Argonne NATIONAL LABORATORY

An Experimental Investigation of Low Octane Gasoline in Diesel Engines

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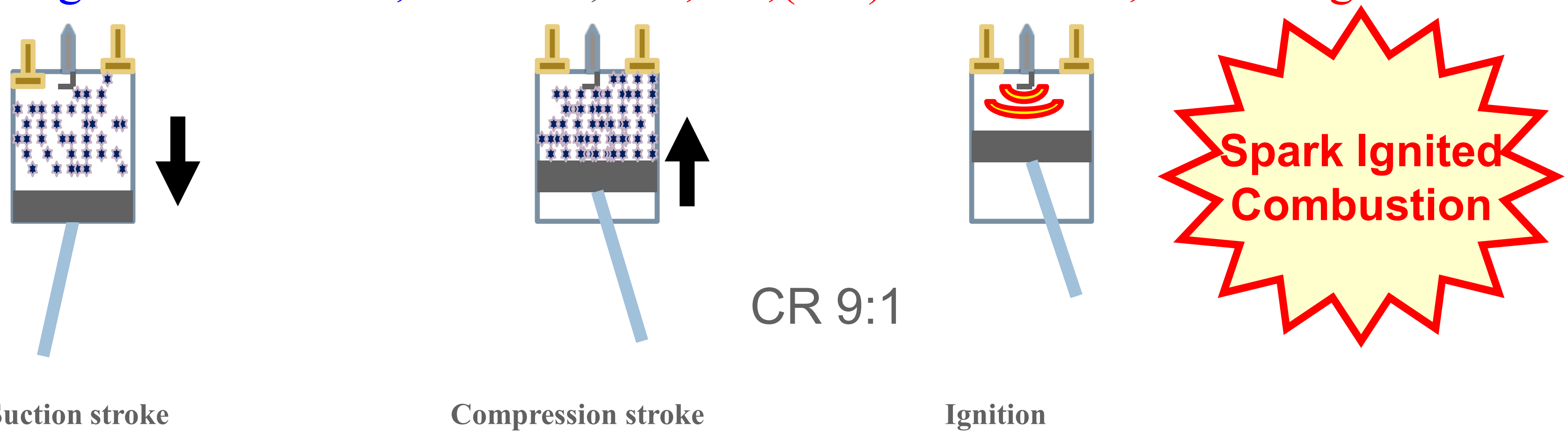
Objectives

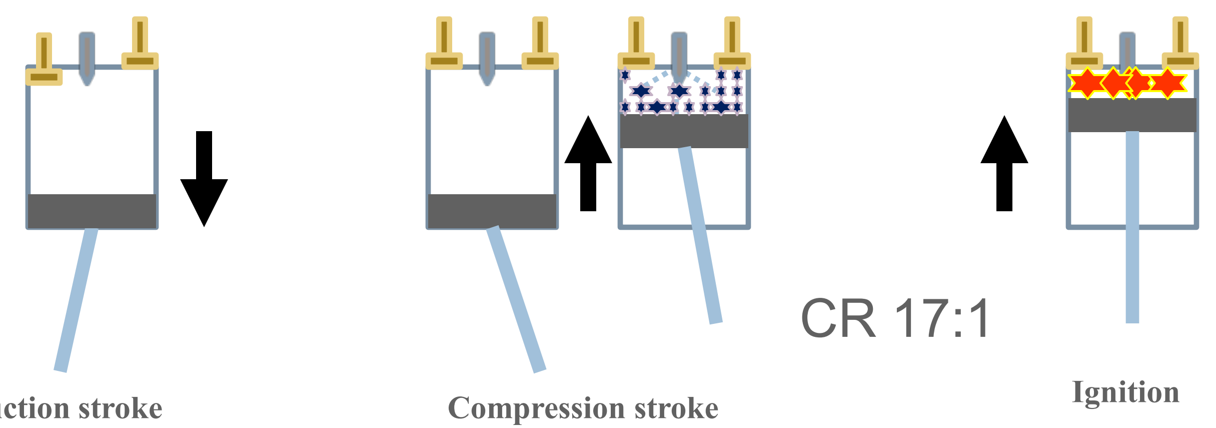
- The concept of using low-octane gasoline fuel to achieve a dictated premixed combustion in a diesel engine
  - Simultaneous reduction soot and NO_x
  - Fuel/(Air+EGR) will be premixed, but not well mixed
- Maintain relatively high power densities (10 to 12 bar BMEP) while retaining high efficiency and low emissions
- To study the mixture formation effects through early pilot or early pilot and pre injections followed by a main injection schemes in gasoline LTC.
- Control combustion phasing by utilizing in-cylinder controls and study the influence of EGR, boost pressure and injection pressure on gasoline operated diesel engine in LTC mode

Conventional Combustion Process

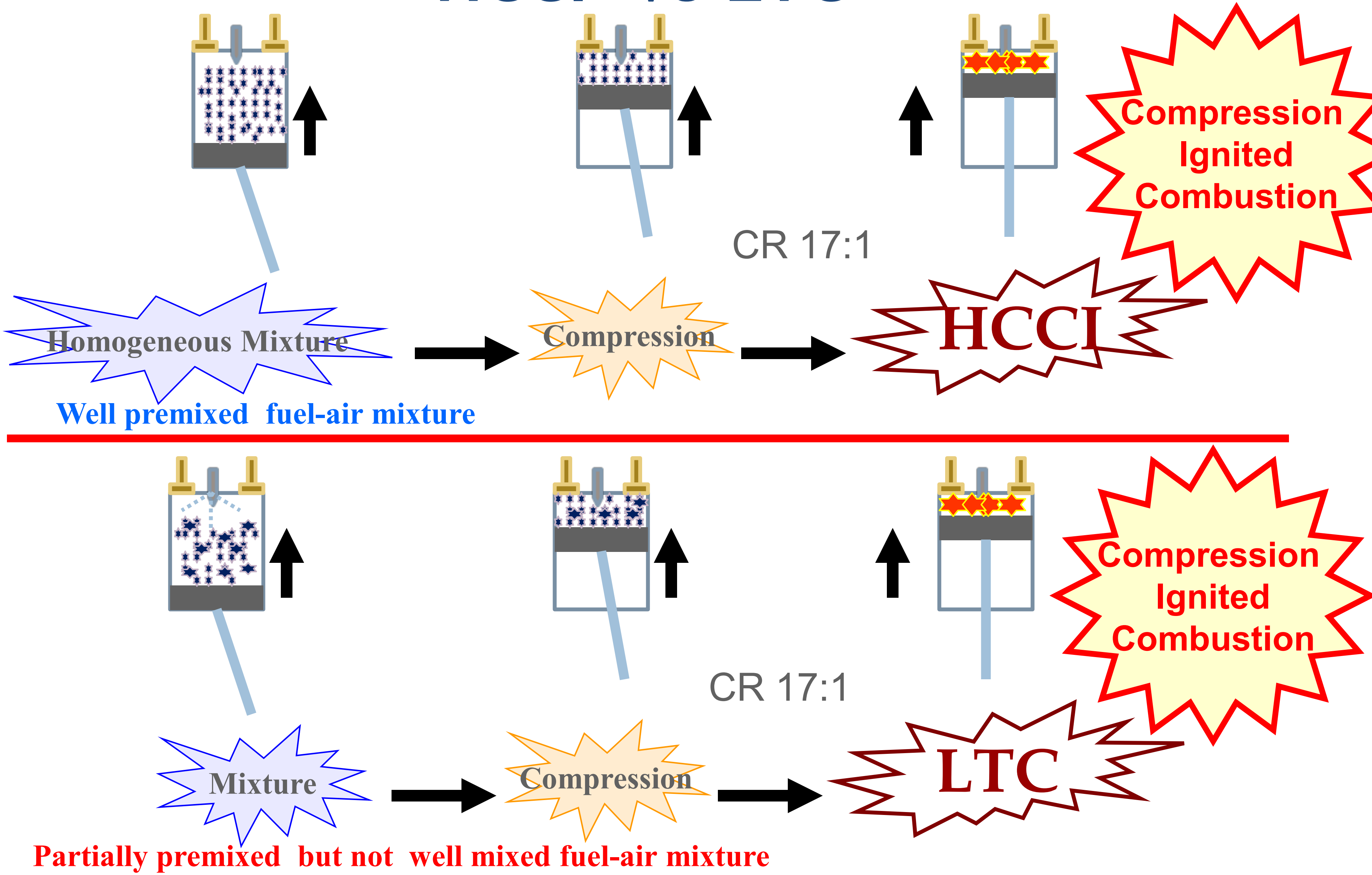
SI –Homogeneous Mixture, No soot ; HC,CO,(NO) –Emissions; Throttling losses



CI –Diffusion combustion, Fuel Efficient; High Smoke and NOx

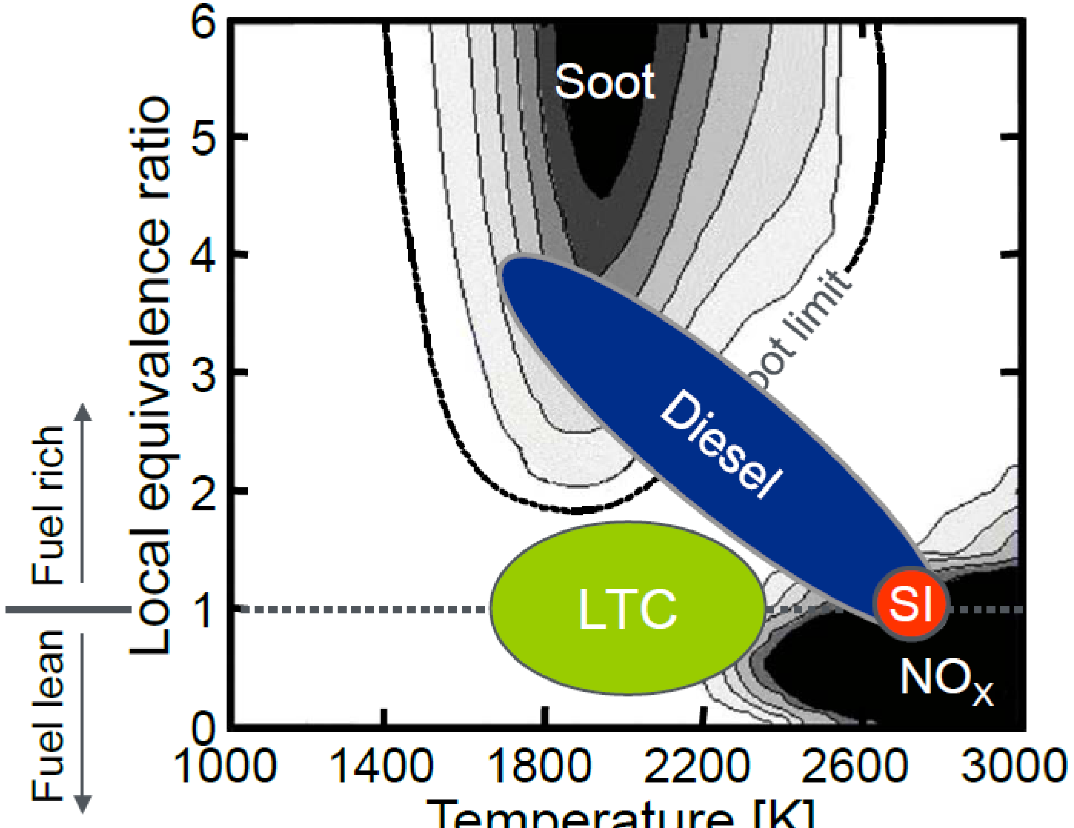


HCCI Vs LTC



Compression Ignited Combustion
CR 17:1
Homogeneous Mixture
Compression
HCCI
Well premixed fuel-air mixture
Compression Ignited Combustion
CR 17:1
Mixture
Compression
LTC
Partially premixed but not well mixed fuel-air mixture

Why is LTC an attractive solution to efficiency and emissions challenges?



