Exploration of Fuel Property Impacts on the Combustion of Late Post Injections Using Binary Blends and High-Reactivity Ether Bioblendstocks

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INTRODUCTION

Late post-injections are used for aftertreatment heat-up operation

Operation of aftertreatment components highly temperature dependent

- DOC light-off temperature ~ 250° C
- Low NO_x conversion efficiency below an SCR bed temperature of ~200° C

Low pollutant conversion efficiency experienced during 'cold start' phase

- No substantial NO_x conversion for the initial 400 s of FTP transient cycle [1]
- Hydrocarbon emissions also spikes due to low conversion by the DOC

[1] C. Sharp, C. C. Webb, G. Neely, M. Carter, S. Yoon, and C. Henry, SAE International Journal of Engines, vol. 10, no. 4, pp. 1697–1712, 2017.

MOTIVATION AND OBJECTIVES

Late post-injections have the potential to decrease catalyst heat-up period

- Fuel energy released late in the cycle used to increase exhaust gas temperature
- Challenges: high fuel penalty, unstable combustion leading to high engine-out CO and HC emissions

Determine if the following fuel properties impact engine operation during catalyst heating stage:

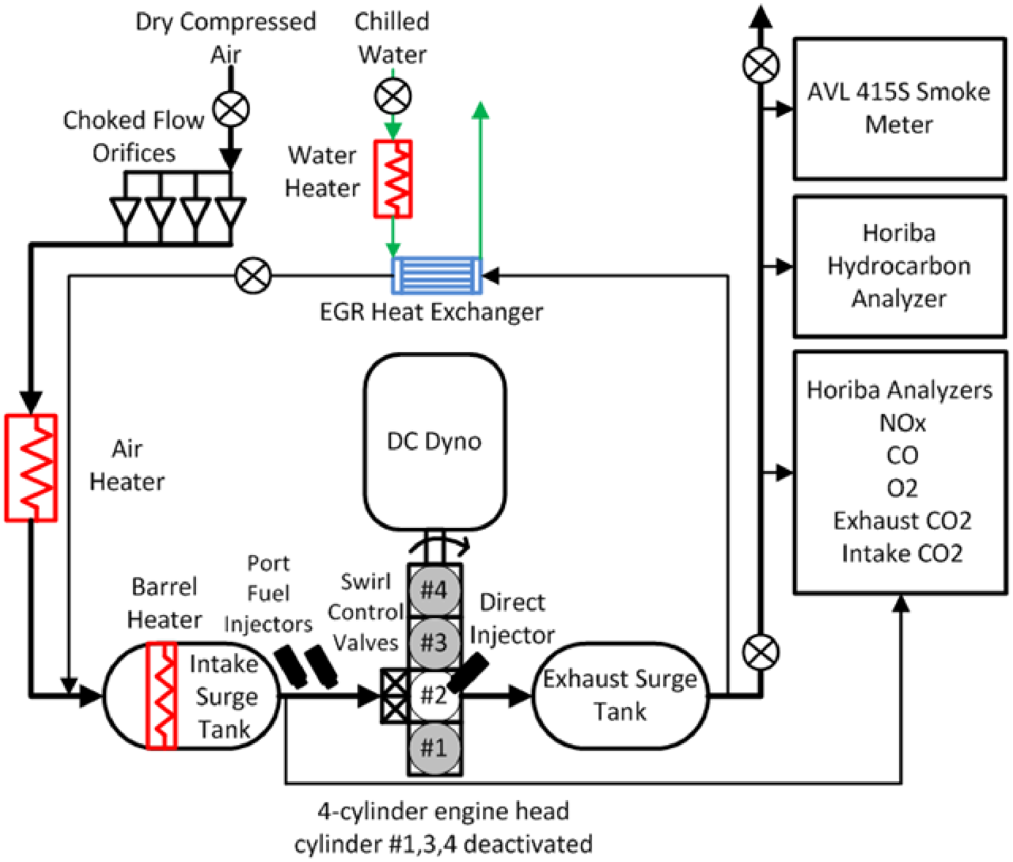
- Fuel reactivity as quantified by Cetane Number (CN)
- Fuel volatility as determined using the distillation characteristics

METHODS: EXPERIMENTAL SETUP

Single-cylinder light-duty engine (GM 1.9L) used for experiments

Engine geometry details.

Parameter	Units	Value
Con. rod length	mm	145.5
Bore x stroke	mm	82 x 90.4
Displacement	L	0.475
IVO/IVC	CAD	350°/-138°
EVO/EVC	CAD	122°/-346°
Compression Ratio	-	17:1
Swirl Ratio	-	2.3



Schematic of the test cell.

METHODS: OPERATING CONDITIONS

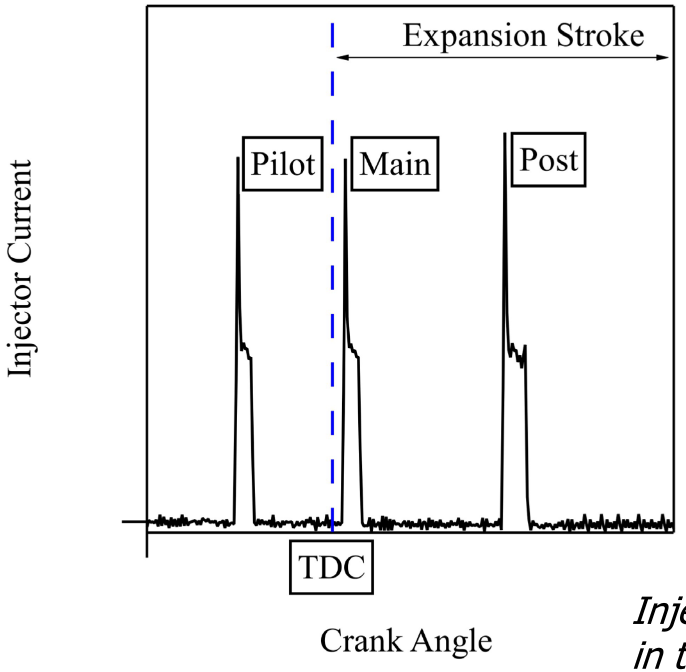
A three-injection strategy investigated using a <u>fixed pilot and main phasing</u>

- Post-injection timing swept at a constant engine load ($IMEP_g$= 3 bar) & speed (1500 RPM)

Operational parameters used in this study

Parameter	Units	Value
Intake temp.	K	328
Intake pressure	kPa	100
EGR	%	30
Inj. pressure	bar	500
Pilot SOI*	CAD	-14
Main SOI*	CAD	1
Oil temp.	K	328

