System-Response Issues Imposed by Biodiesel in a Medium-Duty Diesel Engine

Timothy J. Jacobs,
Joshua A. Bittle, Jason Esquivel, Bryan M. Knight, Brandon T. Tompkins
Department of Mechanical Engineering
Texas A&M University

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MECHANICAL ENGINEERING

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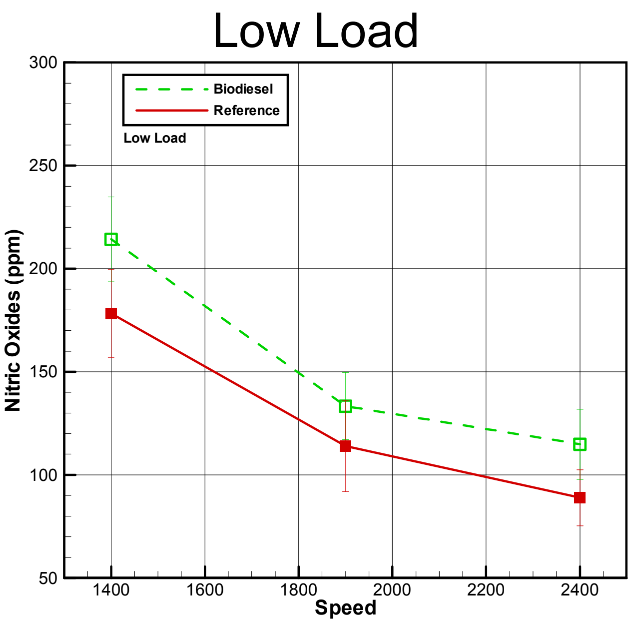
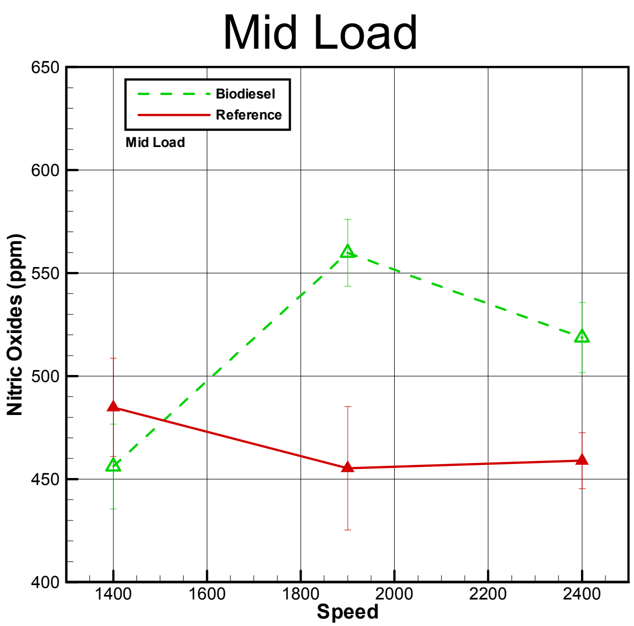
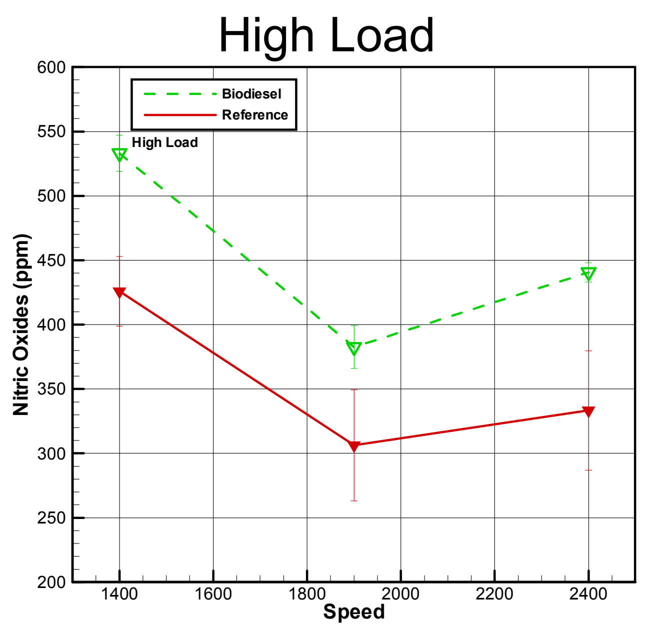
Motivation

- Although inconsistencies exist in literature, biodiesel is generally reported to result in increased NOx emissions, relative to petroleum diesel.







