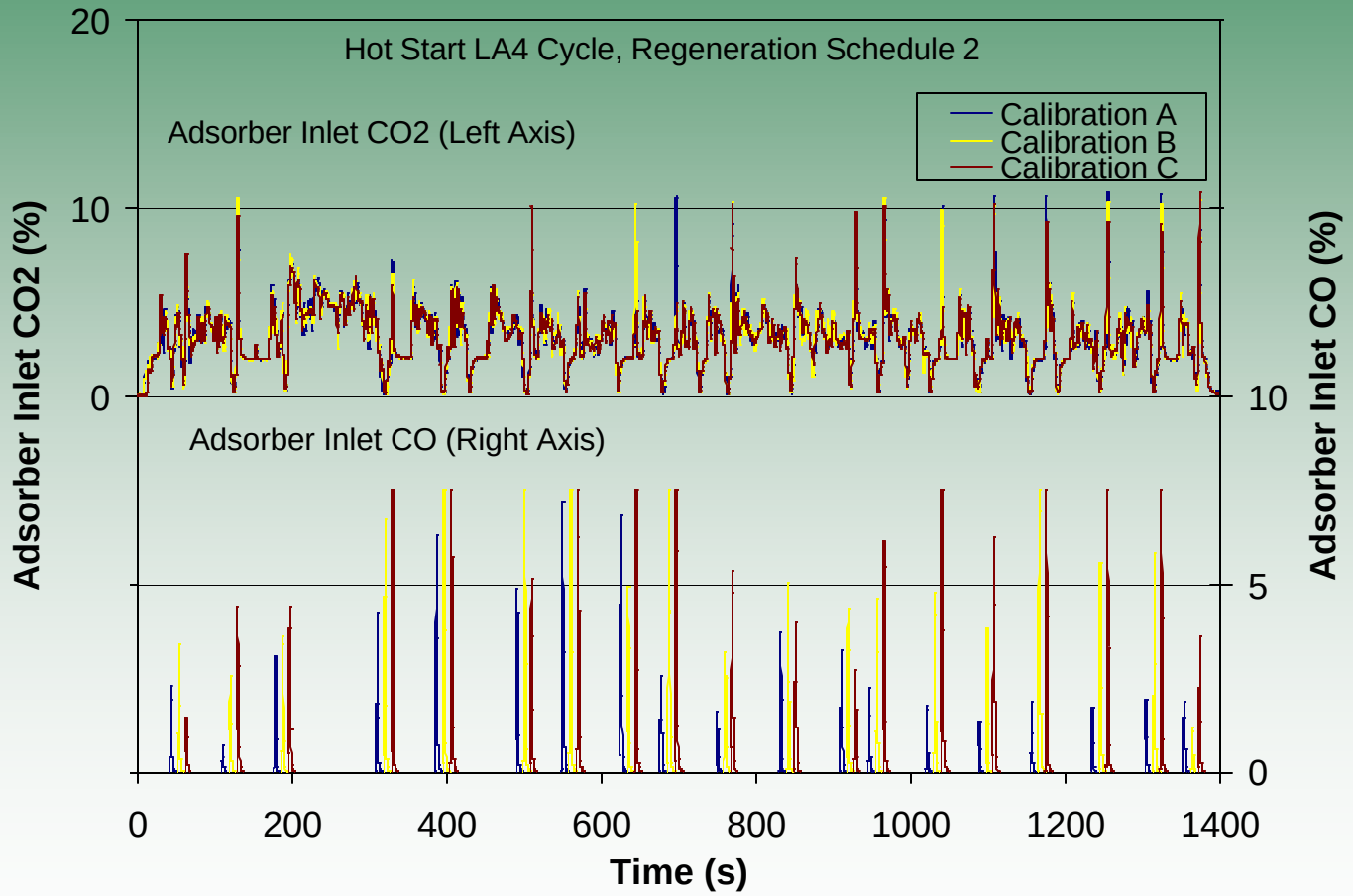


Schedule 2 temperatures were slightly higher than schedule 1.

