A Comprehensive Characterization of Spark Ignited Exhaust Emissions during Transient Load Cycles

Dylan Lehmier, Dr. Casey Allen

Marquette University
Department of Mechanical Engineering
**Objective and Motivation**

**Objective:** To characterize the transient response of individual hydrocarbon species and explore prediction accuracy based on steady-state maps.

**Emissions Inventories**
Quasi-steady maps could be used for real-time estimation of exhaust species for use in emissions inventories.

**Catalyst Development**
Prediction of exhaust species to evaluate catalyst performance during standard drive cycles. Catalyst efficiency depends on species.

**Emissions Control**
Engine controller action may consider relative emissions of unique unburned hydrocarbons – such a controller requires an appropriate cost function that considers individual species.
**SPECIATE**: EPA’s database containing speciated profiles of volatile organic compounds (VOCs) and particulate matter.

Speciate was developed for:
1. Air quality modeling
2. **Estimate hazardous and toxic air pollutant emissions**
3. Provide input to chemical mass balance receptor models
4. Verify profiles derived from ambient measurements using multivariate receptor models
Background

**Literature:**
- Transient response analysis largely based on *unburned hydrocarbons* as a class. (Karjalainen et al., Iodice et al.)
- Prediction strategies generally include “fudge factor” applied to a steady state map. (Gao et al., Ericson et al.)

**Gao et al. (2010):** Modeled the transient, in-cylinder temperature which was used to adjust quasi-steady map predictions.

**Ericson et al. (2005):** Modeled the departure of AFR from quasi-steady conditions during transient events and used as correction basis.

\[
\dot{m}_{i,\text{corr}} = \dot{m}_{i,\text{QS}} \frac{EI_i(\lambda_{\text{dyn}})}{EI_i(\lambda_{\text{QS}})}
\]
Unburned Hydrocarbon Profile

How does the unburned hydrocarbon profile change with the speed/load condition?

- Emissions profile varies with respect to engine speed and load
- Each species has its own reliance on engine operation

Not all hydrocarbons respond equally
Using different frequency transient loads to examine transient emission response.

2 profiles with varying period lengths were examined.

BMEP = 0.8-3.44 bar
Experimental Method

Developed model based on engine operating points at steady state

Steady State:
- Engine speed and load
- Exhaust and coolant temperature
- Oil pressure
- FTIR inlet temperature
- Emission rates
High Frequency Transient Load Results

Nitric Oxide (NO)
- Estimate follows pattern
- Estimation error at minima and maxima

Acetylene
- Estimate follows pattern
- High estimation error at low load conditions
- Combustion Intermediate
- Inversely proportional to load
High Frequency Transient Load Results

Ethylene
- Limited transient response
- Increase in concentration over time
- Possibly affected by history in engine
- More rapid oscillations
- Intermediate
- Follows cyclic pattern
- Gasoline component
Low Frequency Transient Load Results

Nitric Oxide (NO)
• Follows pattern proportional to load
• Estimation error reduced

Acetylene
• Follows pattern corresponding to inverse proportionality to load
• Estimation error reduced
Low Frequency Transient Load Results

Ethylene
- Transient response increases
- Begins to follow pattern with respect to load profile

Ethanol
- Delay in response
- Rapid oscillations from high frequency transient diminished
- Follows cyclic pattern with respect to load profile
Conclusions

- Transient emissions of certain species can be predicted using steady state maps at low frequencies (NO and acetylene at 10 second period)
- No species can be accurately estimated by using steady state maps during high frequency transient load conditions (5 second period)
- Hydrocarbons do not act as a class. Each individual species exhibits a unique transient response.

Future Work

- Characterize larger set of unburned hydrocarbons and identify their unique cutoff frequencies where steady state map prediction can be implemented.
- Identify a transient modeling strategy to estimate emissions where steady state maps are inaccurate.