- As a result, biodiesel may face challenges penetrating certain markets (e.g., State of Texas).

Objective

- The objective of the current research is to assess differences in NOx emissions between biodiesel and petroleum diesel fuels, resulting from fundamental issues and system-response issues.

Methodology

Bore	106 mm
Stroke	127 mm
Displacement	4.5 L
Rated Power	115 kW at 2400 rev/min
Compression Ratio	17.0:1 (nominal)
Ignition	Compression
Fuel System	Electronic common rail, direct injection
Air System	Variable geometry turbocharger with exhaust gas recirculation

Capabilities Include:

- In-cylinder pressure measurement (Kistler 6056A)
- Injector command current and needle lift motion
- Gaseous species (Horiba MEXA 7000D)
- Exhaust smoke concentrations (AVL 415S)

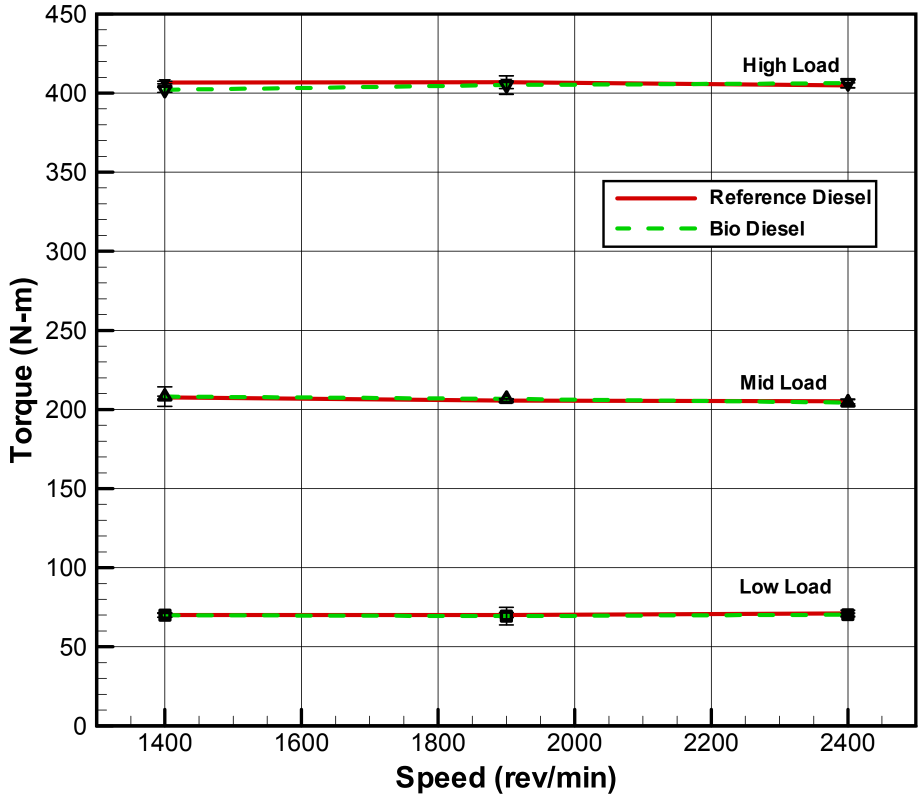
Methodology

Property	ULS 2007 Certification Diesel	Palm Olein Biodiesel
Density (kg/m^3)	845	876
Net heating value (MJ/kg)	42.89	37.14
Gross heating value (MJ/kg)	45.11	39.77
Sulfur (ppm)	8.2	2.1
Viscosity (cSt)	2.1	4.53
Cetane #	44	63.5
Hydrogen (%-m)	13.10	12.44
Carbon (%-m)	86.90	76.63
Oxygen (%-m)	0	10.93

Comparisons are between D100 and B100

Methodology

- Engine speed and torque are matched between two fuels.
  - Designed considering that end user will demand the same torque, regardless of fuel used.
- Uncertainty bars represent test repeatability determined over several days of testing.