- **Inlet and Monolith temperature spikes increase ~50 C.**
- **Average temperatures during the lean periods rose slightly, but probably not significantly.**

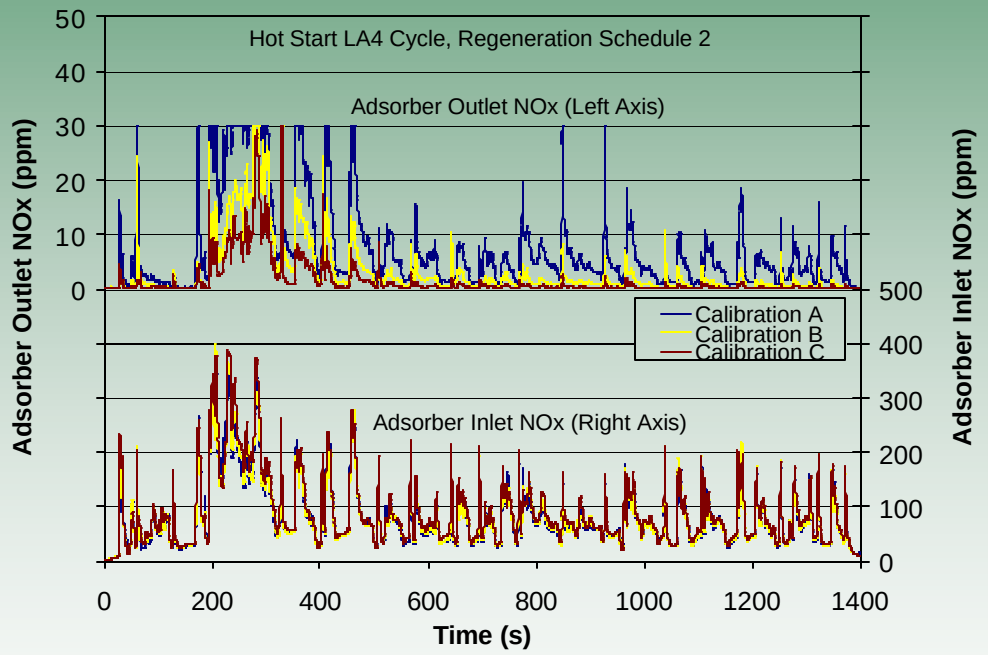


Schedule 2 CO and CO_2 levels show marginally increased combustion, but generally the same trends as schedule 1.



Schedule 2 system effectiveness increased marginally.

- **Cycle Average Efficiencies:**
  - **Calibration A: 92%**
  - **Calibration B: 97%**
  - **Calibration C: 98%**
- **Some improvement in the "hill 2" problem. (Probably most of the improvement.)**
- **Slight improvement in the amount of NO_X slip at regeneration.**



Calibrations A, B, and C on schedule 3 have thus far yielded mixed results.

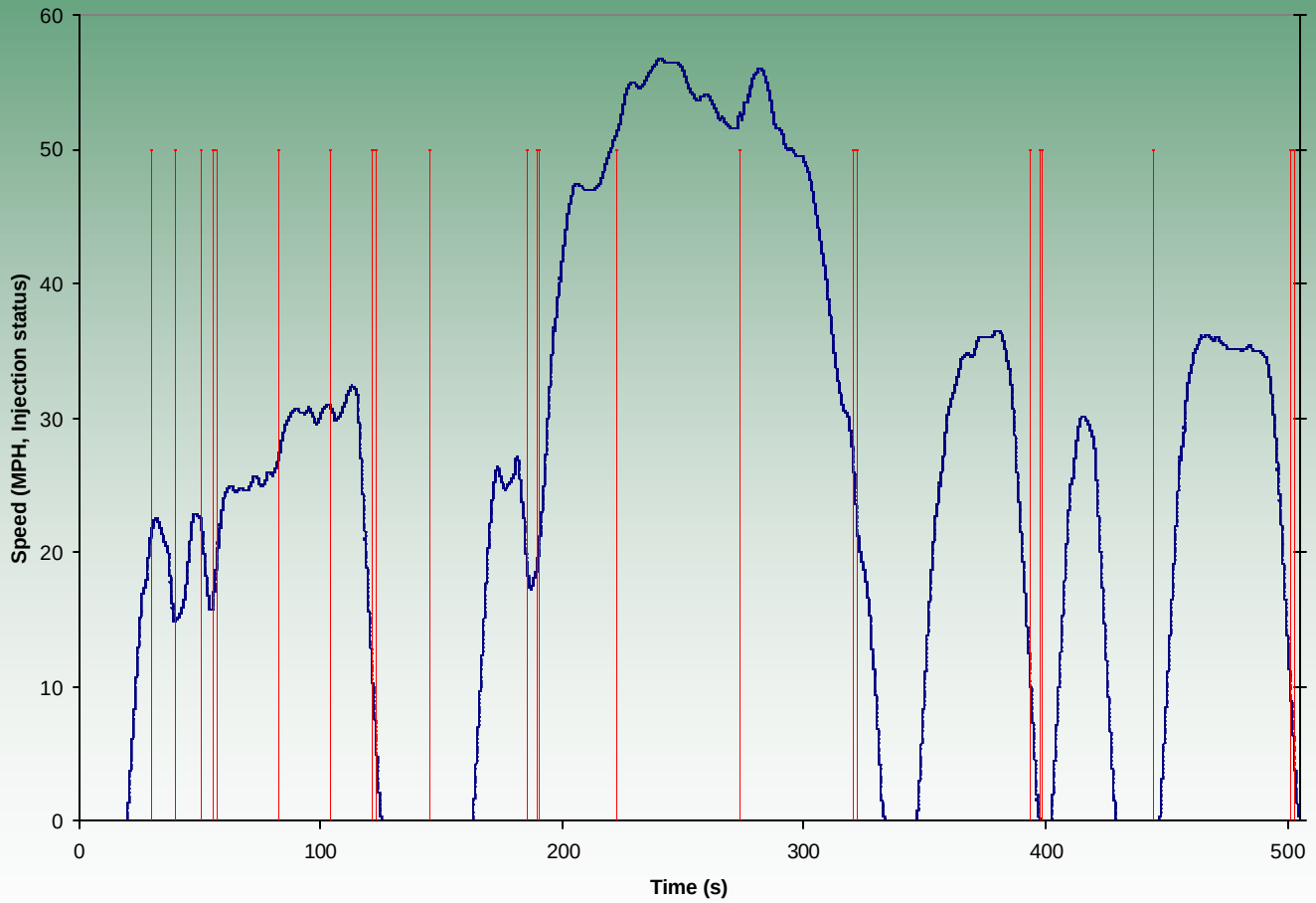
- **Calibrations A, B, and C not always rich enough for the more aggressive schedule 3.**
- **Temperature profiles for schedule 3 were very similar to those of schedule 2.**
- **The lower temperatures from schedule 3 compared with those of the original DVECSE work suggest that changes to the synthesis gas are contributing to lower overall exhaust temperatures.**