** for #2 diesel operation*

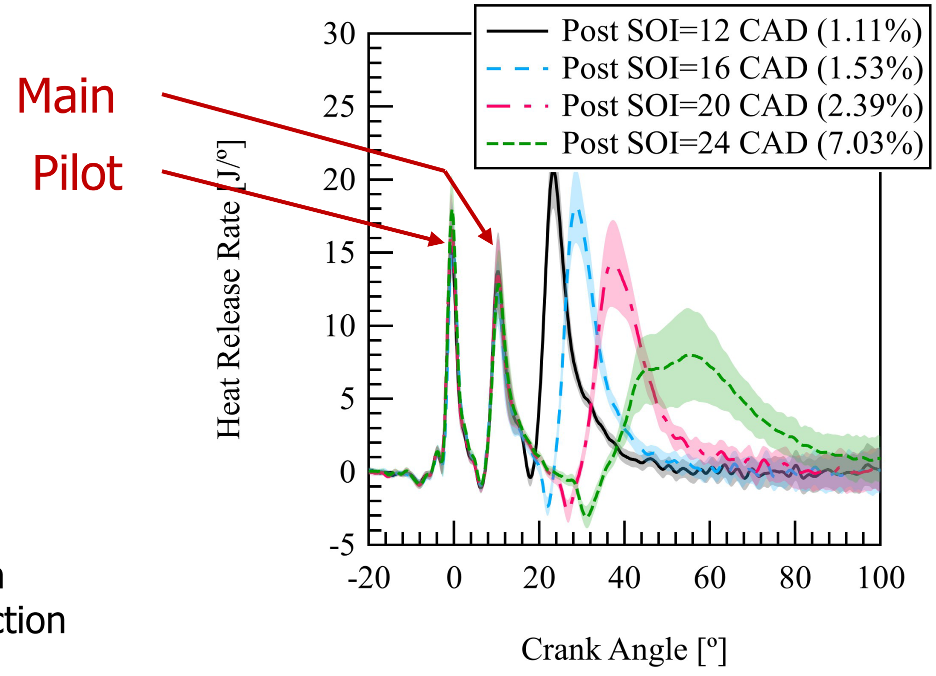


Injection schedule used in this study

RESULTS: BASELINE OPERATION

Post-injection sweep with #2 diesel established baseline engine operation

- Pilot and main injection SOI and DOI held constant
- Post injection DOI adjusted to hold engine load constant



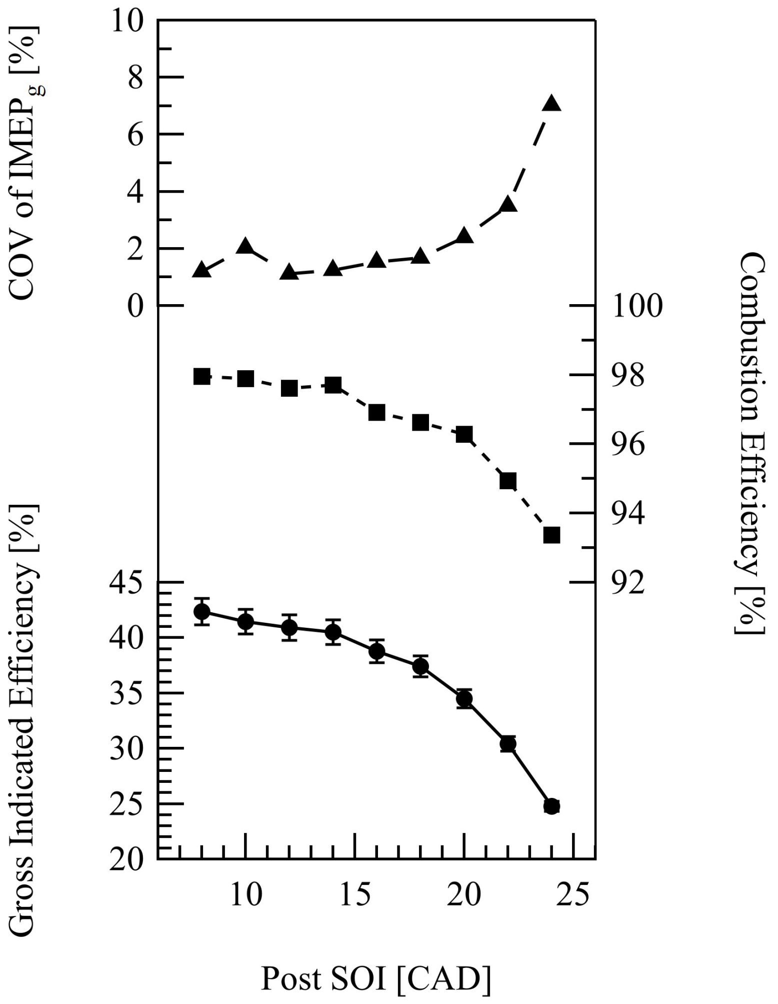
HRR profile at different injection timings for #2 diesel. Corresponding value of COV of $IMEP_g$ is listed in parentheses.

SOI: Start of Injection
DOI: Duration of injection

RESULTS: BASELINE OPERATION

Retarding post-injection timing:

- Increases combustion duration
- Decreases combustion stability
- Decreases combustion & thermal efficiency



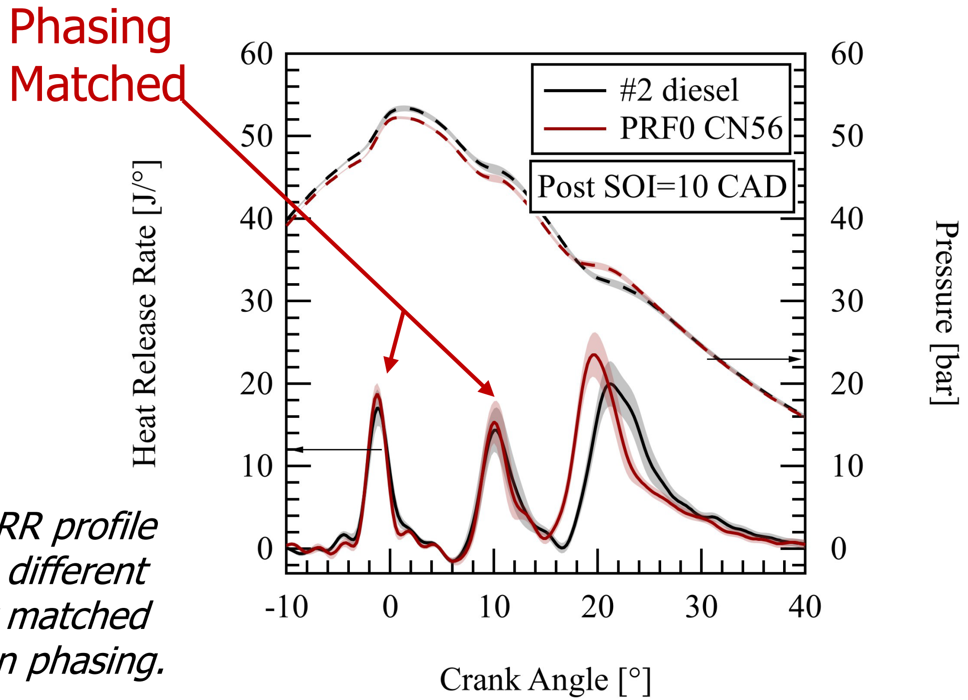
Thermal and combustion efficiency and COV of IMEP$_g$ as a function of post-injection timing.