Fundamental vs. System Response

Fundamental issues are manifested by fuel property effects that directly affect combustion or nitric oxide formation mechanisms. Examples include:

- Alterations to spray penetration, atomization, breakup and vaporization due to differences in fuel density, viscosity, surface tension, and vapor pressure
- Potentially different adiabatic flame temperatures due to lower heating values, but offset by correspondingly lower air-fuel ratios.
- Decreased radiation heat transfer, resulting from decreased soot (fuel-bound oxygen, lower aromatics, and different precursor soot mechanisms), potentially leads to higher reaction temperatures.
- Shorter ignition delay, partially resulting from increased double-bond structure, leads to advanced start of combustion

Fundamental vs. System Response

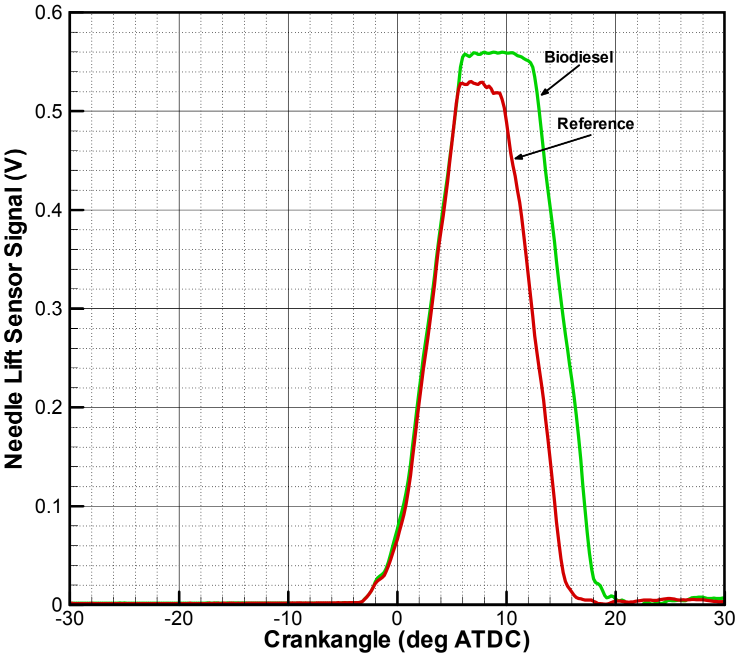
System Response Issues are Classified into Two Categories:

Indirect System Response

Difference in fluid property manifests a change in engine behavior, leading to indirect changes to combustion and nitric oxide formation mechanisms.

- Higher bulk modulus leads to advance in injection timing
- Lower exhaust temperatures lead to differences in boosting capabilities

A lower heating value, in spite of a slightly higher density, requires a longer injection pulsewidth to deliver roughly the same amount of energy, to deliver the same brake torque.