Ref. SAE 2003-01-1789 , Takaaki Kitamura et.al

LTC Approach

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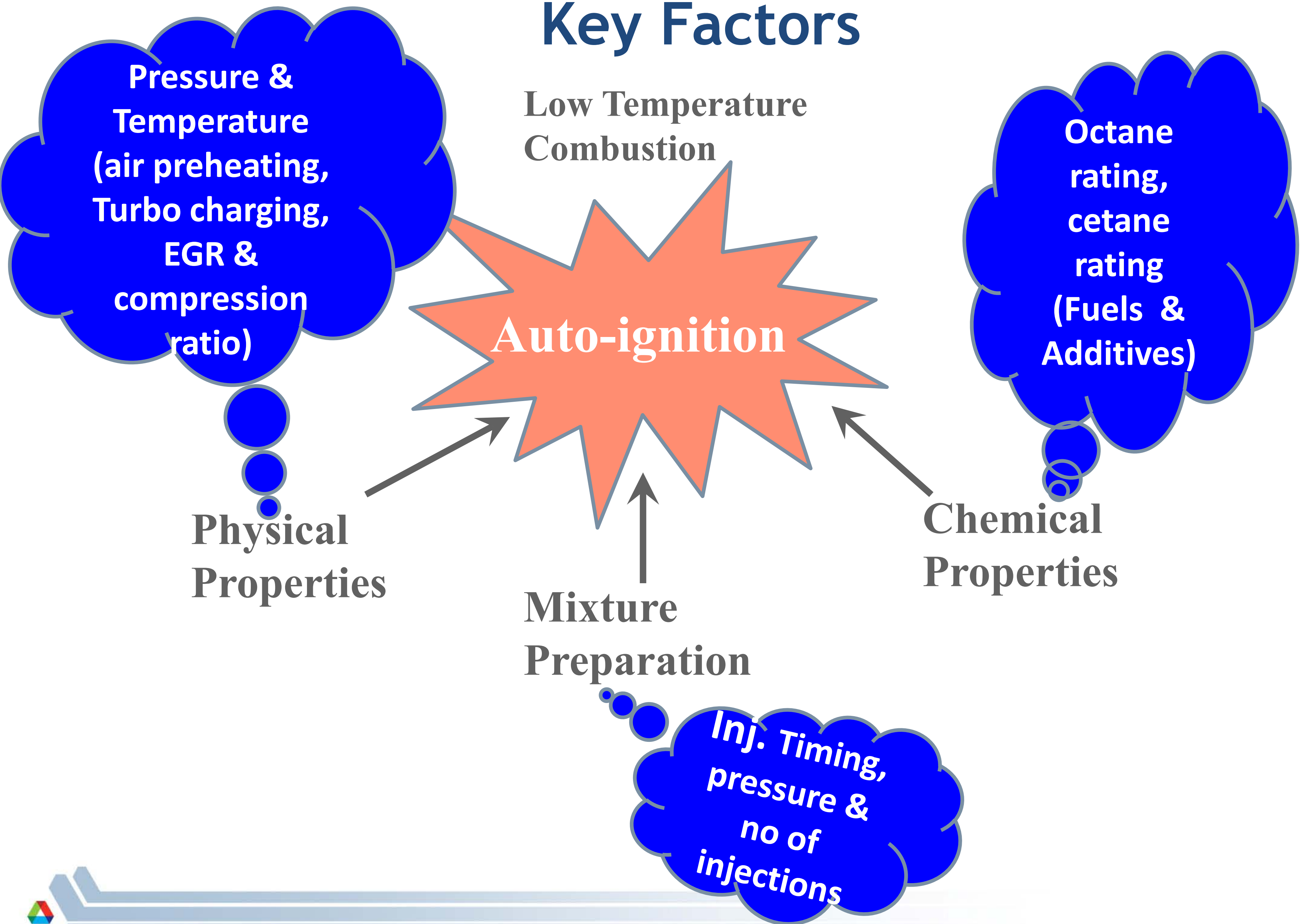
- **Lean Mixtures**
- **Fuel Flexibility**
- **Low NOx and Soot**

?

- **Mixture formation difficulties**
- **High HC and CO levels**
- **Combustion control Problems**

- This study explored the use of low octane/high volatility fuel
  - Increase ignition delay
  - Limit/eliminate wall and piston fuel wetting
- Gasoline-like fuels with low cetane/high volatility
- Lubricity additive to insure operation of diesel injection equipment
- Use fluid mechanics to control combustion phasing and engine load

Key Factors



Low Temperature Combustion
Pressure & Temperature (air preheating, Turbo charging, EGR & compression ratio)
Auto-ignition
Octane rating, cetane rating (Fuels & Additives)
Physical Properties
Mixture Preparation
Chemical Properties
Inj. Timing, pressure & no of injections

Engine Specifications and Tested Fuels properties

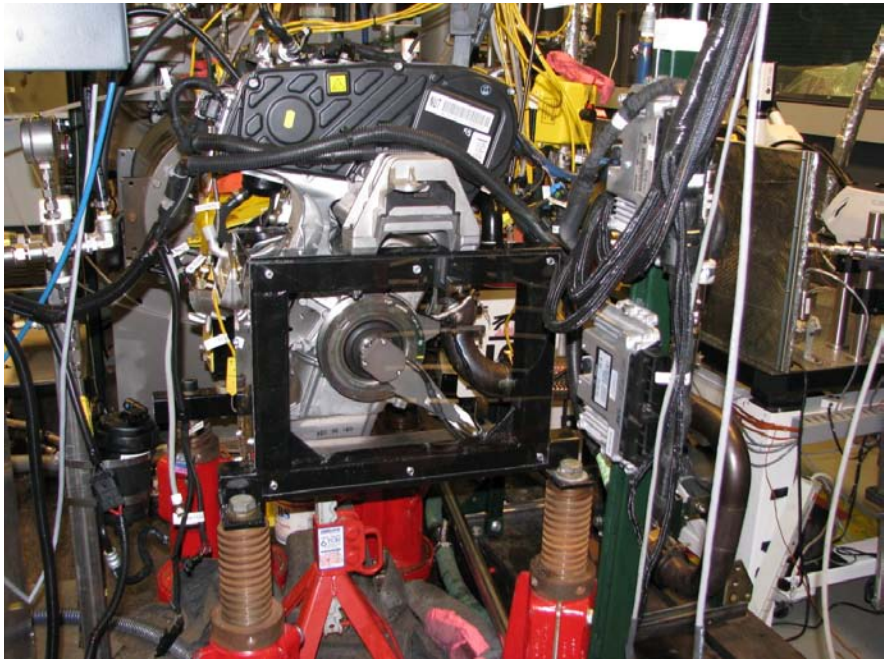
Engine Specifications

Compression ratio	17.8:1
Bore (mm)	82
Stroke (mm)	90.4
Connecting rod length (mm)	145.4
Number of valves	4
Injector	7 holes, 0.15-mm diameter

G.M 1.9 L; 110 kW @ 4500 rpm - designed to run #2 diesel ; Bosch II nd generation common rail injection system

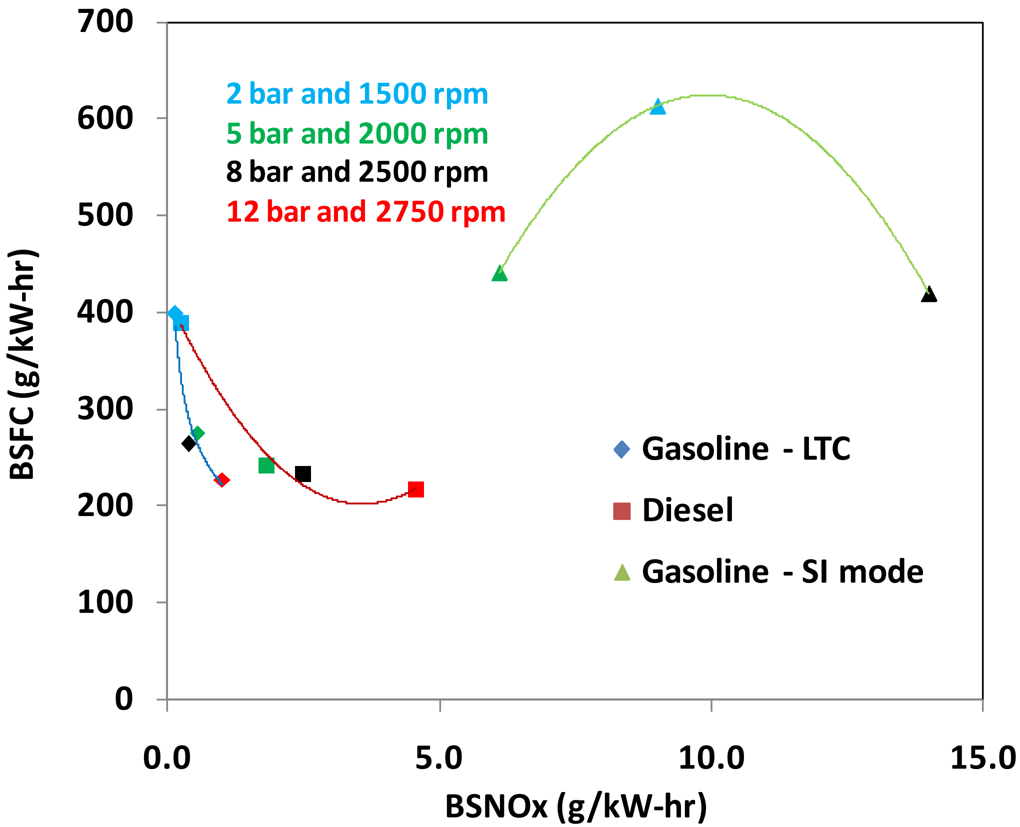
Properties of the Two Tested Fuels

Property	#2 diesel	Low-octane gasoline
Specific gravity	0.8452	0.7512
Low heating value (MJ/kg)	42.9	42.5
Initial boiling point (°C)	180	86.8
T10 (°C)	204	137.8
T50 (°C)	255	197.8
T90 (°C)	316	225.1
Cetane Index	46.2	25.0



