Effects of Ignition Quality and Fuel Composition on Critical Equivalence Ratio

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Overview

Motivation

- Multi-cylinder, turbocharged, common rail, direct injection study in which high ignition quality fuel was found avoid NO_X, PM, THC and CO emissions while maintaining brake thermal efficiency during PCCI operations.

  - *Lilik, G.K. and A.L. Boehman, Advanced Diesel Combustion of a High Cetane Number Fuel with Low Hydrocarbon and Carbon Monoxide Emissions. Energy and Fuels, 2011. 25 (4): p. 1444–1456.*

Presentation Focus

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

  - Critical Φ is defined as the minimum Φ at which a fuel can autoignite.

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

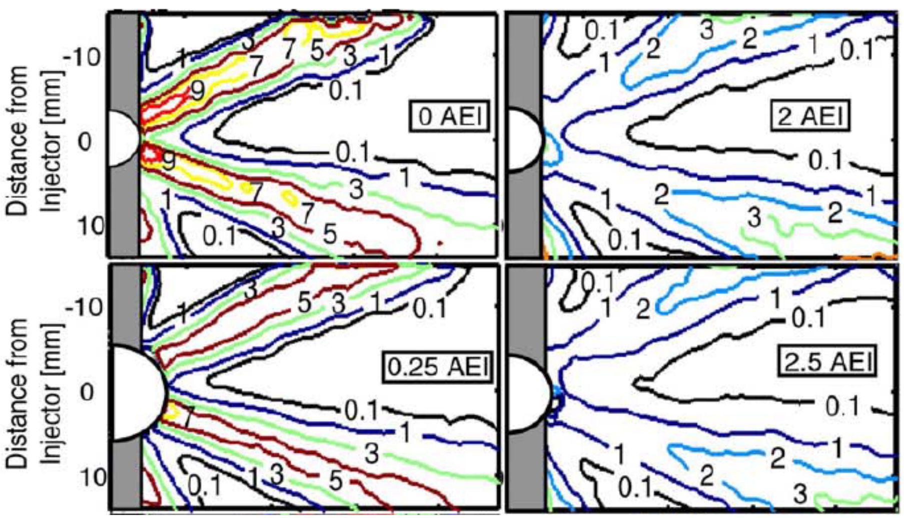
Background

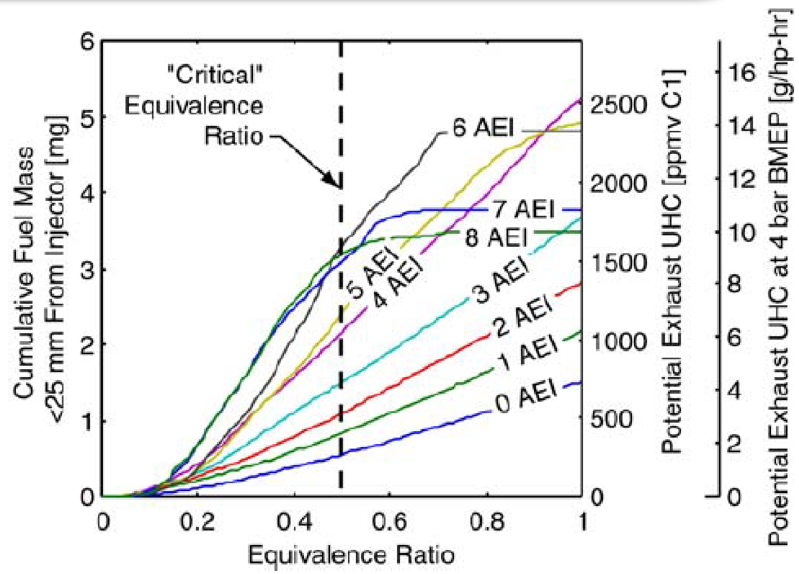
HC & CO emissions in PCCI