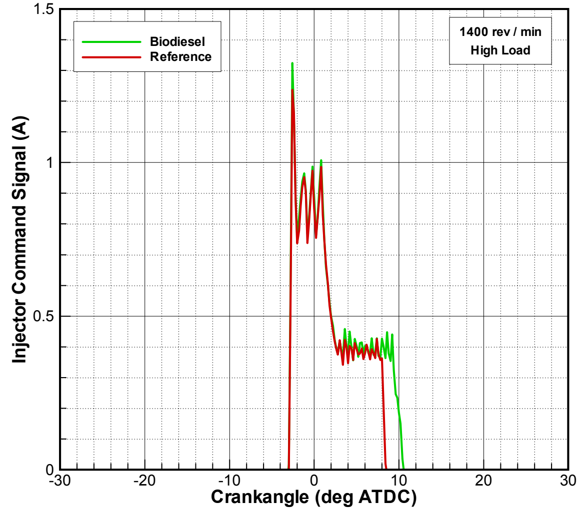


Controlled System Response

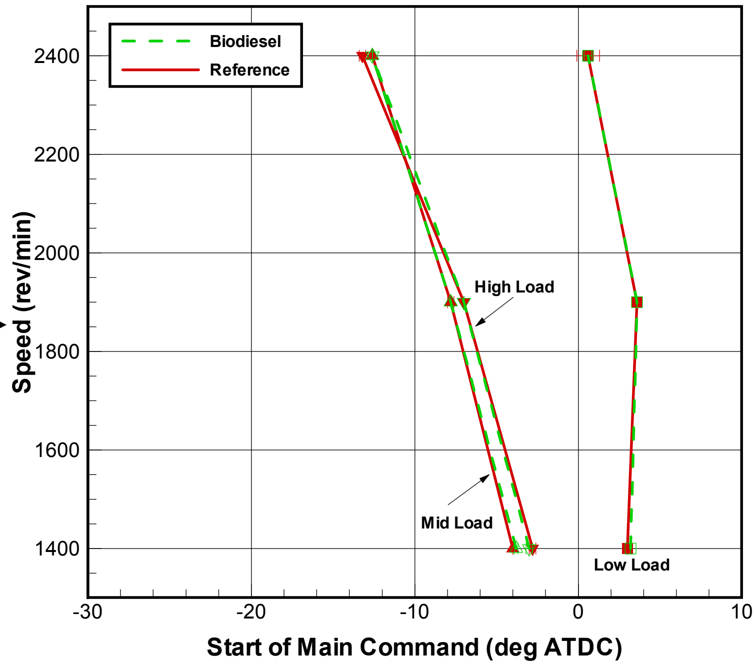
The necessarily longer injection pulsewidth (to match engine torque) manifests a change in a controlled parameter.

- All controlled parameters could be adjusted, including, a) injection timing, b) rail pressure (if applicable), c) EGR level (if applicable), and d) VGT vane setting (if applicable).