COV: Coefficient of Variability

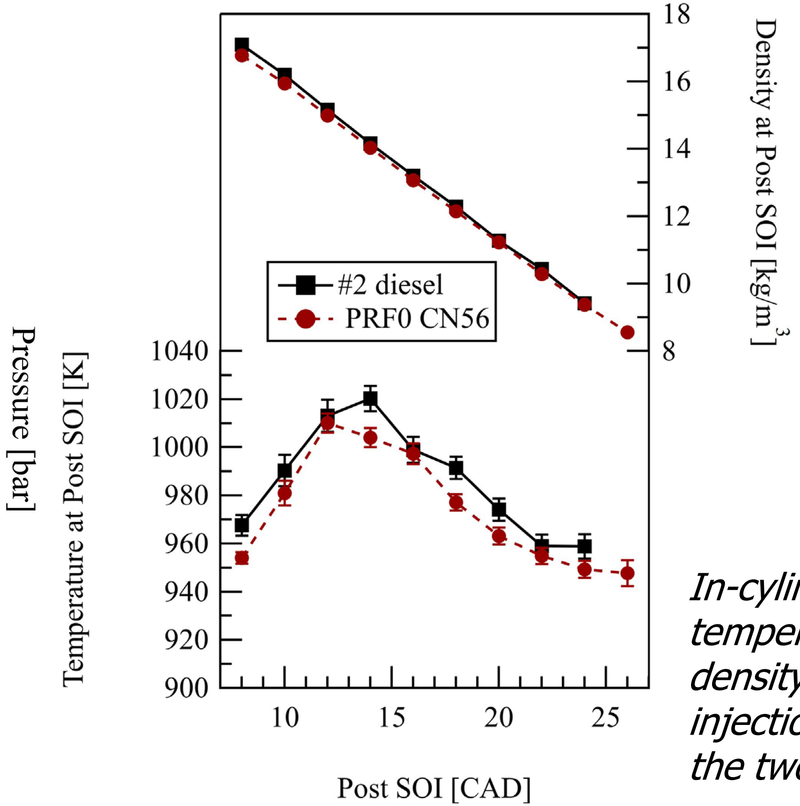
RESULTS: COMPARING DIFFERENT FUELS

Fuels compared at matched pilot & main combustion phasing

- Achieved by adjusting pilot and main injection SOI
- Matched thermodynamic conditions for fuels at a constant post-injection timing



Pressure & HRR profile for fuels with different reactivity but matched pilot and main phasing.



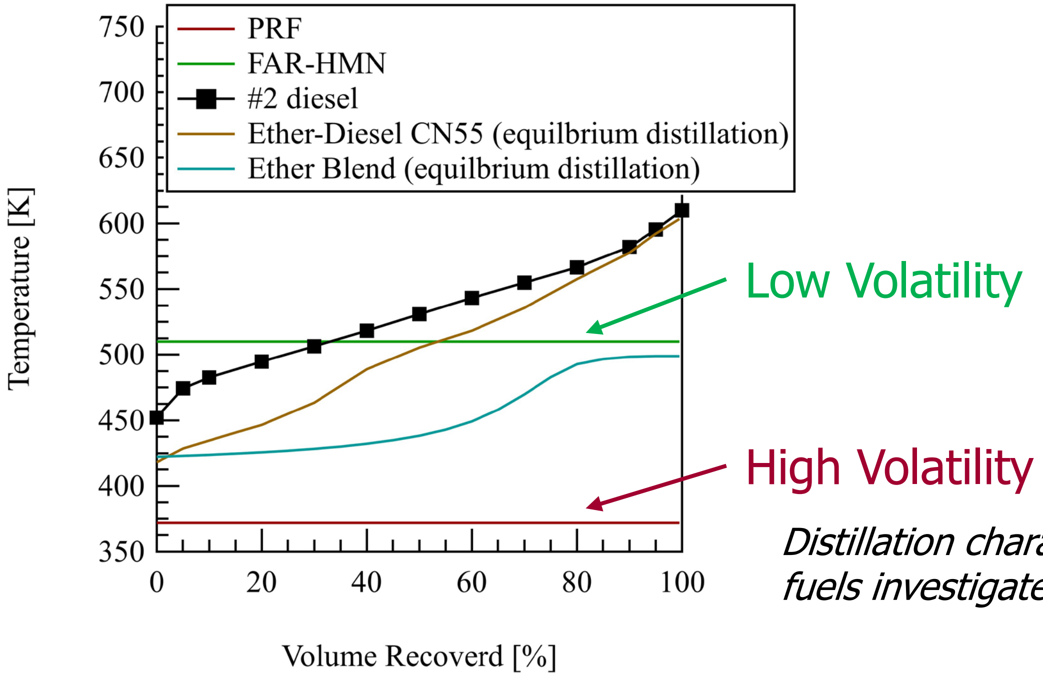
In-cylinder bulk gas temperature, and density at different injection timings for the two fuels

RESULTS: IMPACT OF FUEL VOLATILITY

Fuels with different boiling points used to investigate the effect of volatility

- Two set of binary fuel blends with low and high boiling points (BP) were studied
  - PRF 0 and FAR-HMN at matched reactivity (CN 56) were compared
- Binary fuel components have similar physical properties (density, MW etc.)

PRF: Primary reference fuel (blend of iso-octane and n-heptane)
FAR: Farnesane
HMN: Heptamethylnonane