Experimental Setup

Effect on BSFC and BSNOx emissions



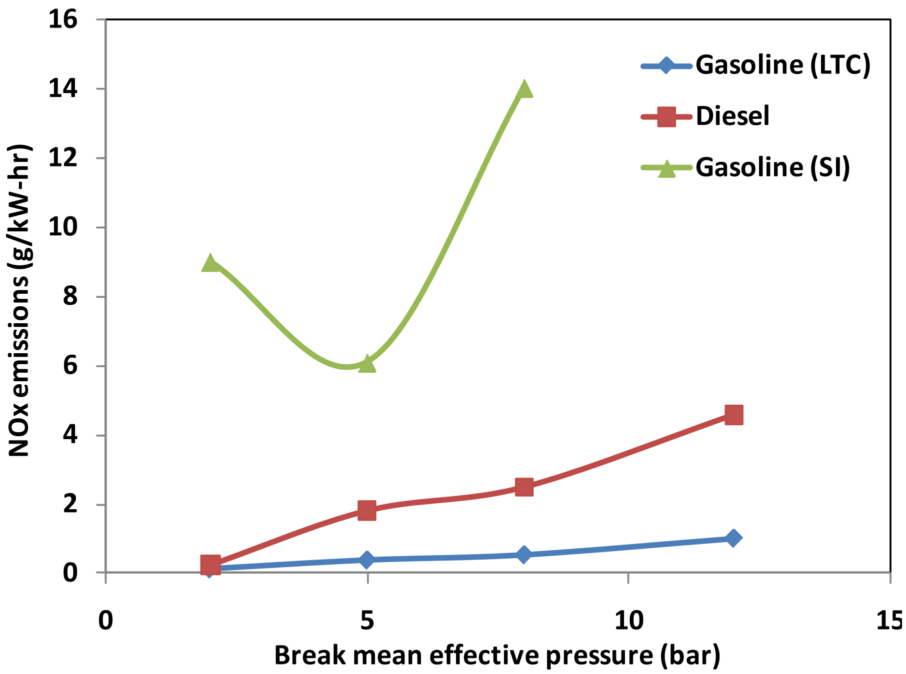
Color of the trend line reads the fuel (green – gasoline, red – diesel & blue - LTC)

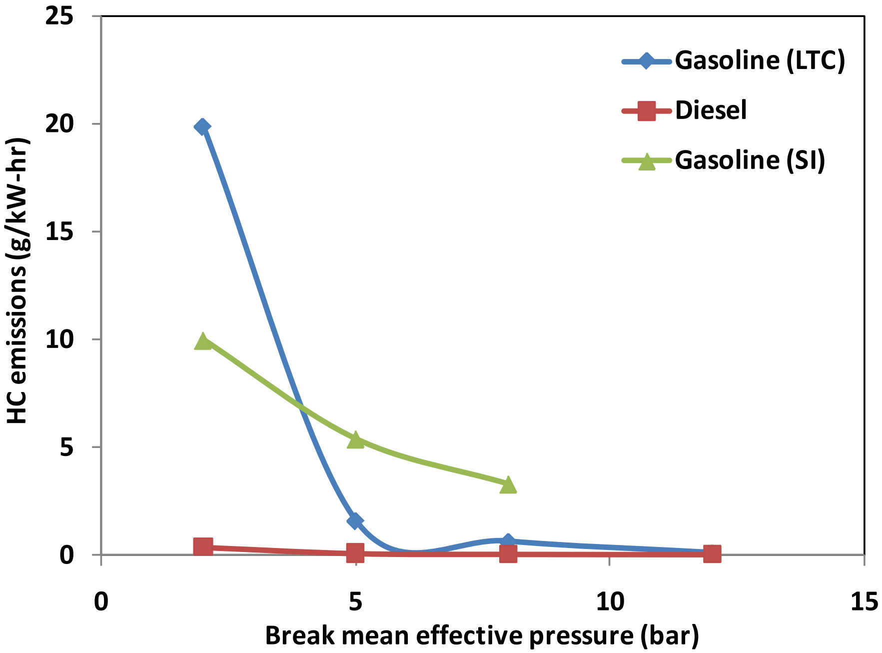
Color of the marker reads the operating condition (blue – 2 bar, green – 5 bar, black – 8 bar & red – 12 bar)

Standard gasoline operation in SI mode was referred from

Thomas Wallner, Scott A. Miers and Steve McConnell, A Comparison of Ethanol and Butanol as Oxygenates Using a Direct-Injection, Spark-Ignition Engine, 2008 ASME Spring Technical Conference ICES2008, 2008

Emissions behavior (NOx and HC)





Split Injection Strategies in LTC gasoline operation

FIRST STRATEGY (GAS-I):
First Injection - (-40°CA to -140°CA) (Partially premixed charge was prepared through this first injection)

Second injection - (0°CA) around TDC (heat release rate was maintained through this second injection)
Injection pressure - 600 bar to 900 bar (high injection pressures at higher load conditions)

SECOND STRATEGY (GAS-II):
An equal split of two early injections were employed.

First injection - (-70°CA) ; Second injection - (-25°CA).
Injection pressure - 600 bar.

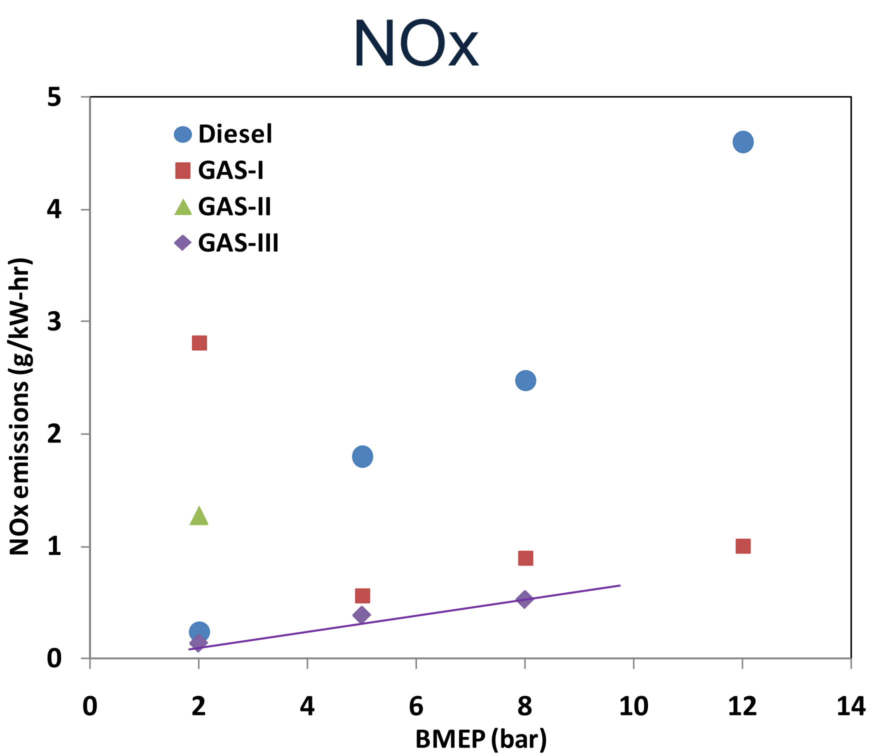
This strategy had issues of severe knocking and hunting at 5, 8 and 12 bar BMEP conditions.

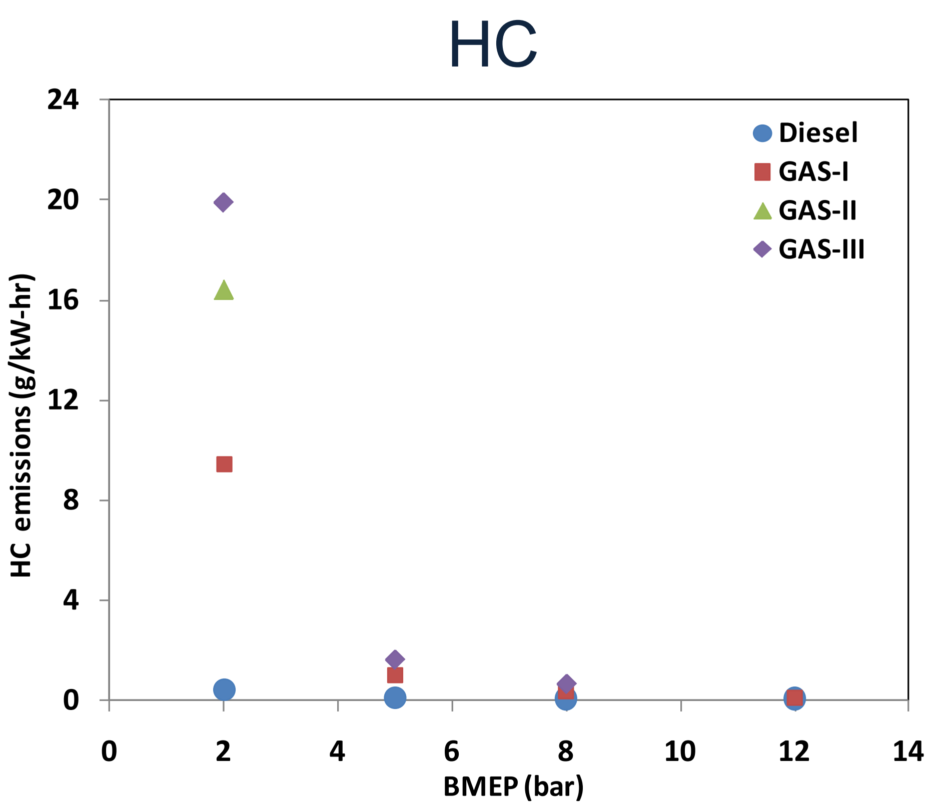
THIRD STRATEGY (GAS-III):
This strategy was nothing but a refinement of the first strategy.