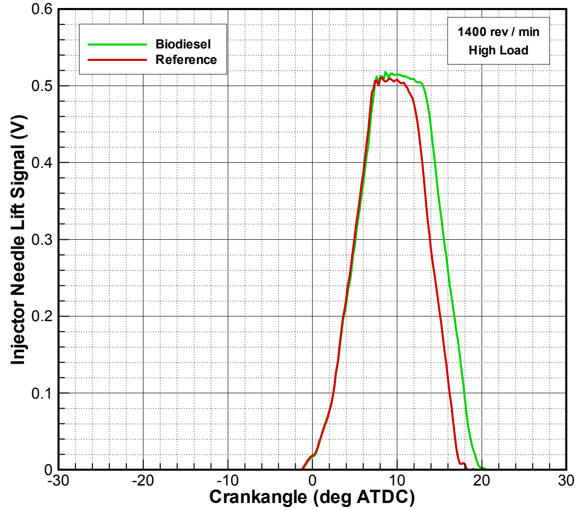
Injection Timing



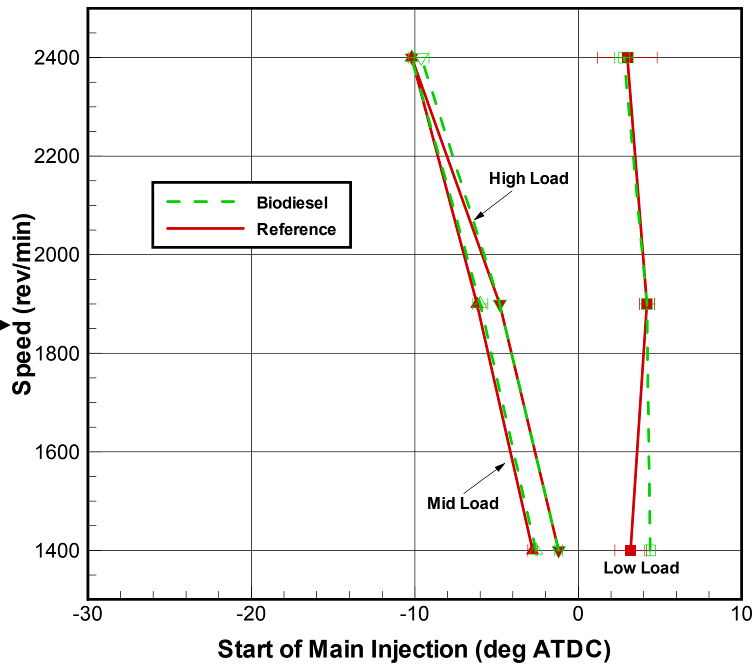
No "Controlled" system response



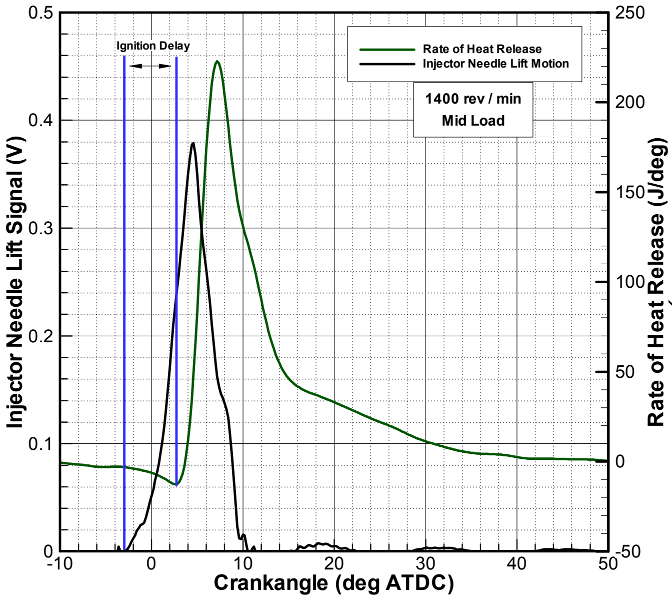
The commonly observed artificial advance in injection timing is not present in the common rail engine.