- **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)***

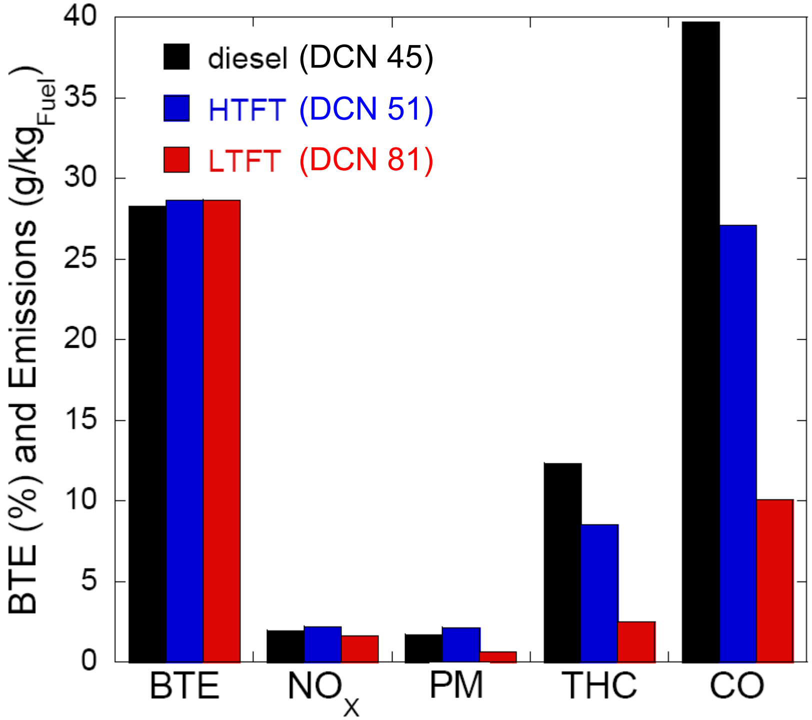




Obtained via planar laser-induced fuel-tracer (toluene) fluorescence at LTC conditions (Musculus et. al, 2007)

Motivation
Multi-Cylinder PCCI Study

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



Comparison of Optimized SOI Timing, in a DDC/VM Motori 2.5L operating in high efficiency clean combustion (HECC) mode at 1500 rpm at ~2.7 bar BMEP with ~40% EGR

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)

Work Plan

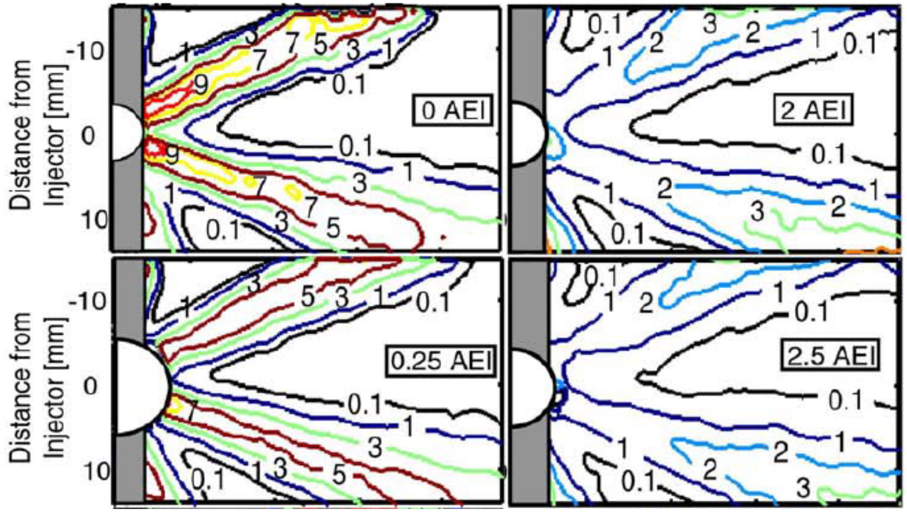
A high cetane number fuel will have a lower combustion lean limit than a lower cetane number fuel, thus avoiding incomplete combustion.

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 Φ of fuels.

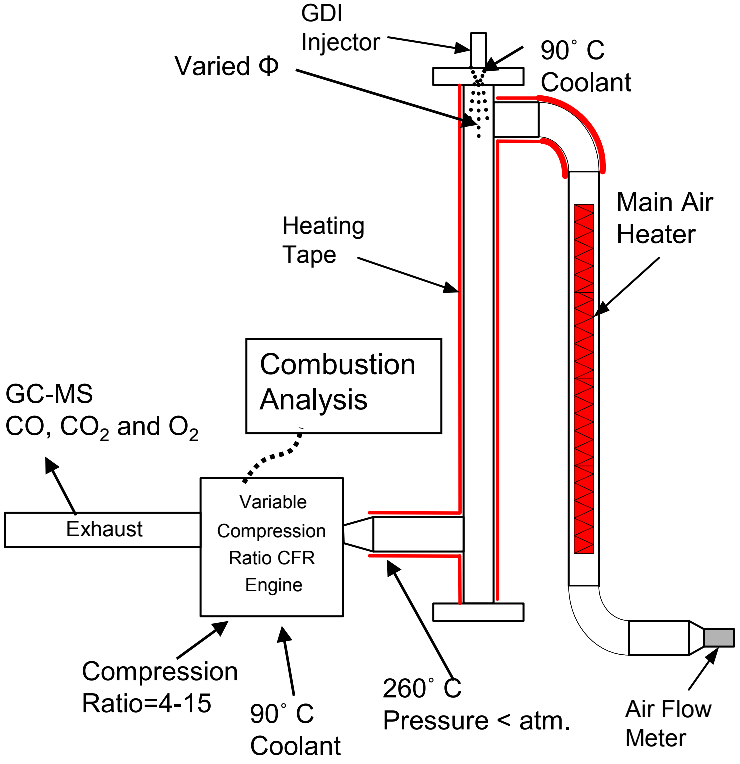
Task 2: Find critical Φ of fuels in the presence of simulated EGR(dilution of O_2 with N_2 and CO_2).