Very early single injection scheme (- 95°CA) – 2 bar BMEP

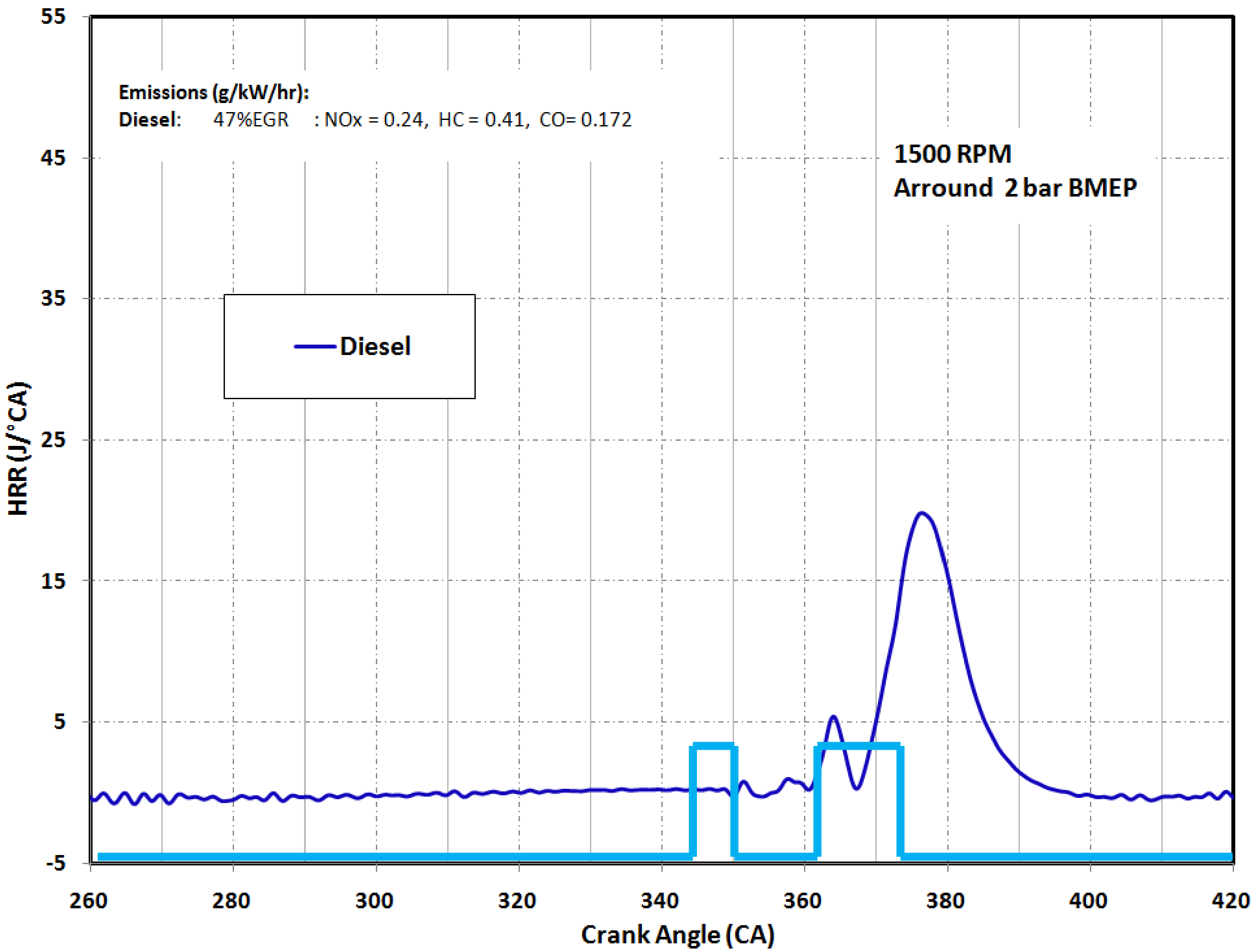
Equal split of an early injection and a main injection scheme - 5 bar and 8 bar BMEP conditions
Early injection - (- 60°CA to -80°CA) ; Main injection – Closely after TDC.
Injection pressure - 600 bar

LTC Split Injection Strategies - Emissions





Gasoline in LTC mode 1500 RPM and 2 bar BMEP



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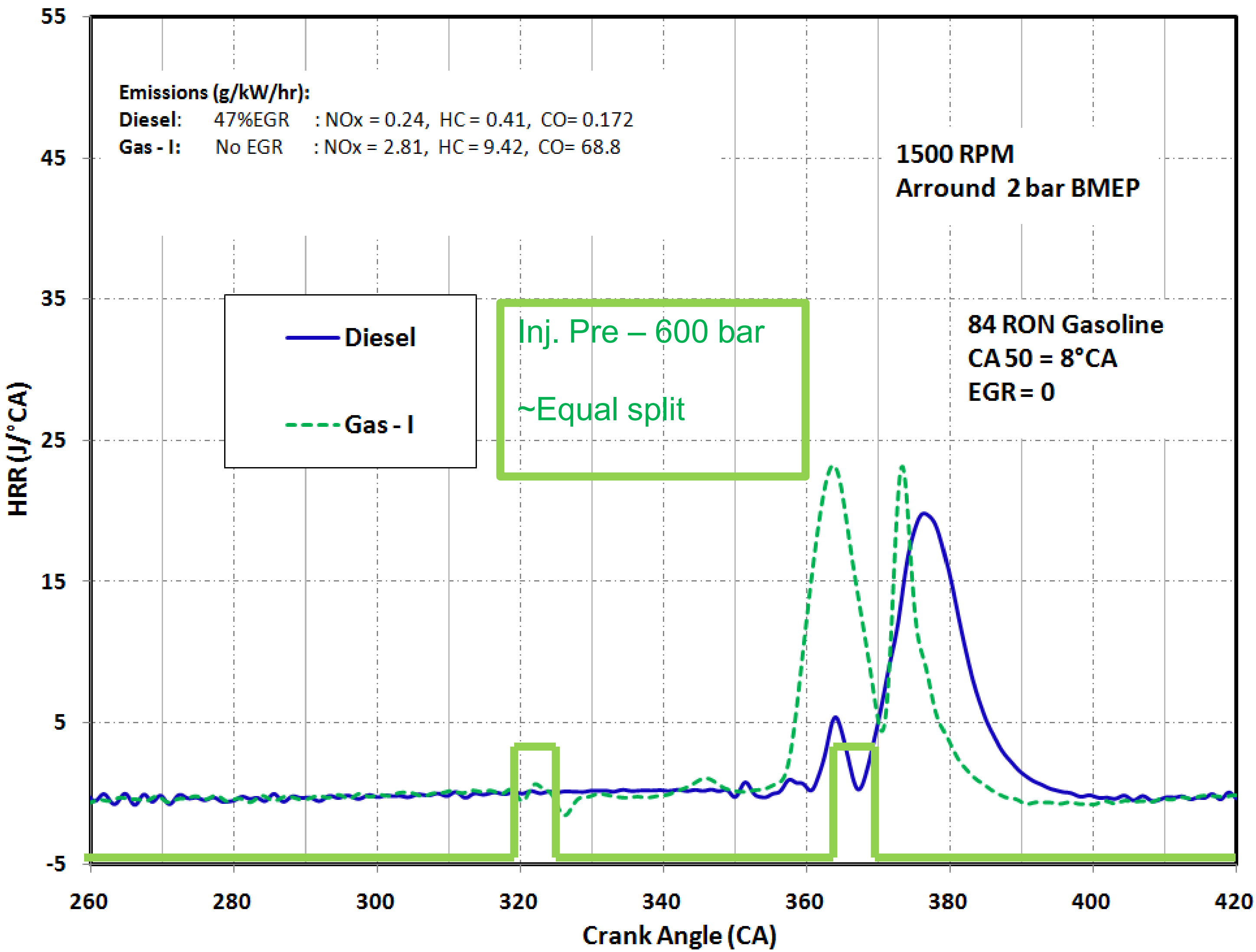

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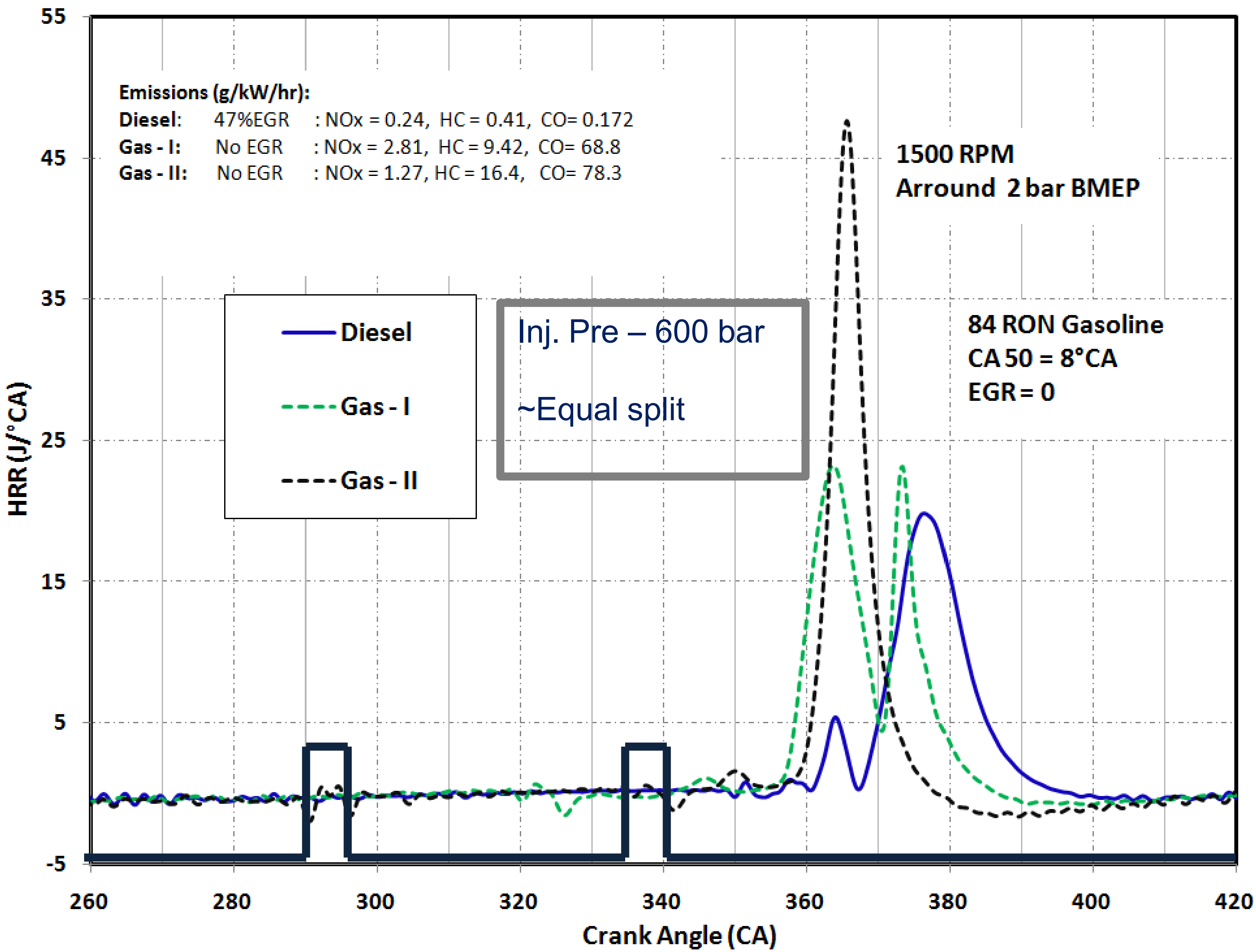