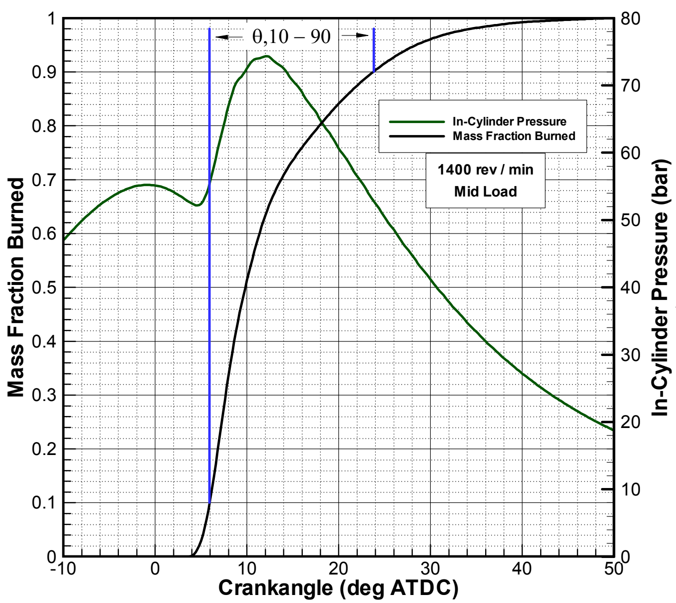


No "Indirect" system response

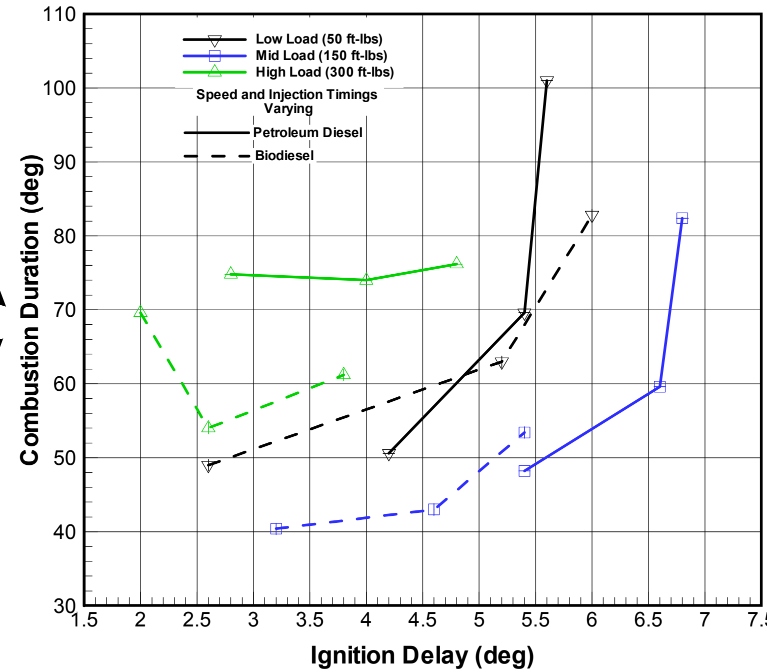


Ignition Delay

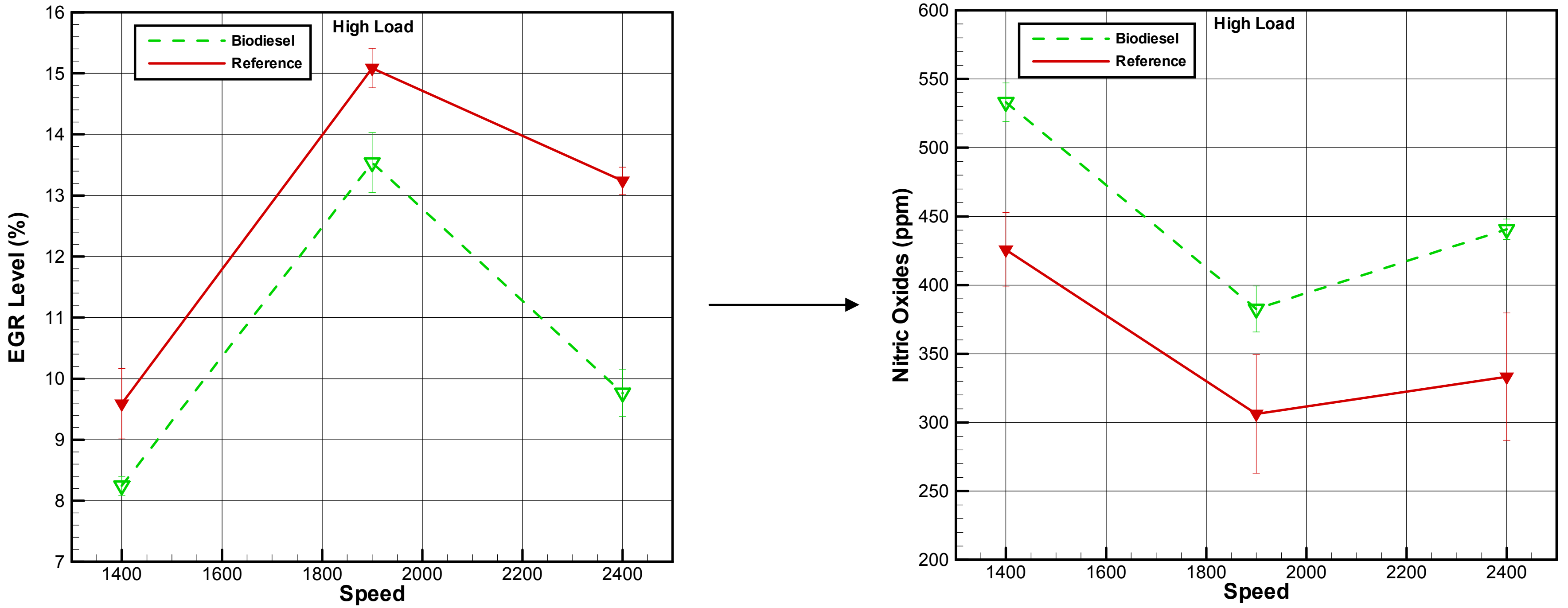




In spite of no controlled or indirect change to injection timing, start of combustion still advances as a result of the biodiesel's inherently shorter ignition delay.