Focusing on schedule 2, calibration B demonstrates that the most improvement can be gained in bag 1.

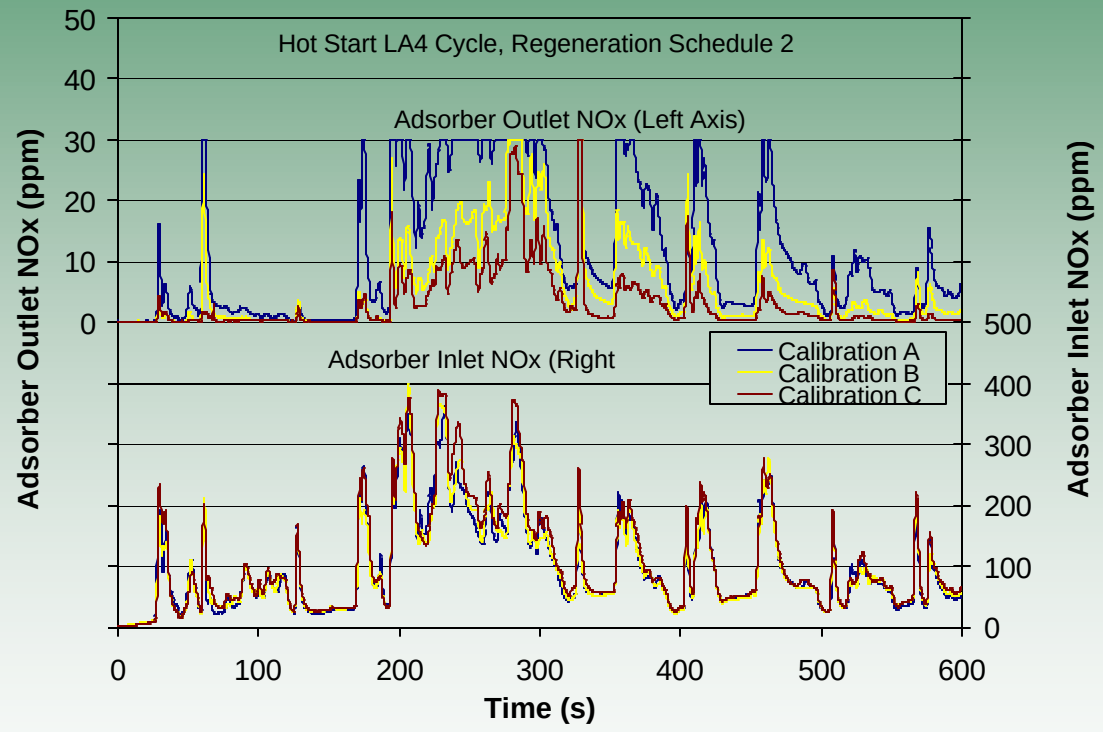
- **“Bag 1” (First 505 seconds): 95% NOX efficiency**
- **“Bag 2” (Remaining time): 99% NOX efficiency**