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

Test Plan

	N_2 (%)	O_2 (%)	CO_2 (%)	Compression Ratio	Cooling Jacket (°C)	Air intake (°C)
Ambient air	79	21	0	4,5,6 and 8	90	260
Simulated EGR	80.5	12	7.5	8		



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

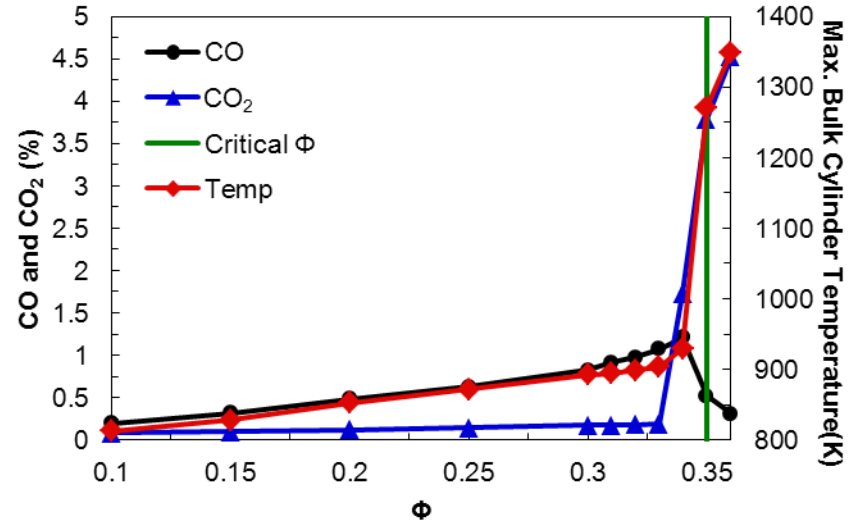
Experimental fuels

	DCN	FBP (°C)
Diesel T90 cut	43	329
HTFT T90 cut	51	369
LTFT T90 cut	77	308
n-hexane	42*/ 50	69
n-heptane	53	98
n-dodecane	74	216

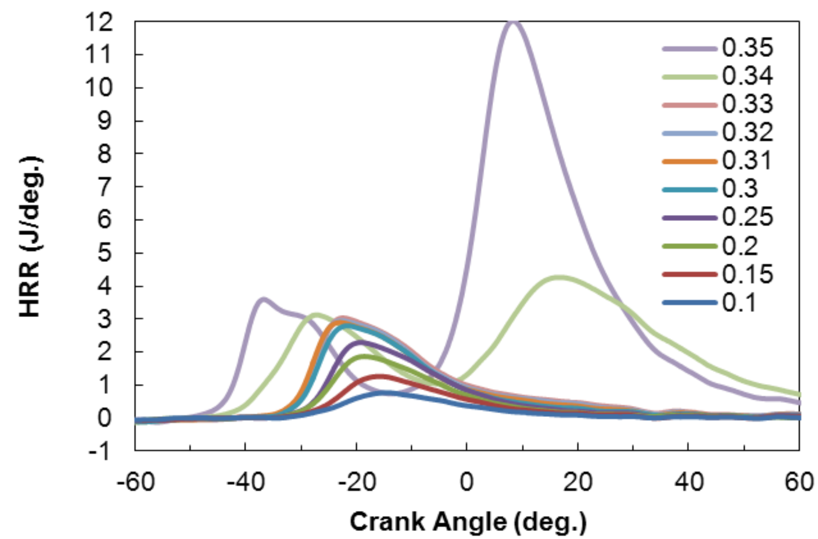
**Note: n-hexane is reported to have a motored cetane number of 42. n-hexane produces a DCN of 50.2 in the IQT.*

Critical Equivalence Ratio Criterion

- In general, critical Φ is indicated during a Φ sweep as the Φ where:
    - CO (% vol.) abruptly decreases
    - CO_2 (% vol.) sharply increases
    - Bulk cylinder temperature (K) sharply increases
    - Sustained high temperature heat release rate occurs
- Critical Φ criterion is chronicled in detail in upcoming publications