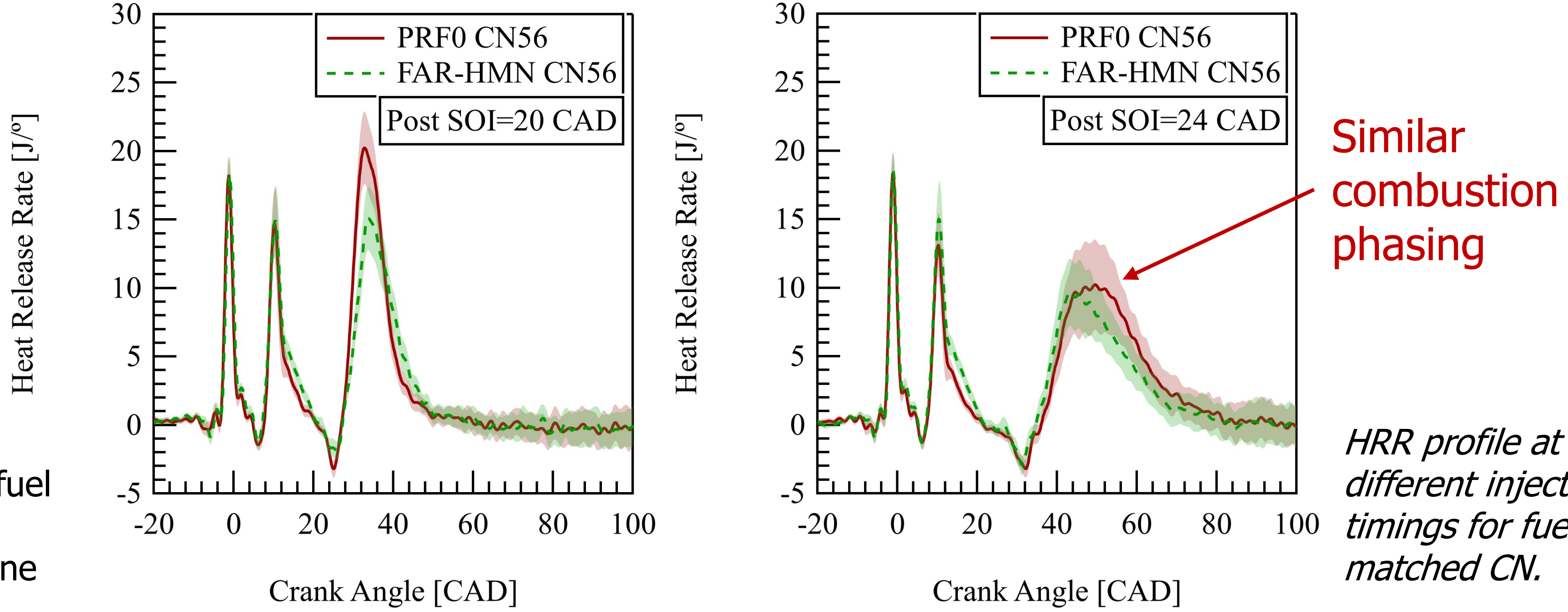


Distillation characteristics of the fuels investigated in this study

RESULTS: IMPACT OF FUEL VOLATILITY

Fuels at matched reactivity showed similar comb. phasing

- Lower BP fuel (PRF 0) predicted to have shorter Liquid Length (L.L.) relative to higher BP fuel (FAR-HMN) [2]
- No significant impact on ignition delay or comb. duration due to difference in LL



HRR profile at two different injection timings for fuels with matched CN.

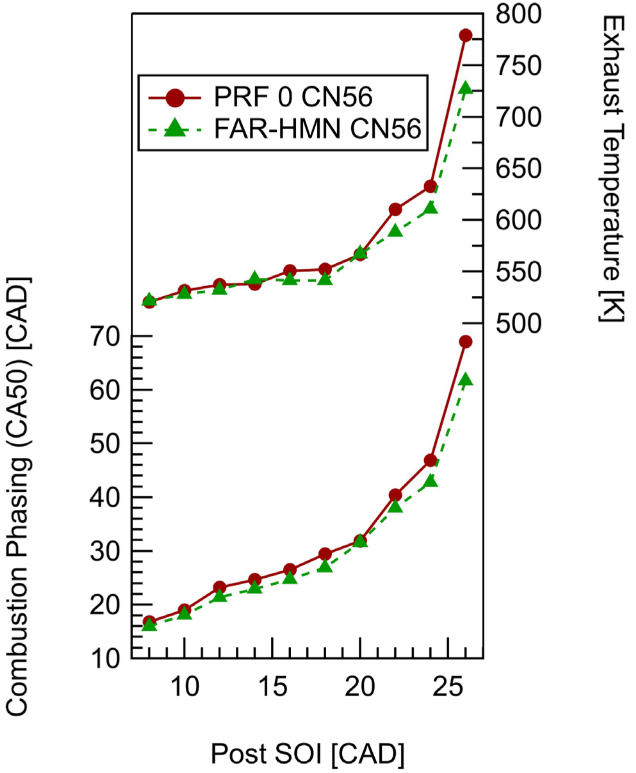
BP: Boiling point
PRF: Primary reference fuel
FAR: Farnesane
HMN: Heptamethylnonane

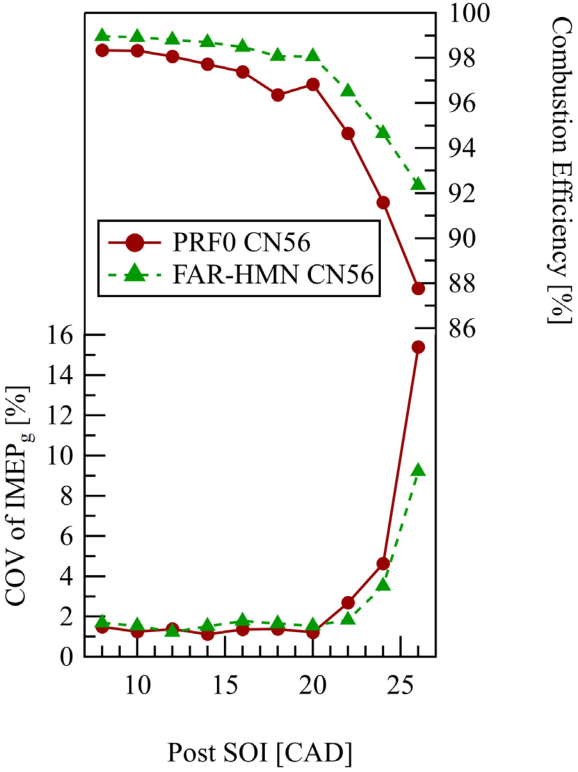
[2] D. Kim, J. Martz, and A. Violi, "Effects of fuel physical properties on direct injection spray and ignition behavior," Fuel, vol. 180, pp. 481–496, 2016.

RESULTS: IMPACT OF FUEL VOLATILITY

Fuels showed similar combustion characteristics and performance

- Similar comb. & emission performance for large portion of the injection sweep
- Deviation at late injection timings due to unstable combustion
- Impact of difference in L.L. minimal
  - Overmixing of fuel maybe the dominant pathway for HC and CO emissions