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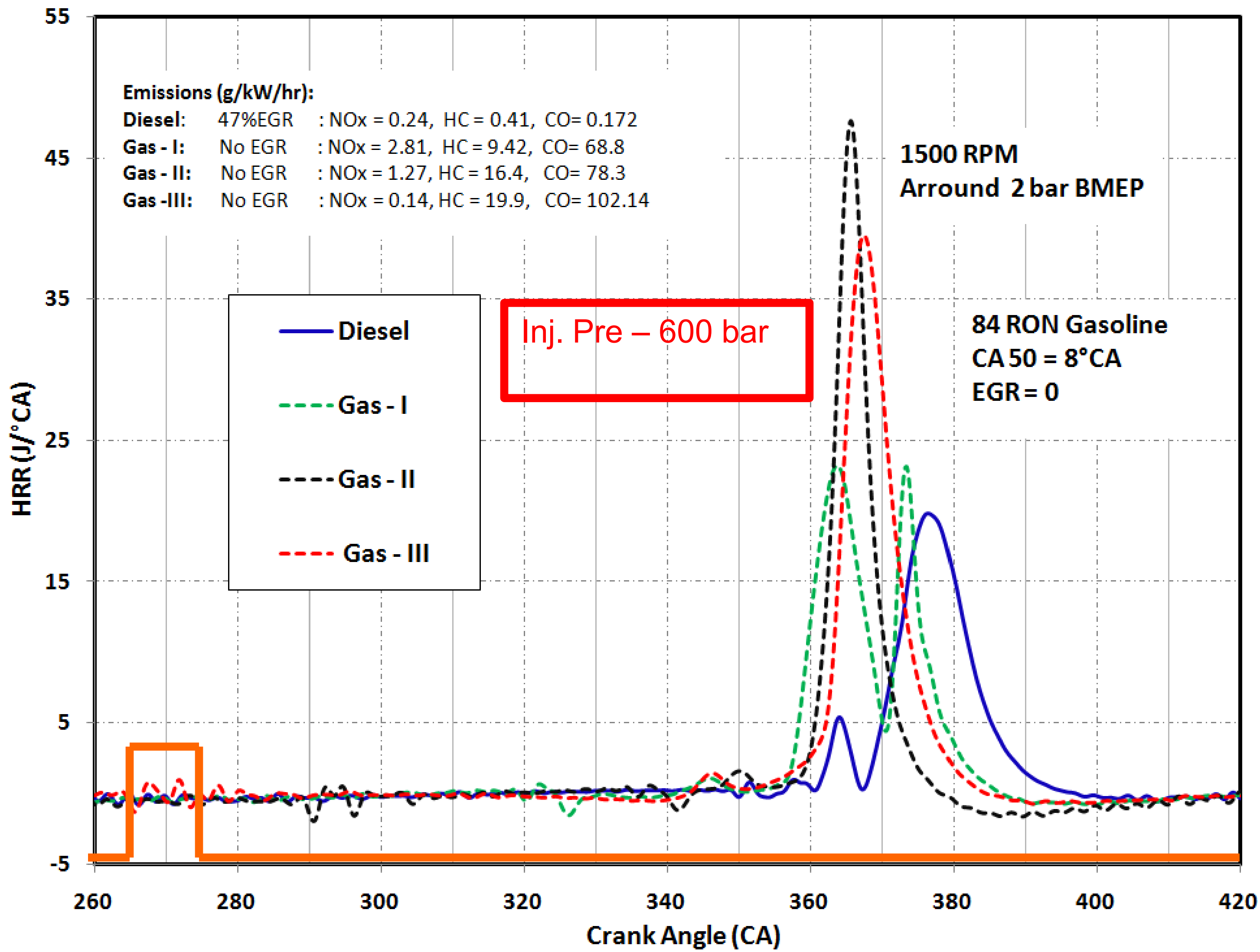
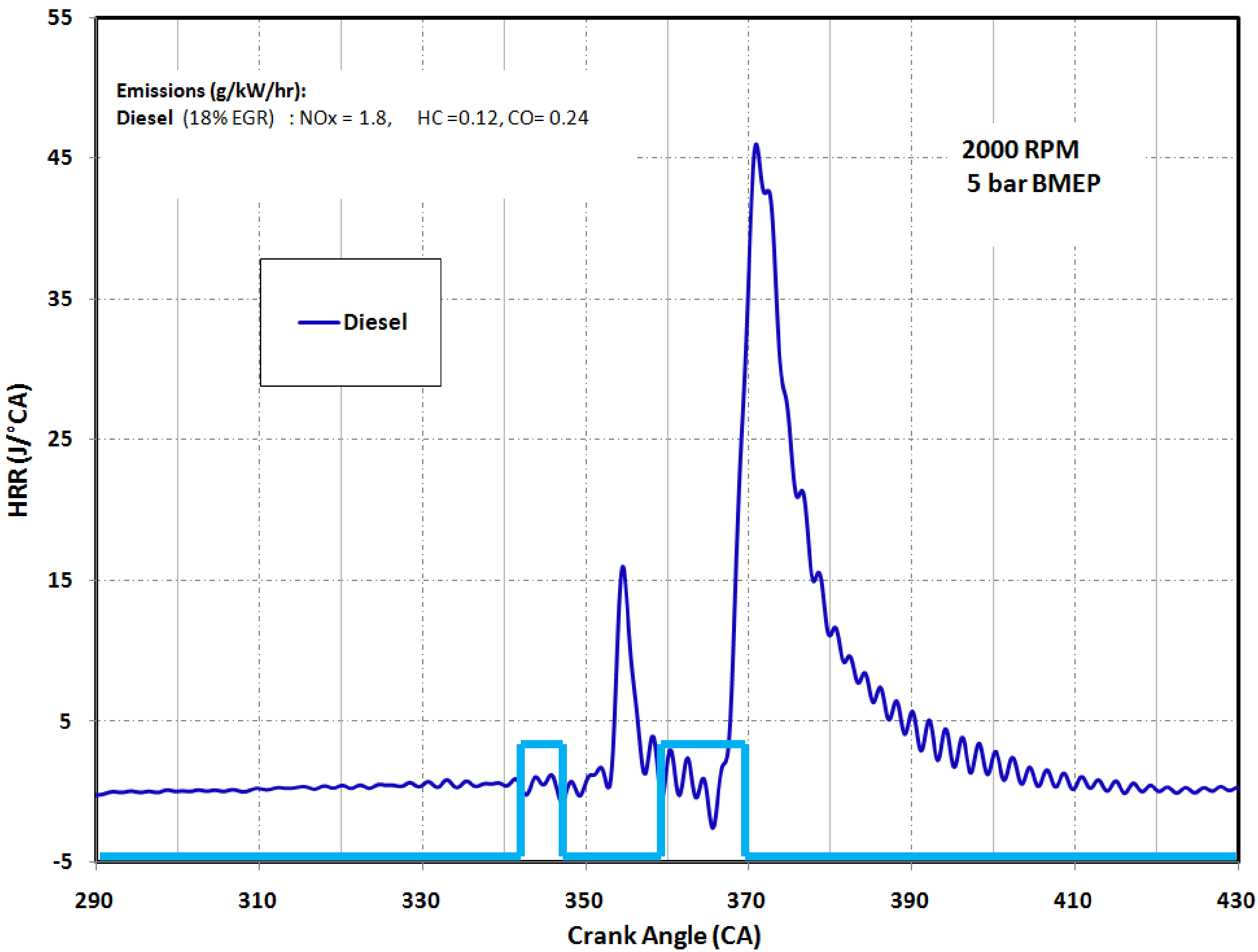


Highest EGR level achieved with stable combustion (COV<5%) @ 2000 RPM and 5 bar BMEP



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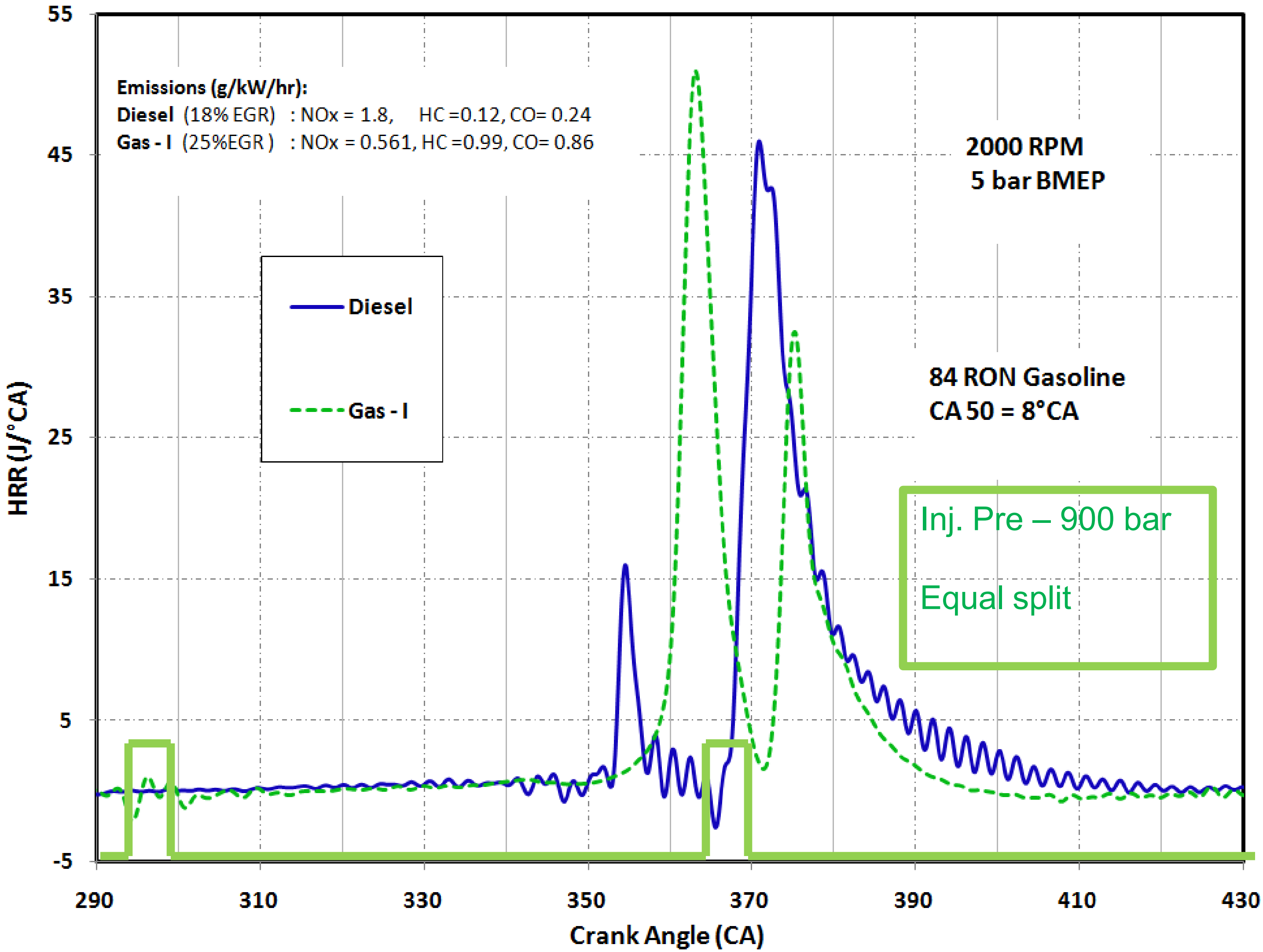