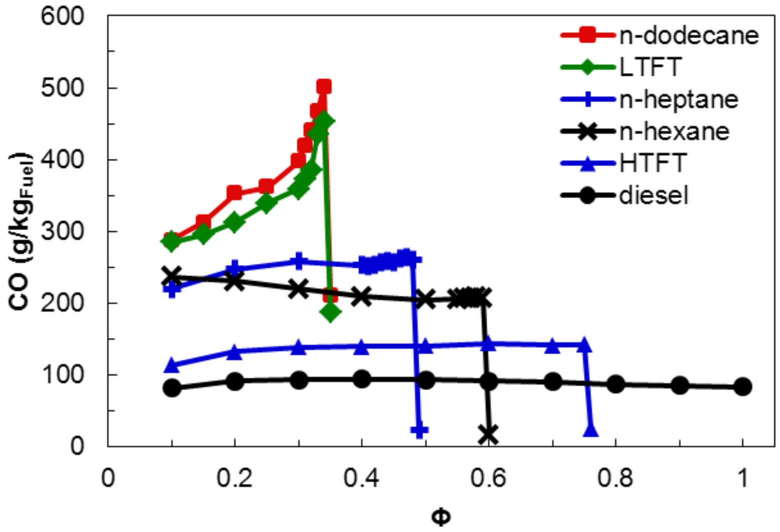


n-dodecane at CR 4

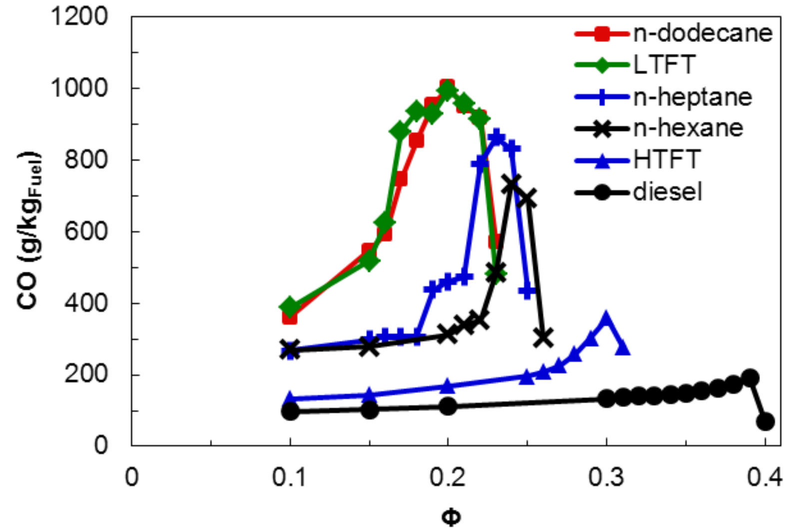


n-dodecane at CR 4

Results



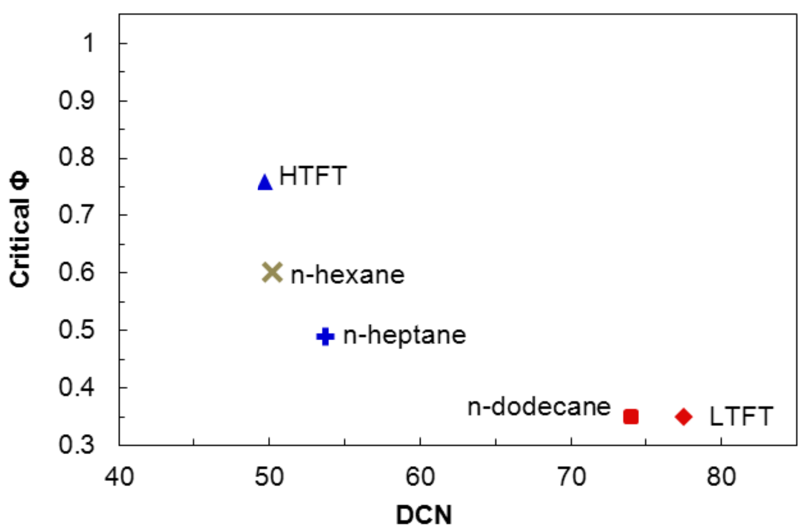
CR 4



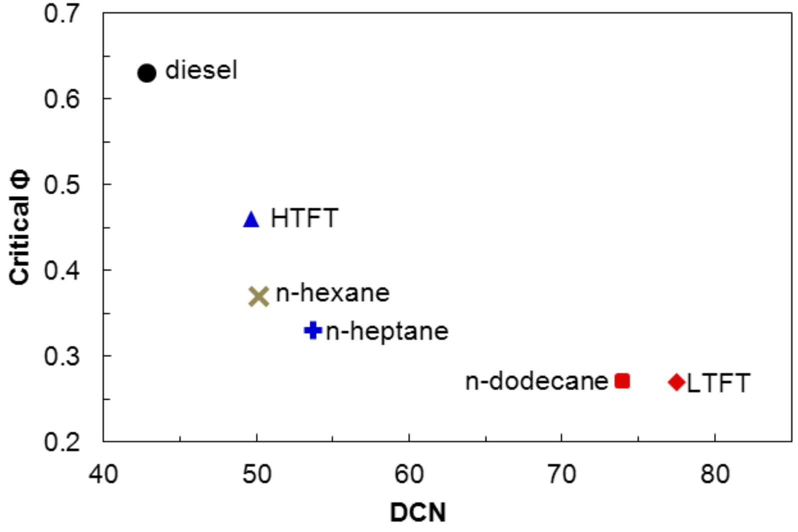
CR 6

- Emission Index CO indicates low temperature fuel reactivity by normalizing variation in fueling rate between Φ.
- Low temperature fuel reactivity is higher for fuel solely composed of n-paraffins and with longer average chain lengths.