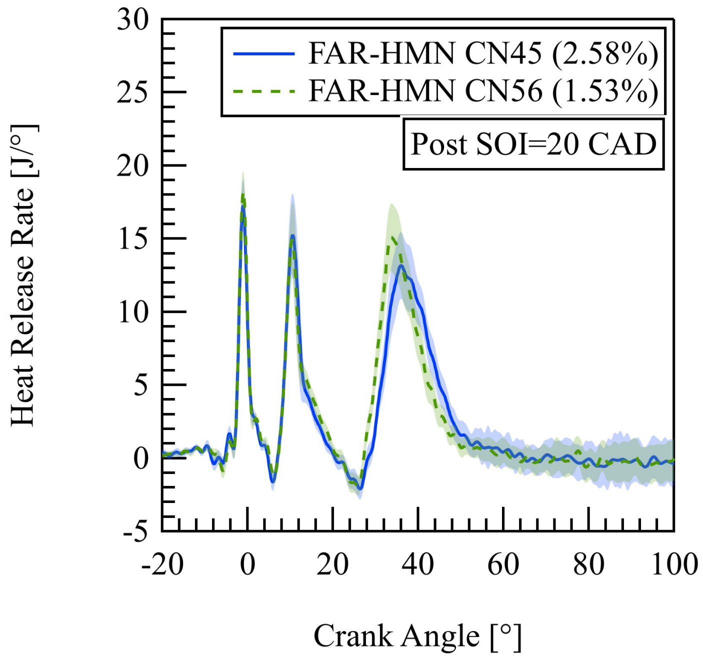


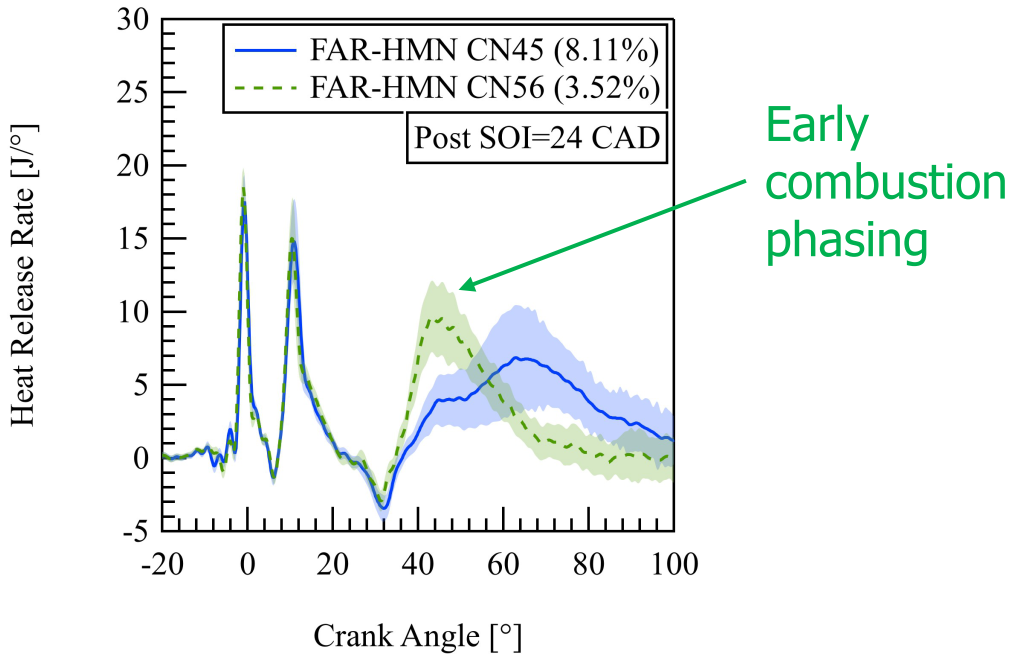
Performance and combustion parameters as a function of post-injection timing for fuels with matched reactivity.

L.L.: Liquid length
PRF: Primary reference fuel
FAR: Farnesane
HMN: Heptamethylnonane

FAR-HMN blend at two different reactivity were compared (CN 45 v 56)

- Combustion phasing difference minimal at early injection timings
- Significant difference in comb. phasing, duration & stability at late injection timings





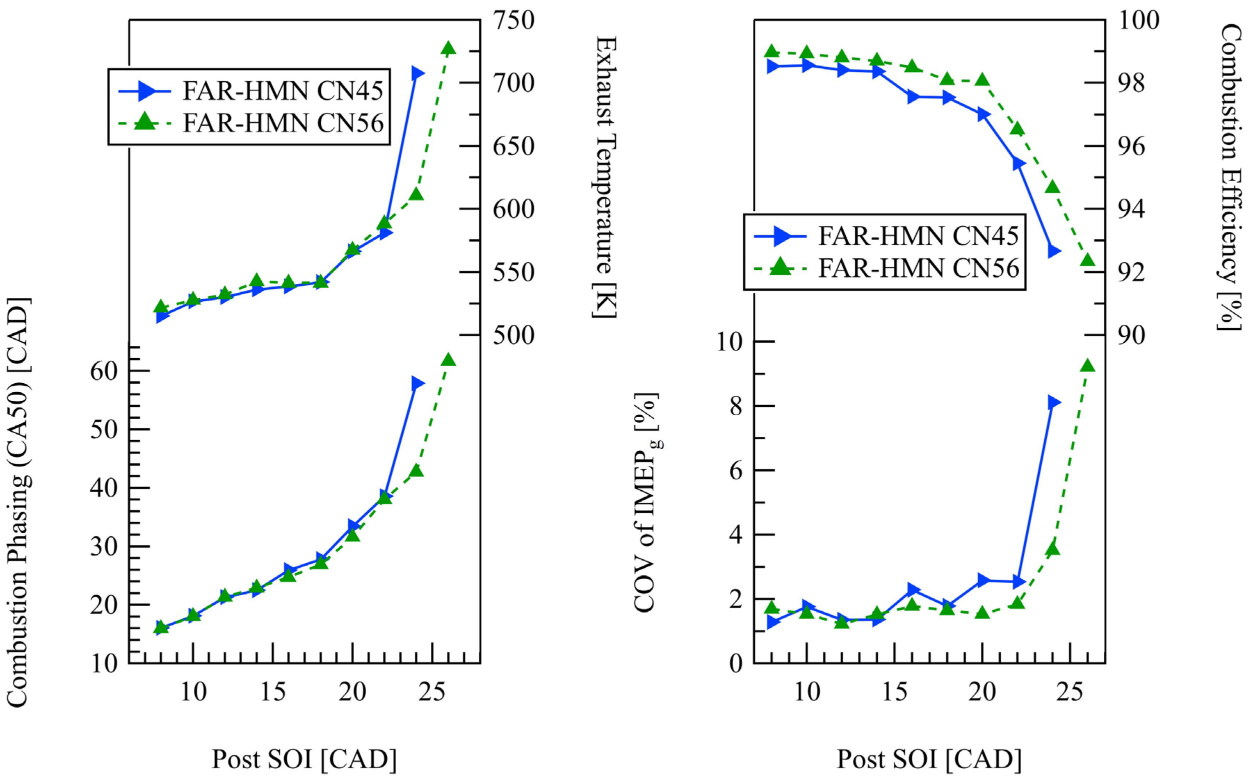
HRR profile at two different injection timings. Corresponding value of COV of IMEP$_g$ is listed in parentheses.