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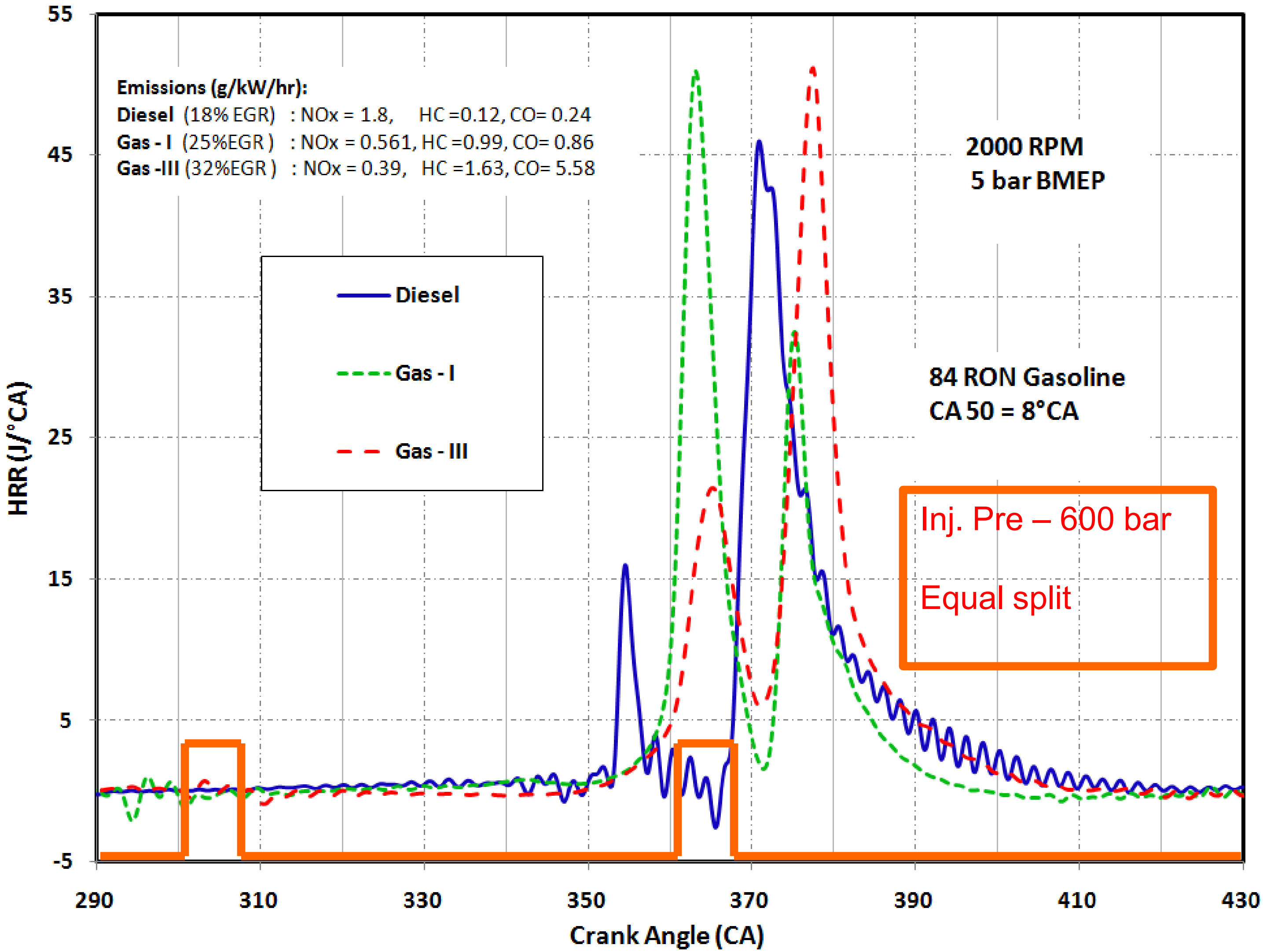
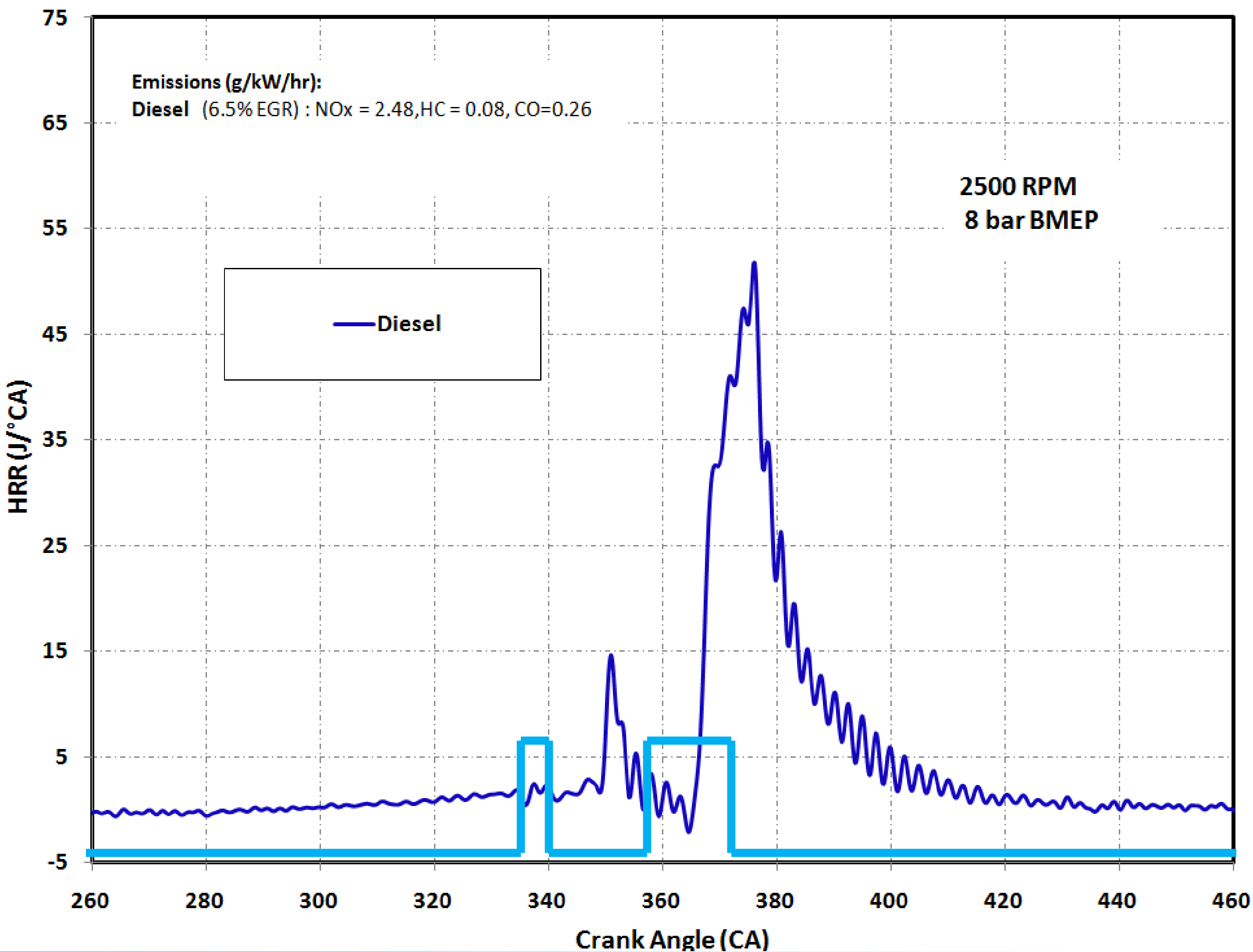


Higher speed/load conditions – 2500 RPM and 8 bar BMEP



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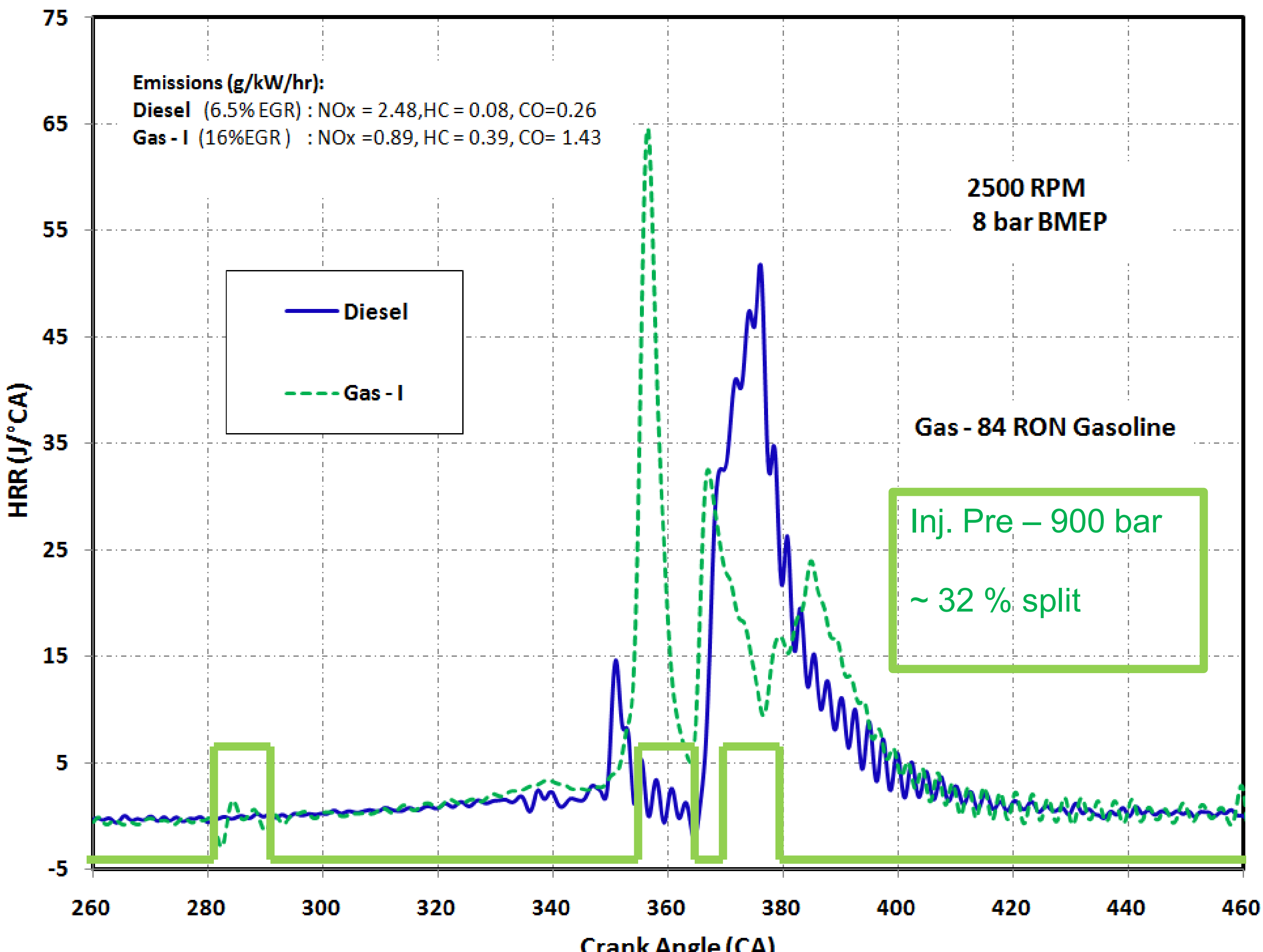