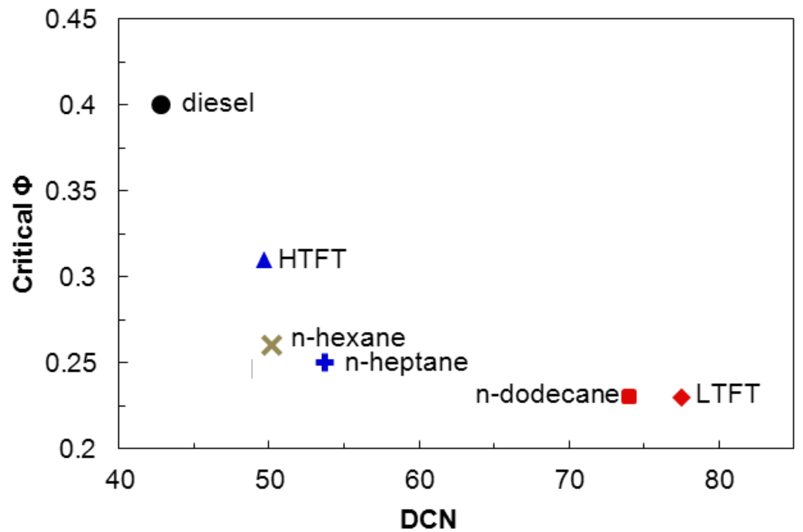
Results



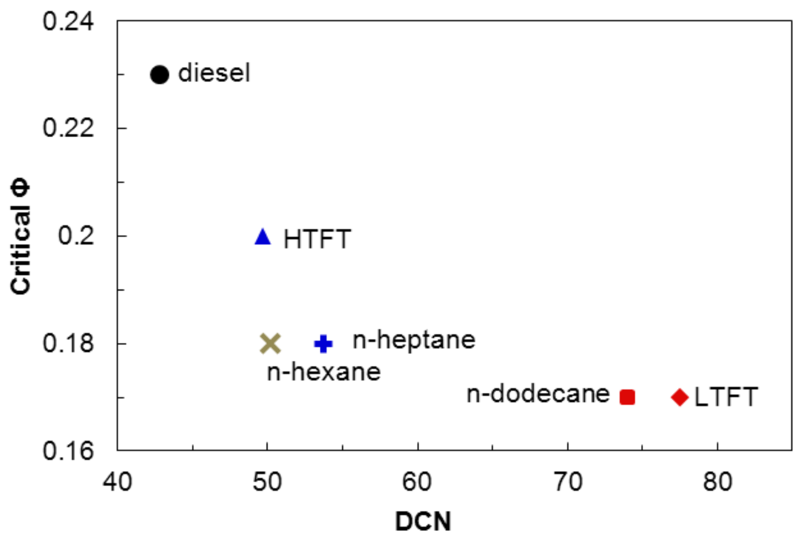
CR 4 (note: diesel did not ignite)



CR 5

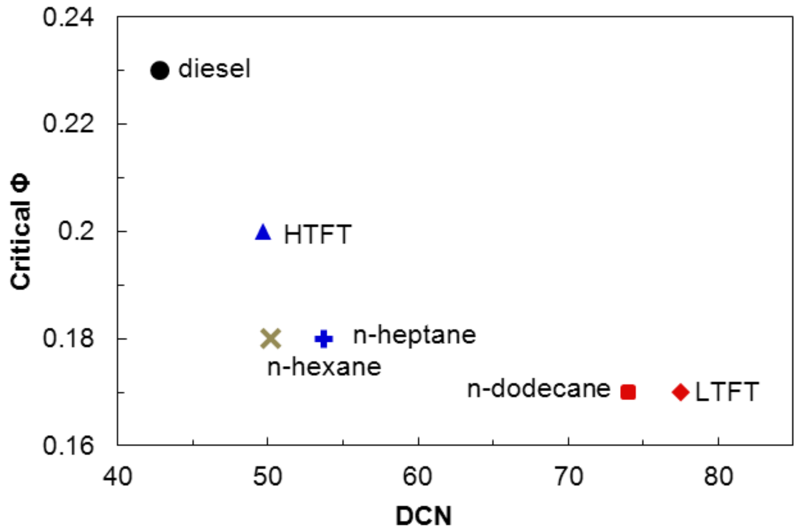


CR 6

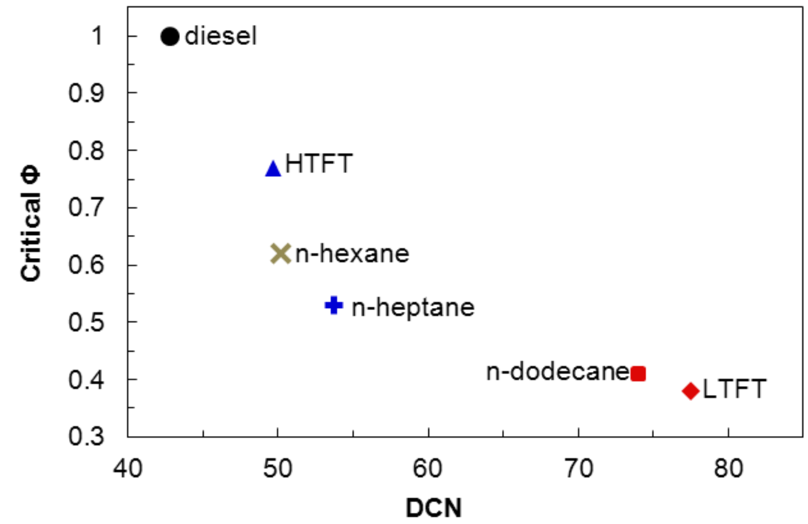


CR 8

Results



CR 8



CR 8 with simulated EGR
(O_2 10.7 vol. %, CO_2 8 vol. % and N_2 81.3 vol. %)