FAR: Farnesane
HMN: Heptamethylnonane

RESULTS: IMPACT OF REACTIVITY (Binary Blends)

Higher CN fuel showed higher thermal & comb. eff. at late timings

- Earlier combustion phasing reduces fuel demand to meet load
- Higher combustion stability improves combustion efficiency
  - Lower exhaust temperatures compared to the lower CN fuel



Performance parameters as a function of post-injection timing for FAR-HMN at two reactivity levels (CN 45 and 56)

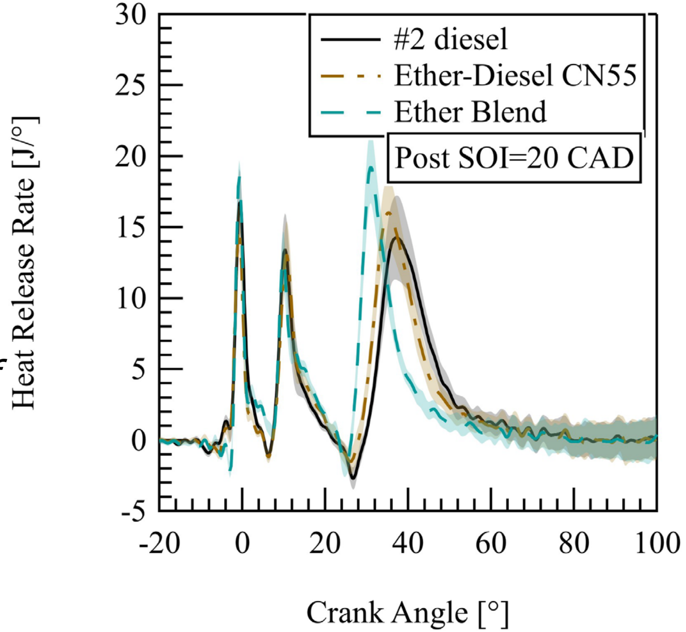
FAR: Farnesane
HMN: Heptamethylnonane

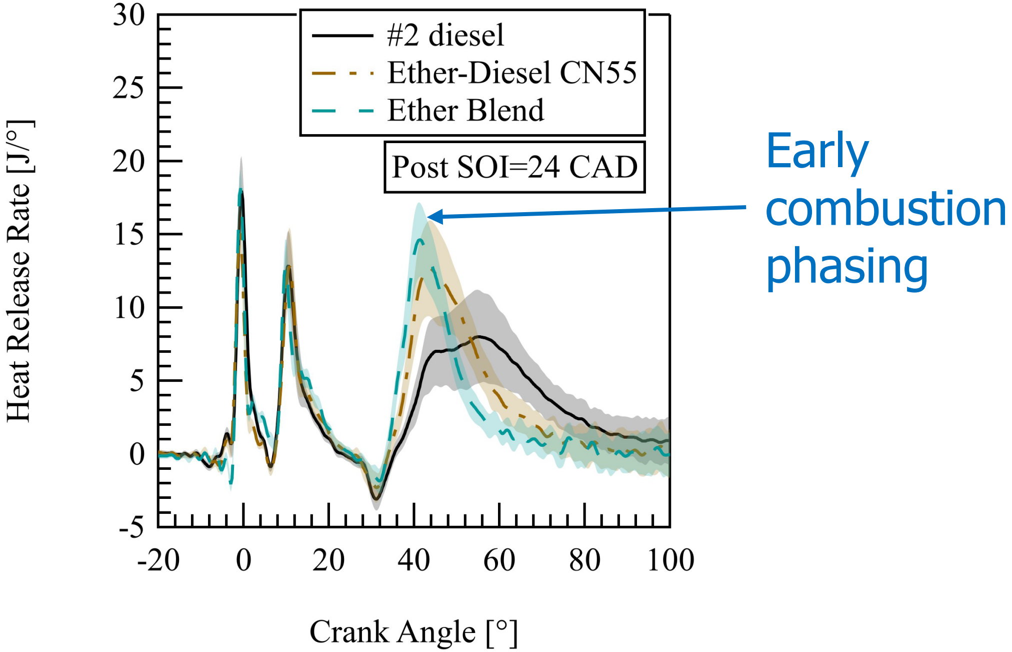
Reactivity study extended using high-reactivity blend of mono-ether components

- Mono-ether components: DBE (v/v: 65%), DHE (33%), and DIE (2%)
- Ether blend was run neat & in-blend configuration with diesel (Ether-Diesel CN 55)
  - Significant advancement in combustion phasing for the Ether Blend (CN>100)

HRR profile at two different injection timings. Corresponding value of COV of $IMEP_g$ is listed in parentheses.

DBE: di-butyl ether
DHE: di-hexyl ether
DIE: di-iso-amyl ether

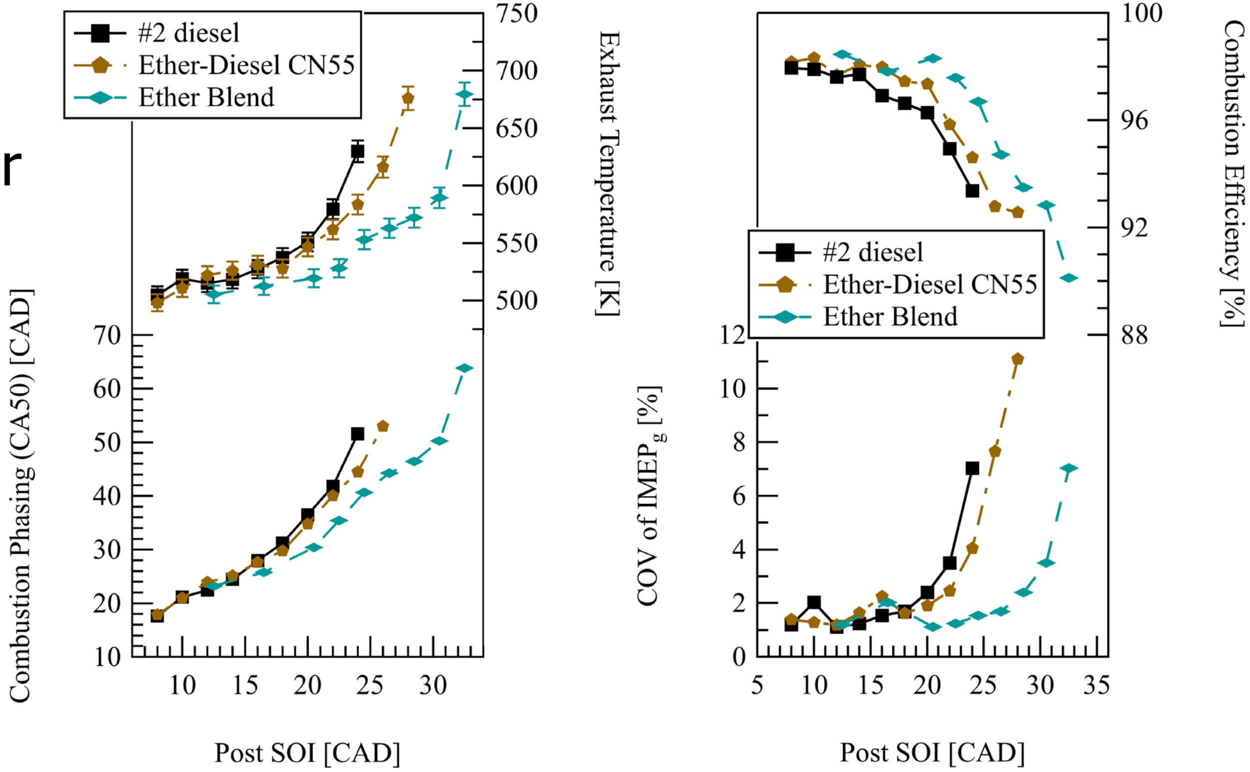




RESULTS: IMPACT OF REACTIVITY (Bioblendstock)