- **Sparse regenerations during “high” speed portion of LA4 cycle.**

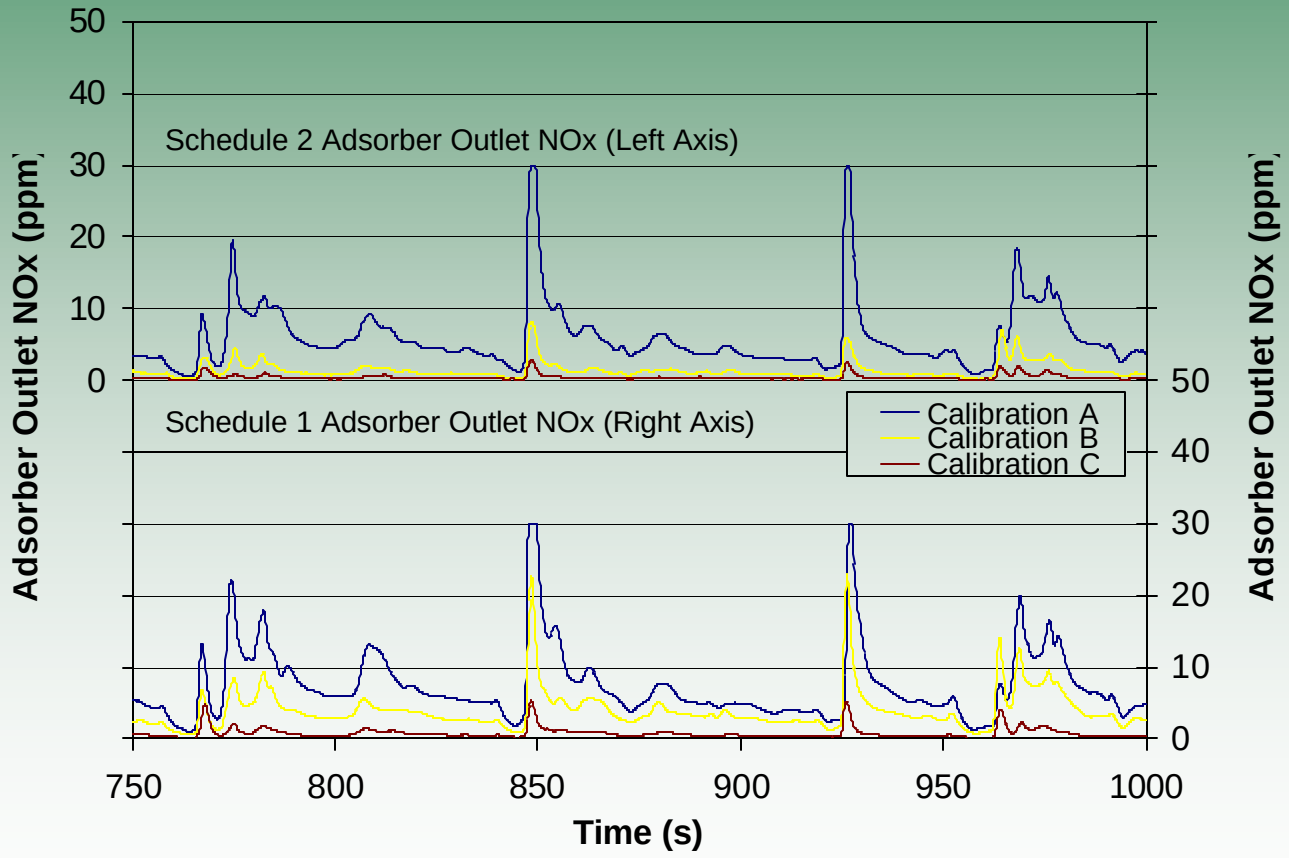
Regenerations were sparse during the second “hill” of the LA4 cycle.



Behavior of NO_X slip indicates that the problem area is due to insufficient NO_X capacity for this regeneration schedule.



Comparing schedules 1 and 2 suggests that calibration A is not sufficient to keep the adsorber "clean."



The data suggest several areas for improvement / investigation for the project.

- **Schedule 3 may be unnecessary if schedule 2 can be improved.**
- **Insulation of the exhaust pipe to investigate slightly higher average temperatures may help.**
- **Adding saturation experiments to determine catalyst capacity would be useful.**
- **Does a second NO_X adsorber show similar performance at these conditions?**
- **Is the oxidation catalyst necessary?**

Additional measurements are planned at "interesting" conditions.

- **Fast-UV spectroscopy to investigate ammonia slip, N_2O production.**
- **Integrated "bag" data to quantify fuel economy penalty, CO slip, etc.**
- **Impinger samples to investigate unusual compounds.**
- **Switch UEGOs to AFR mode.**

Acknowledgement

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