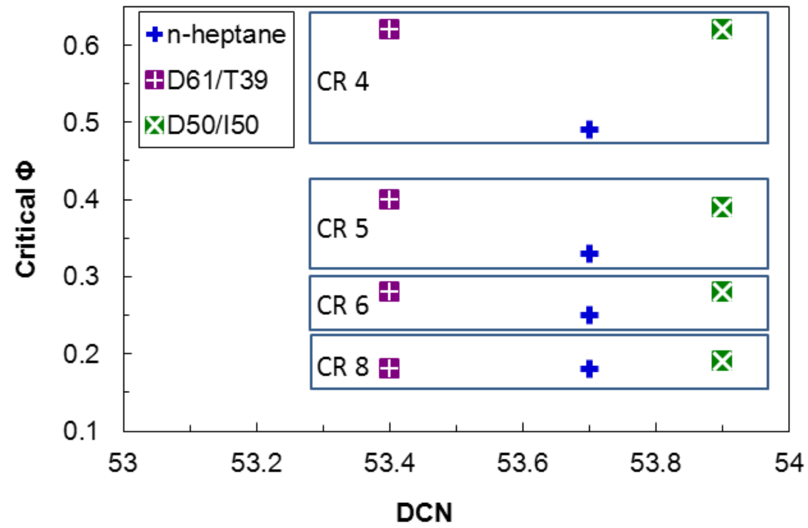
Results

ASTM method D6890 (IQT) was used to determine binary blends with the same DCN as n-heptane:

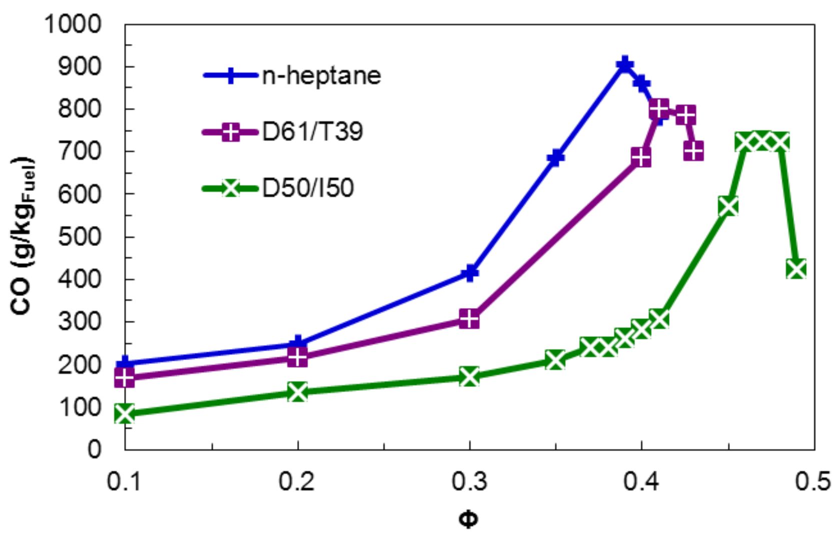
n-heptane: 53.7

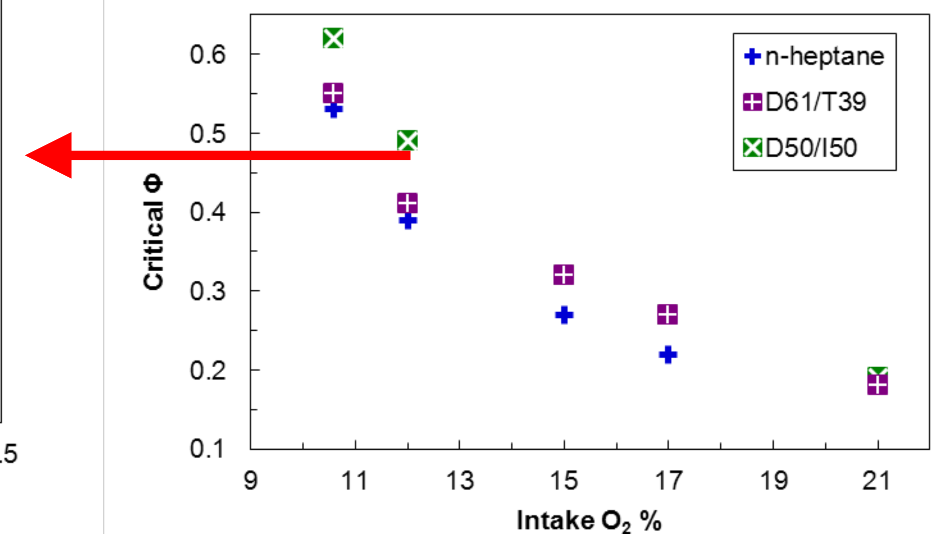
n-dodecane 61% and toluene 39%: 53.4

n-dodecane 50% and iso-octane 50%: 53.9



n-heptane, D61/T39 and D50/I50 at CR 4,5,6 & 8





CR 8 with simulated EGR

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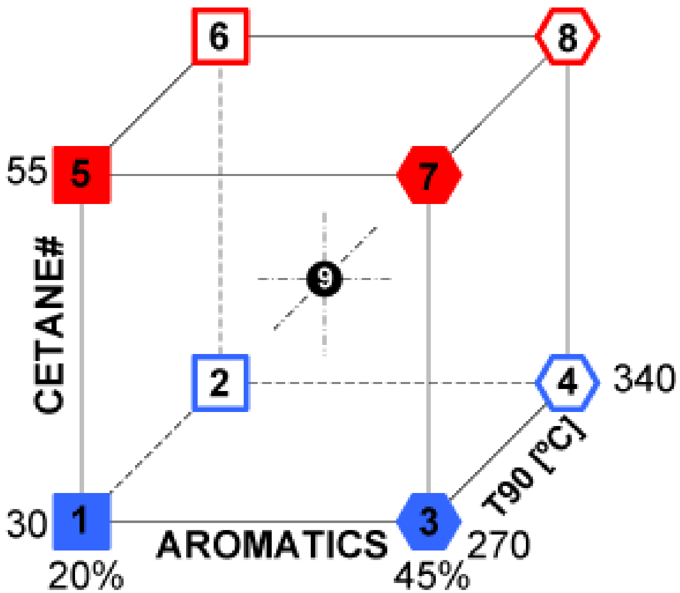
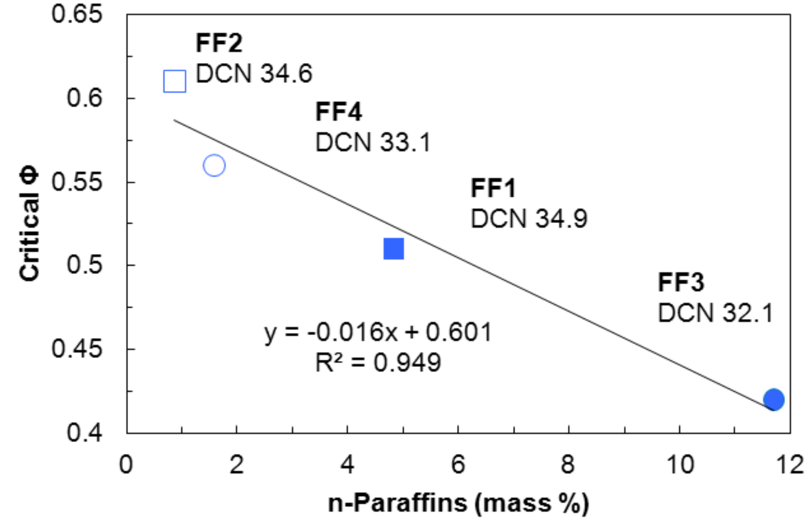
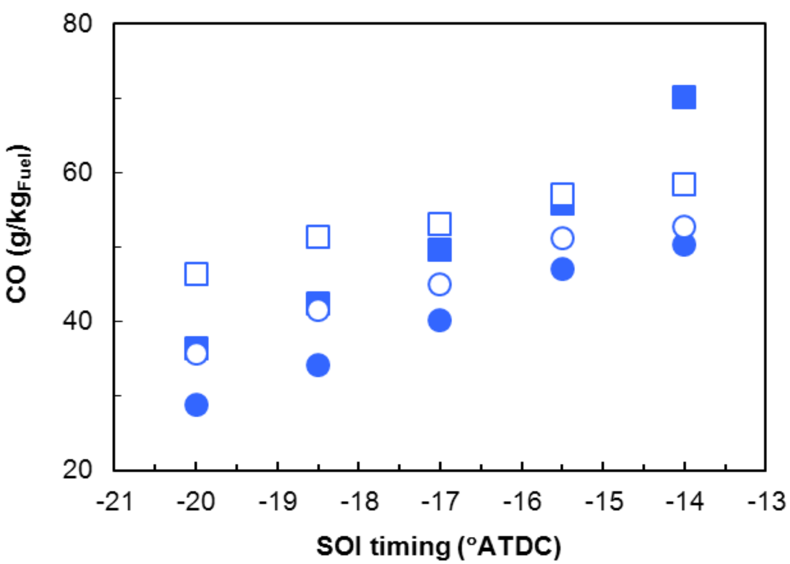
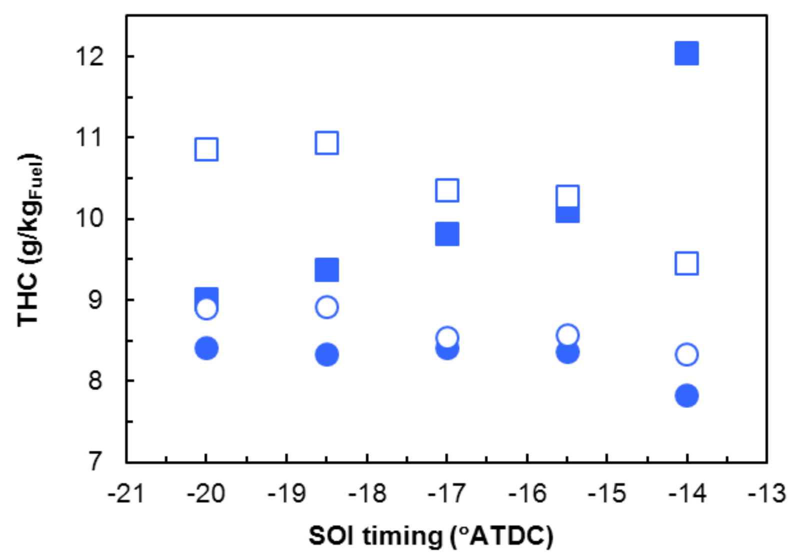