Higher-reactivity fuels showed improved comb. performance at late timings

- Higher combustion stability & shorter combustion duration
- Higher thermal & combustion efficiency
- Similar exhaust T. achieved at later injection timings



Performance and combustion parameters as a function of post-injection timing for diesel and mono-ether blends

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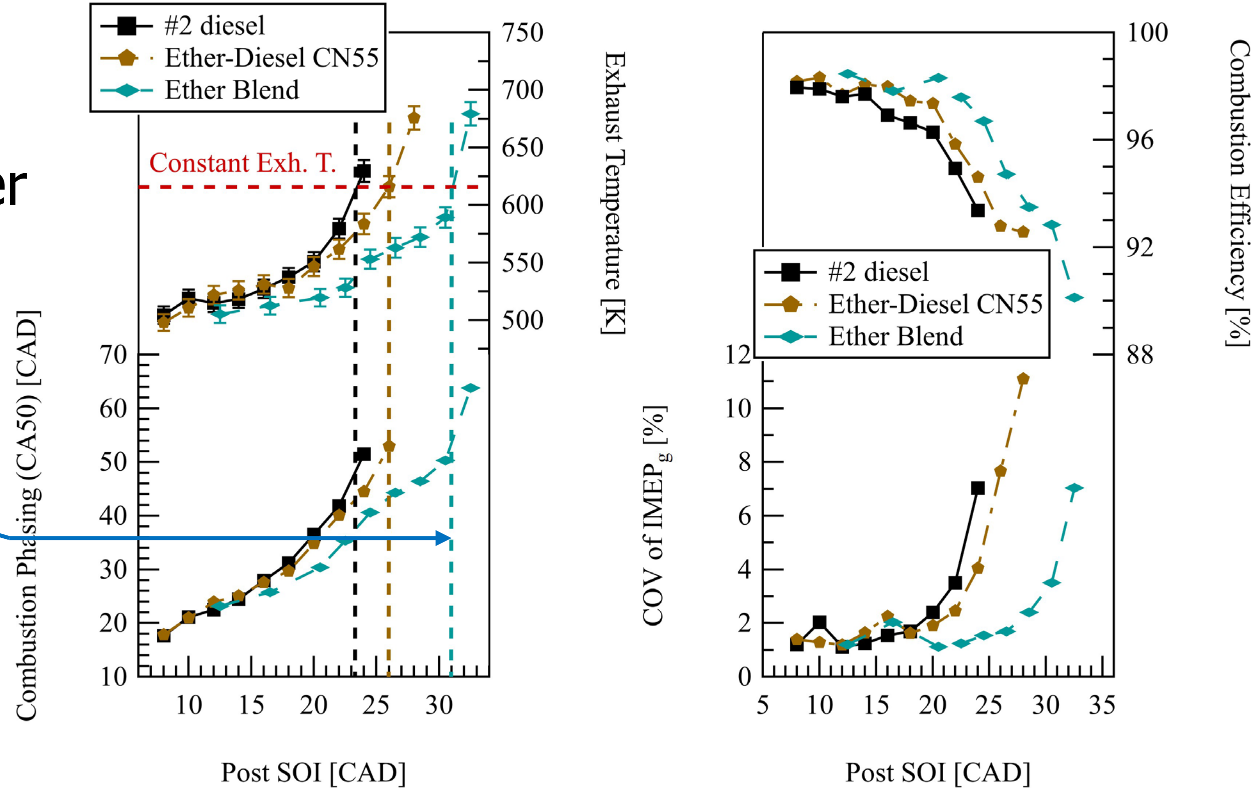
Higher CN→ Later Post SOI