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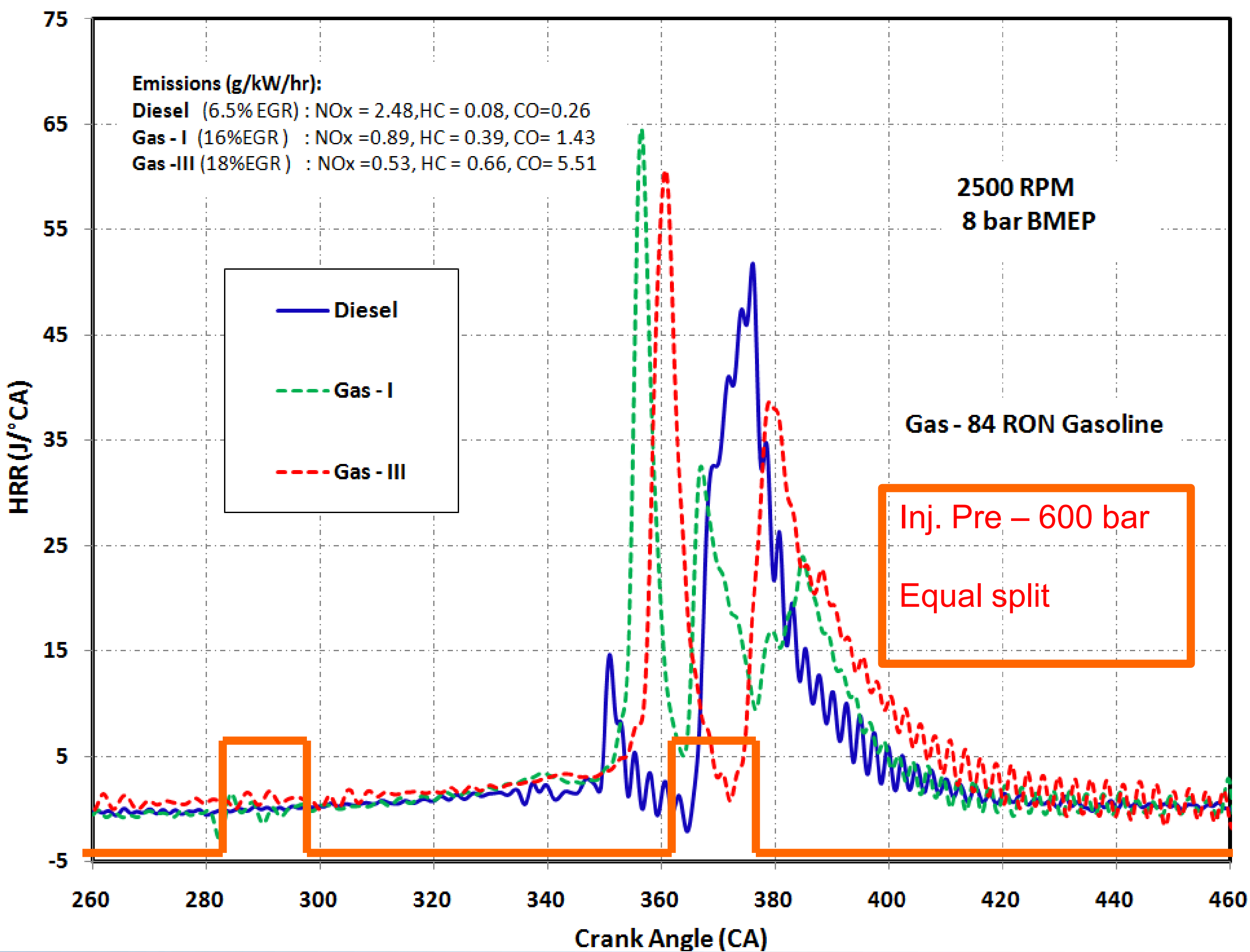
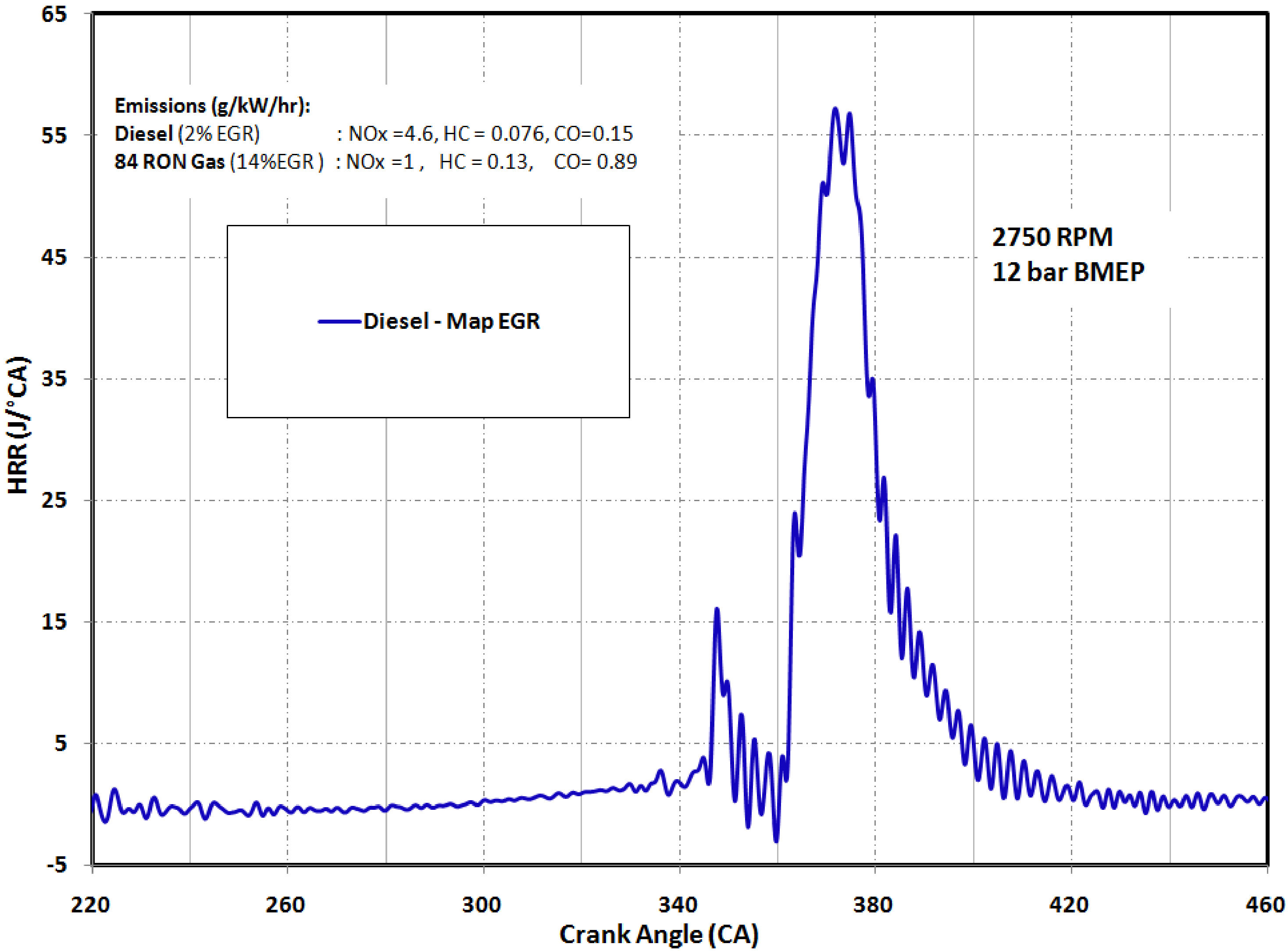


