Effects of Ignition Quality and Fuel Composition on Critical Equivalence Ratio

Gregory K. Lilik* and André L. Boehman**
Formerly of the Pennsylvania State University
*Currently at Sandia National Laboratories CRF
** Currently at University of Michigan

The 18th Directions in Engine-Efficiency and Emissions Research (DEER) Conference
Dearborn, Michigan
October 19, 2012
Overview

Motivation

- Multi-cylinder, turbocharged, common rail, direct injection study in which high ignition quality fuel was found to avoid NO$_x$, PM, THC and CO emissions while maintaining brake thermal efficiency during PCCI operations.


Presentation Focus

- Modified Cooperative Fuels Research (CFR) engine study in which the critical equivalence ratio ($\Phi$) of a fuel was found to be governed by the fraction of highly reactive components (n-paraffins), which increases LTHR.

  - Critical $\Phi$ is defined as the minimum $\Phi$ at which a fuel can autoignite.

  - Submitted to Energy and Fuels (two publications).
Background

HC & CO emissions in PCCI
• Overly rich mixtures (*Ekoto et al. 2009*)

Overly lean mixtures
• Lean regions with minimal heat release (*Ekoto et al. 2009*)
• Lean squish-volume mixture (*Colban et al. 2007*)
• Overly lean region near the injector (*Lachaux et al. 2007*)

Obtained via planar laser-induced fuel-tracer (toluene) fluorescence at LTC conditions (*Musculus et al., 2007*)
Motivation
Multi-Cylinder PCCI Study

A high ignition quality fuel was found to reduce incomplete combustion of an overly lean charge.

Factors:
- Combustion phasing
- Ignition dwell
- “Critical” equivalence ratio

Effect of LTFT with respect to diesel at the optimized injection timing of -4° ATDC:
- BTE increased by ~1.5%
- NO\(_X\) decreased by ~17%
- PM decreased by ~63%
- THC decreased by ~80%
- CO decreased by ~75%

“Paraffin Enhanced Clean Combustion”
- Publication: *Energy and Fuels 2011*
- Patent application drafted and submitted
  - (#2010-3677)
A high cetane number fuel will have a lower combustion lean limit than a lower cetane number fuel, thus avoiding incomplete combustion.

Determine if the LTFT (high cetane) fuel will autoignite at a leaner equivalence ratio.

- Homogenous charge to simulate a localized region in a diesel spray jet.

**Task 1:** Find critical $\Phi$ of fuels.

**Task 2:** Find critical $\Phi$ of fuels in the presence of simulated EGR (dilution of $O_2$ with $N_2$ and $CO_2$).

Obtained via planar laser-induced fuel-tracer (toluene) fluorescence at LTC conditions (Musculus et al., 2007)
Test Plan

**Modified Cooperative Fuels Research (CFR) engine (Szybist et al., 2007)**

*Note: n-hexane is reported to have a motored cetane number of 42. n-hexane produces a DCN of 50.2 in the IQT.*
In general, critical $\Phi$ is indicated during a $\Phi$ sweep as the $\Phi$ where:

- CO (% vol.) abruptly decreases
- CO$_2$ (% vol.) sharply increases
- Bulk cylinder temperature (K) sharply increases
- Sustained high temperature heat release rate occurs

Critical $\Phi$ criterion is chronicled in detail in upcoming publications.
Emission Index CO indicates low temperature fuel reactivity by normalizing variation in fueling rate between $\Phi$.

Low temperature fuel reactivity is higher for fuel solely composed of n-paraffins and with longer average chain lengths.
CR 4 (note: diesel did not ignite)

CR 5

CR 6

CR 8
Results

CR 8 with simulated EGR
(O₂ 10.7 vol. %, CO₂ 8 vol. % and N₂ 81.3 vol. %)
ASTM method D6890 (IQT) was used to determine binary blends with the same DCN as n-heptane:

n-heptane: 53.7
n-dodecane 61% and toluene 39%: 53.4
n-dodecane 50% and iso-octane 50%: 53.9
Results

FACE Fuel 1, 2, 3 and 4 at CR 7

CO, 2.6bar BMEP, ~15.6% intake O₂

THC, 2.6bar BMEP, ~15.6% intake O₂
A high cetane number fuel has a lower critical $\Phi$, which is a factor which contributes to reduced incomplete combustion.

EGR significantly influences the critical $\Phi$ of fuels with DCN that vary from 43 to 73.

The critical $\Phi$ of a fuel is governed by the fraction of reactive components (n-paraffins), which increases LTHR.

These results suggest that a fuel can be blended to have a low ignition quality, which is desired for high efficiency advanced combustion operations and with a high n-paraffin content to reduce CO and THC.
Acknowledgments

- Diesel Combustion and Emissions Laboratory
  Vince Zello, Steve Kirby, Peter Perez, Kuen Yehliu, Yu Zhang,
  Prof. John Agudelo and Prof. Magin Lapuerta

- Support
  DOE Graduate Automotive Technology Education center at PSU
    Dr. Joel Anstrom - GATE Center Director at PSU
  GM R&D Laboratory
    Russell Durrett
  Volvo North America (DE-EE0004232)
    Samuel Mclaughlin

- Special Thanks
  Garry Gunter - ConocoPhillips, Advanced Hydrocarbon Fuels Group
    (now with Phillips 66)

Thank you for your attention.