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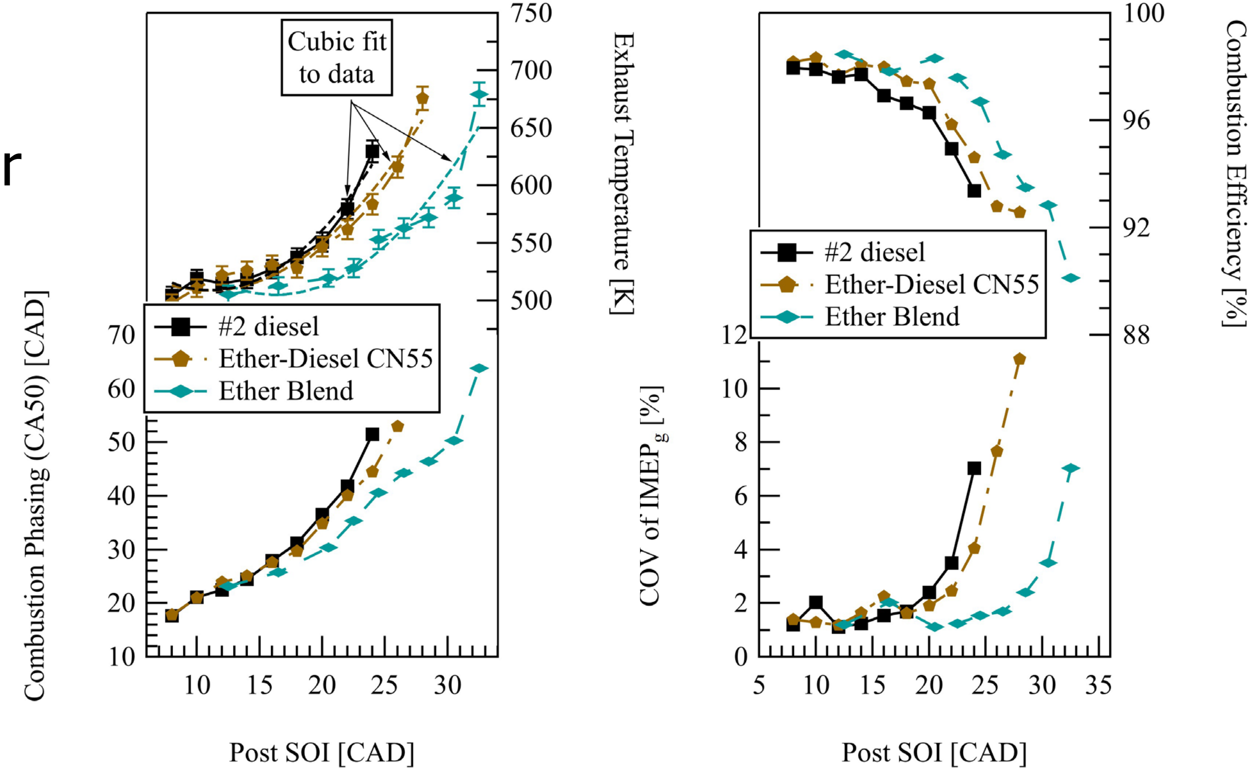
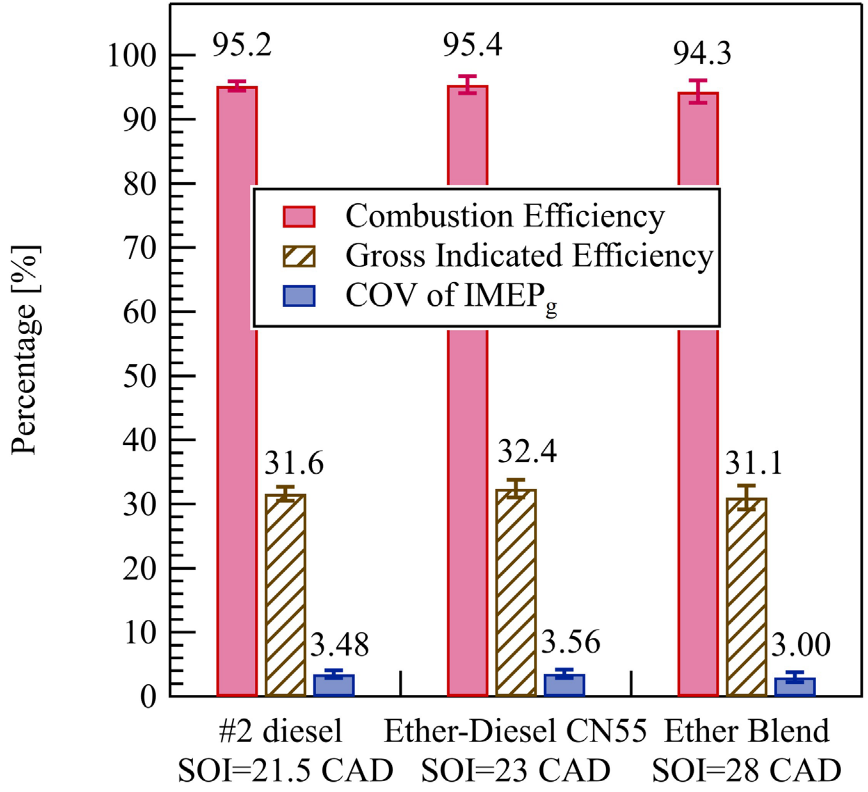


Performance and combustion parameters as a function of post-injection timing for diesel and mono-ether blends

RESULTS: IMPACT OF REACTIVITY (Bioblendstock)

Does reactivity offer any benefits in thermal or combustion eff. at matched exhaust temperature?

- Fuels with different reactivity compared at a constant exhaust temp. (300 ° C)
- Benefits in combustion parameters were minimal, if any



Performance parameters as a function of fuel reactivity at matched exhaust temperature of 300° C (573 K)

CONCLUSIONS

A three-injection strategy was investigated to understand the effects of fuel properties on thermal management operation of aftertreatment system

- Fuel components selected enabled isolating the effects of certain fuel properties
- Fuels were compared at relatively matched in-cyl. thermodynamic conditions

<u>KEY TAKEAWAYS:</u>

- <u>Effects of volatility:</u> Minimal effect of boiling point was observed on any combustion or performance parameters
- <u>Effects of reactivity:</u>
  - At a constant post-injection timing higher CN fuel showed higher combustion stability & efficiency relative to a lower CN fuel
  - At matched exhaust temperature fuels with different reactivity achieved similar combustion and thermal efficiency

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THANK YOU!

Title: Exploration of Fuel Property Impacts on the Combustion of Late Post Injections Using Binary Blends and High-Reactivity Ether

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BACK-UP: FUEL PROPERTIES

Parameter	Units	#2 diesel	PRF	FAR-HMN	FAR-HMN	ED CN 55	Ether Blend
Derived cetane number	-	41	56	46	56	55	-
Cetane number	-	42	56	46	56	-	>100
Density	kg/m^3	854	687	772	772	838	778
Normal boiling point	K	442-606	371	523	523	419-605	414-501
Kinematic viscosity	cSt	2.509	0.496	2.96	2.96	-	-
Lower heating value	MJ/kg	42.62	44.50	43.60	43.60	41.78	38.96
Molecular weight	g/mol	204	100	215	215	187	145
H/C	-	1.84	2.28	2.13	2.13	1.91	2.22
O/C	-	0.0	0.0	0.0	0.0	0.0225	0.110
AFR_{st}	-	14.54	15.13	14.93	14.93	14.17	12.94
Oxygen ratio (Ω_r)	-	0.0	0.0	0.0	0.0	0.0076	0.0353
ΔH_{vap} (Enthalpy Demand)	kJ/kg	1184.22	1312.54	1298.50	1301.28	1196.26	1220.09
Liquid heating		479.96	116.64	502.61	498.10	450.45	307.49
Phase change		268.93	327.98	256.66	261.23	272.20	288.94
Vapor heating		435.33	867.92	539.23	541.95	473.61	623.66
% diesel	vol. %	100	0	0	0	75	0

ED: Ether Diesel
PRF: Primary reference fuel
FAR: Farnesane
HMN: Heptamethylnonane

BACK-UP: ETHER FUEL COMPONENTS

Parameter	Units	DBE	DHE	DIE
CAS #	-	142-96-1	112-58-3	544-01-4
Cetane number[†]	-	>100	>100	96.3[*]
Density	kg/m^3	770	793	780
Normal boiling point	K	414	501	445
Kinematic viscosity	cSt	0.89	2.14•	1.64•
Lower heating value	MJ/kg	37.98	39.94	39.20
Molecular weight	g/mol	130.2	186.3	158.3
H/C	-	2.25	2.17	2.20
O/C	-	0.125	0.083	0.10
AFR_{st}	-	12.72	13.35	13.09
Oxygen ratio (Ω_r)	-	0.040	0.0269	0.0323
ΔH_{vap}	kJ/kg	341.0	344.0	261.5
YSI	-	12.9[‡]	-	51.6[‡]
% in Ether blend	vol.%	65	33	2

DBE: di-butyl ether
DHE: di-hexyl ether
DIE: di-iso-amyl ether