FACE Fuel 1, 2, 3 and 4 at CR 7

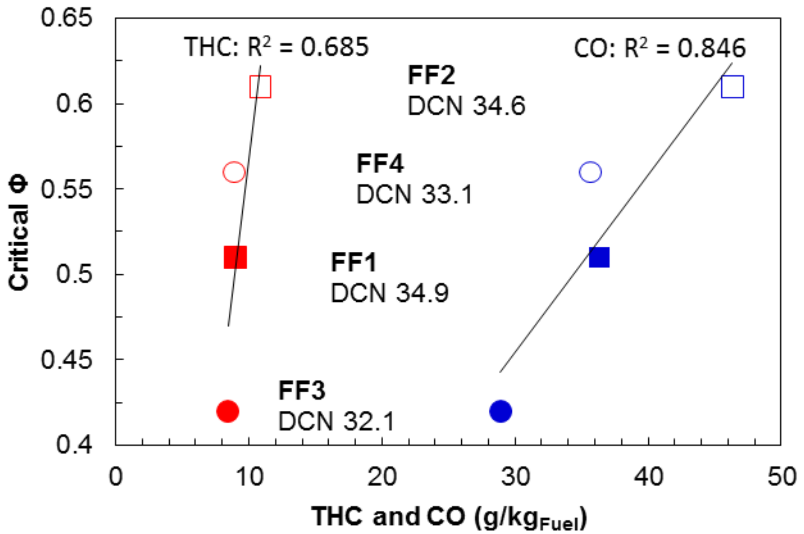


CO, 2.6bar BMEP, ~15.6% intake O_2

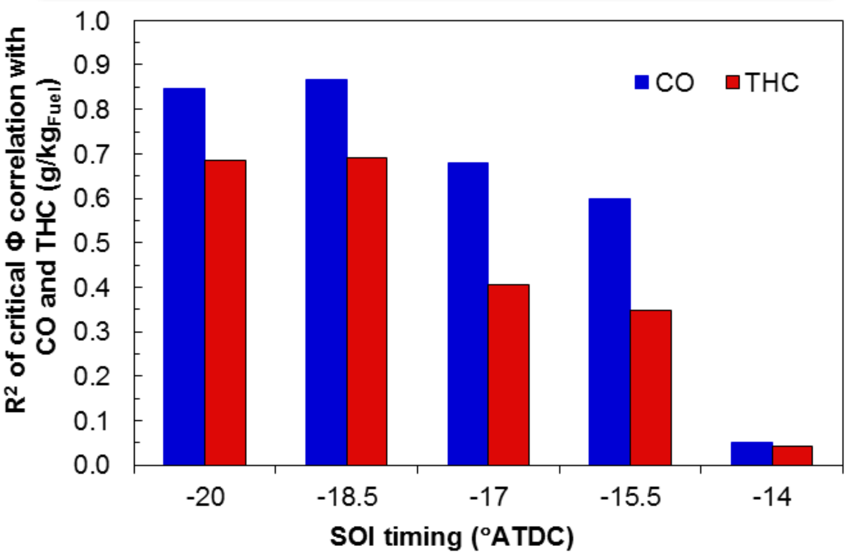


THC, 2.6bar BMEP, ~15.6% intake O_2

Conclusions



Correlation between critical Φ and CO / THC
SOC of -20 ºATDC



Correlation between critical Φ and CO / THC

- A high cetane number fuel has a lower critical Φ, which is a factor which contributes to reduced incomplete combustion.
- EGR significantly influences the critical Φ of fuels with DCN that vary from 43 to 73.
- The critical Φ 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.

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Thank you for your attention.