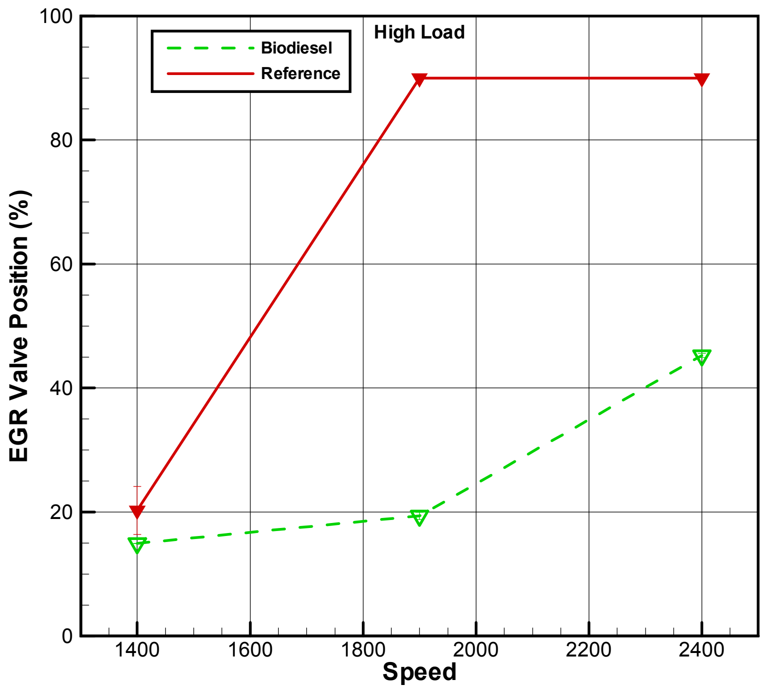
EGR Level

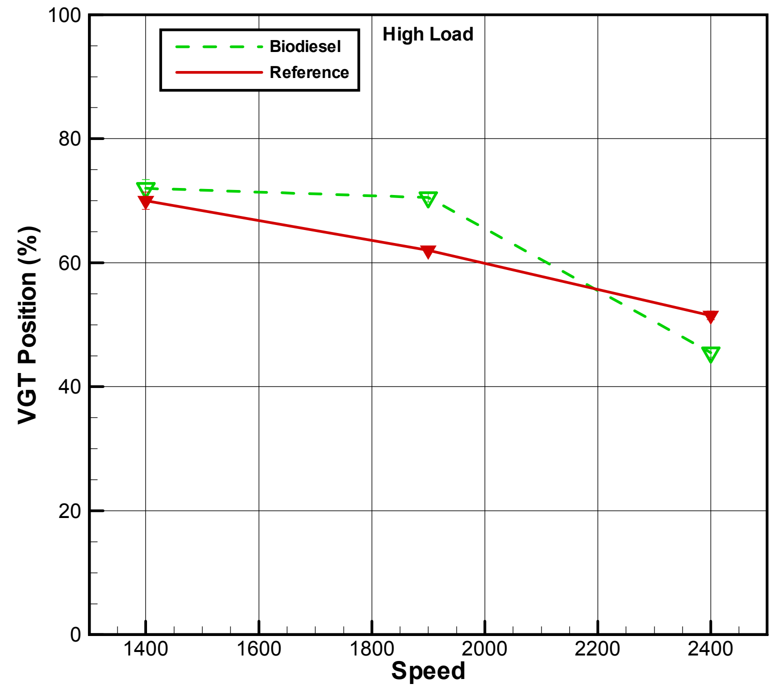


The lowered EGR level with biodiesel is a system-response that at least partially causes the higher nitric oxides at this condition.

But what causes EGR level to be lower for biodiesel?

EGR and VGT Control Positions





A controlled system response!

The perceived increase in load (via longer injection pulsewidth) causes a decrease in demanded EGR, partially contributing to increased nitric oxides.