2750 RPM and 12 bar BMEP - significant reductions in NOx with very low HC penalty



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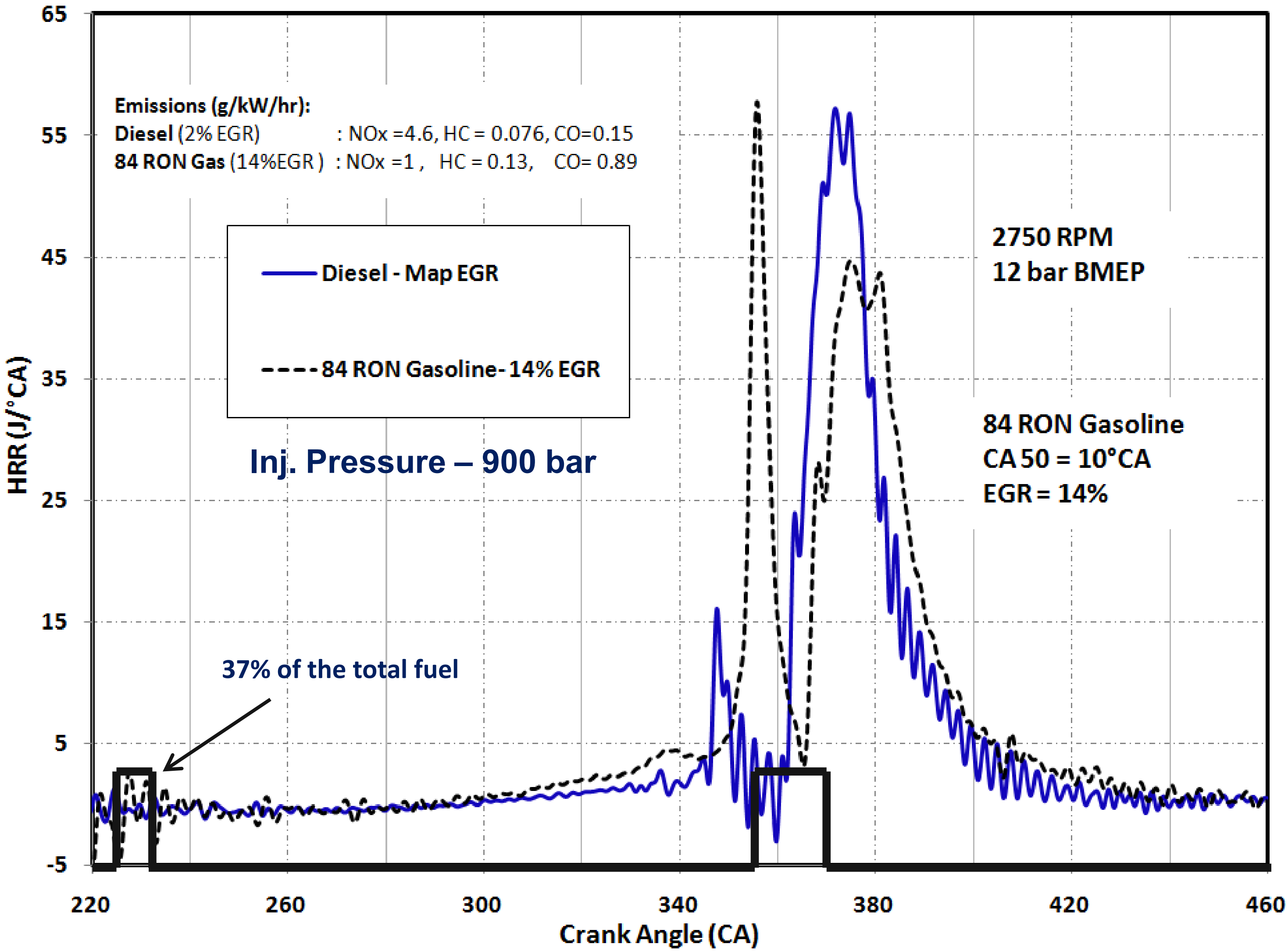


Design of Experiments Study

Design of experiment (D.O.E) matrix

Exp No	EGR	Boost	Injection Pressure
1	(-)	(-)	(-)
2	(+)	(-)	(-)
3	(-)	(+)	(-)
4	(+)	(+)	(-)
5	(-)	(-)	(+)
6	(+)	(-)	(+)
7	(-)	(+)	(+)
8	(+)	(+)	(+)

***Yates Algorithm was used**

George E.P Box, William G Hunter and J. Stuart Hunter, Statistics For Experimeners- An Introduction to Design, Data Analysis and Model Building, John Wiley & Sons, Inc, USA.

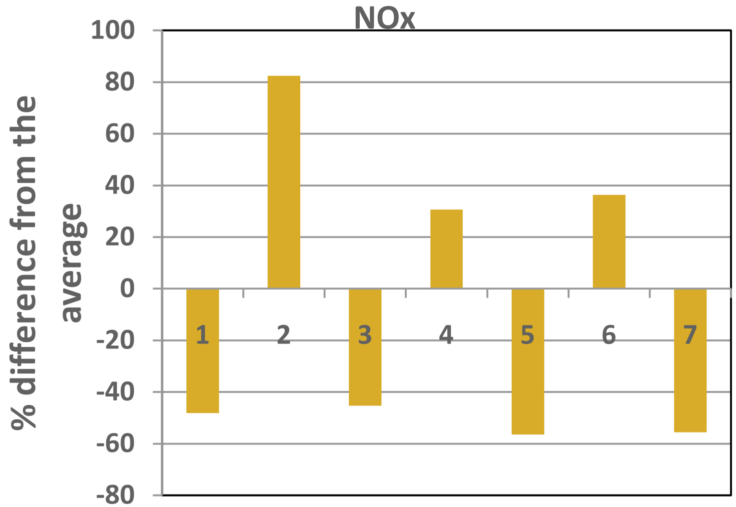
D.O.E matrix parameter values at 8 bar BMEP

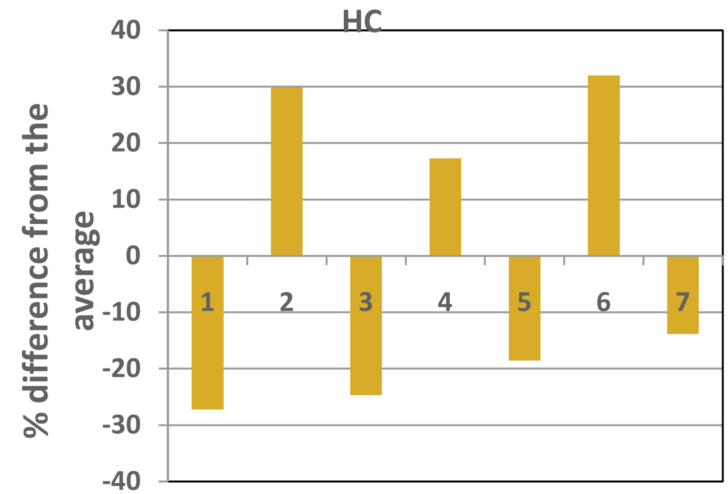
	EGR (%)	Boost (bar)	Injection Pressure (bar)
(+)	21	0.7	1000
(-)	13	0.5	500

Average values from DOE analysis at a BMEP of 8 bar

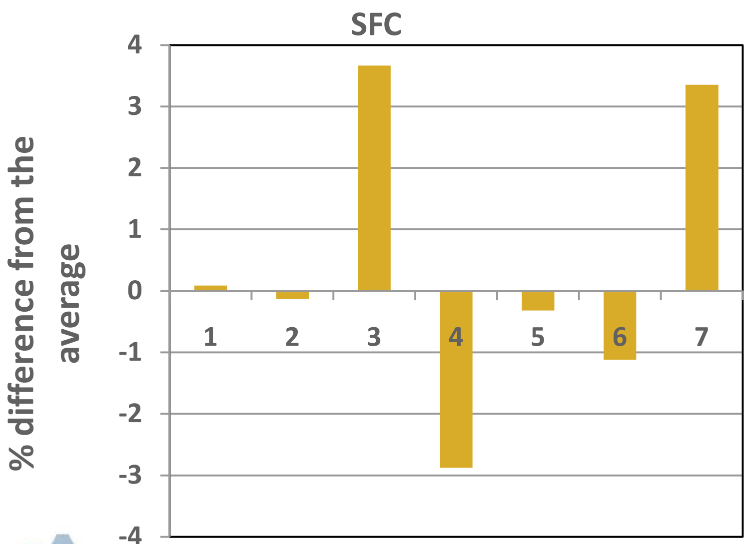
NOx g/kW-hr	HC g/kW-hr	CO g/kW-hr	SFC g/kW/hr	Noise db	COV of IMEP
1.51	1.26	5.36	238.7	93.5	1.3

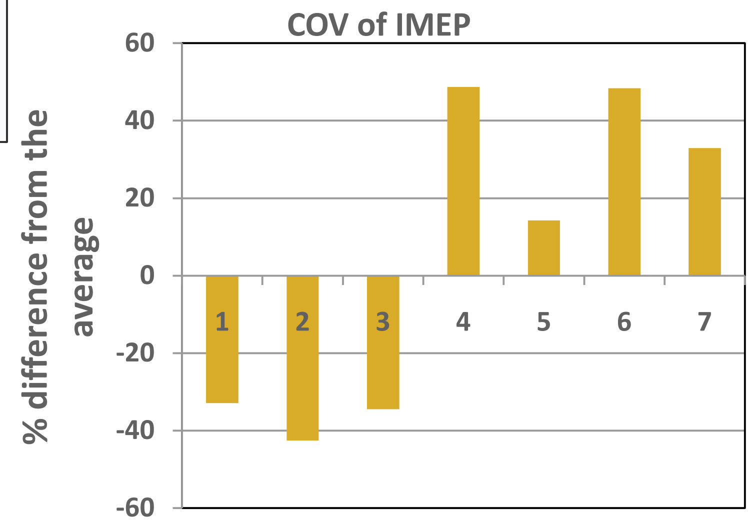
Design of Experiments Study done @ 2500 RPM - 8 bar BMEP with EGR, P_inj and Boost as controls





1 - EGR
2-Boost
3-EGR&Boost
4- Inj. Pressure
5-EGR & Inj. Pressure
6-Boost & Inj. Pressure
7-EGR,Boost&Inj.Pre





Conclusions

- Power density needs are addressed in gasoline LTC operation - SOC is controlled by means of proper split injection strategy.
- Higher HC emissions than conventional diesel mode, but lower than well-premixed (HCCI)conditions
- Combination of low-octane fuel with proper fuel distribution and EGR is required to dictate this partially premixed LTC combustion
- NOx Emissions were reduced through the following injection schemes at different loads.
  - **2 bar BMEP – Single early injection (95°CA bTDC).**
  - **5 bar BMEP – Early(60°CA bTDC) and main at 2°CA aTDC**
  - **8 bar BMEP – Early(75°CA bTDC) and main at 2°CA aTDC**
  - **12 bar BMEP - Early(135°CA bTDC) and main at 2°CA bTDC**
- The operating window is limited by the self-ignition quality of the fuel as well as compression ratio of the engine, so low-octane fuels with lower compression ratios could provide a reasonable solution.
- High EGR and high injection pressure with low boost pressure would be the optimum for emissions, fuel efficiency and COV of IMEP

Thank you

BMEP (bar)	LTC Gasoline EGR rates (%)	Conventional Diesel EGR rates (%)
2	0	47
5	32	18
8	18	6.5
12	14	2

Combustion parameters

BMEP (bar)	Peak Pressure (bar)		peak Pressure location (CA)		Max. Rate of Pressure Rise (MRPR) bar		MRPR Location (CA)	
	Diesel	Gas	Diesel	Gas	Diesel	Gas	Diesel	Gas
2	31.1	49.3	365	364	1.0	1.6	348	354
2 *	-	51.8	-	367	-	3.2	-	365
2**	-	62.6	-	370	-	3.5	-	367
5	48.5	58.1	373	367	2.3	2.5	357	363
5**	-	63.1	-	367	-	2.1	-	361
8	54.4	81.5	368	363	2.4	3.5	351	357
8**	-	94.1	-	363	-	5.7	-	359
12	80.0	84.7	374	362	3.1	4.9	347	355

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	Diesel	Gas	Diesel	Gas	Diesel	Gas	Diesel	Gas
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2**	-	62.6	-	370	-	3.5	-	367
5	48.5	58.1	373	367	2.3	2.5	357	363
5**	-	63.1	-	367	-	2.1	-	361
8	54.4	81.5	368	363	2.4	3.5	351	357
8**	-	94.1	-	363	-	5.7	-	359
12	80.0	84.7	374	362	3.1	4.9	347	355