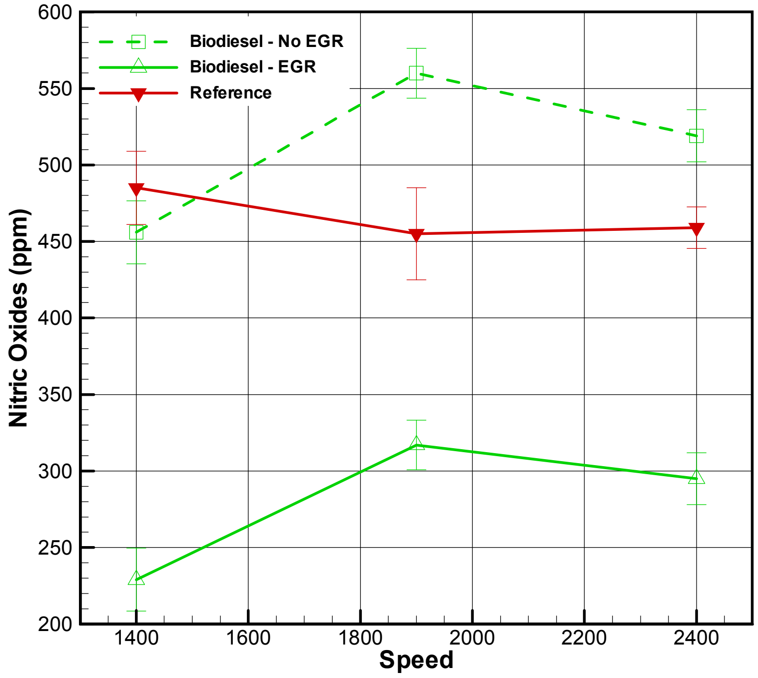
Exhaust Manifold Pressure (bar)

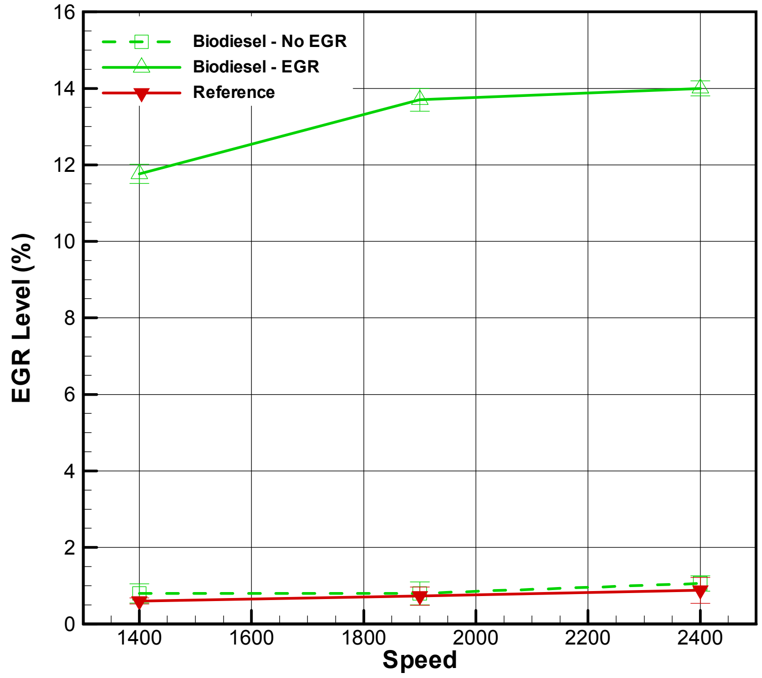
	1400	1900	2400
Reference	1.88	2.22	2.55
Biodiesel	1.96	2.83	2.37

The Influence of System Reponses

A system response issue can be very influential, and be partially responsible for inconsistencies in NOx emissions behavior reported in literature.

Mid-Load Conditions





Conclusions

The major conclusions of this study are as follows:

- Fundamental issues, such as advanced start of combustion and decreased radiation heat transfer, tend to manifest an increase in nitric oxide emissions of biodiesel, relative to petroleum diesel.
    - Based on the observation that in the presence of no system response issues, nitric oxide concentrations are higher with biodiesel than petroleum diesel.

- System response issues, whether indirect or controlled, can aberrate the observation of nitric oxide emissions between the two fuels.
    - System response issues are largely dependent on the design of the engine system, and the calibration and control of the engine.

- In some cases, the presence of advanced technology (such as common rail fuel system, variable geometry turbocharging, and exhaust gas recirculation) can be exploited to neutralize or decrease nitric oxide emissions with biodiesel.

Thank you!

Thank you for your attention!

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