DUAL-FUEL HCCI ENGINE EXPERIMENTS WITH PRIMARY REFERENCE FUELS

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Outline

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- Dual-fuel effects
- Intake temperature effects
- Summary

Introduction

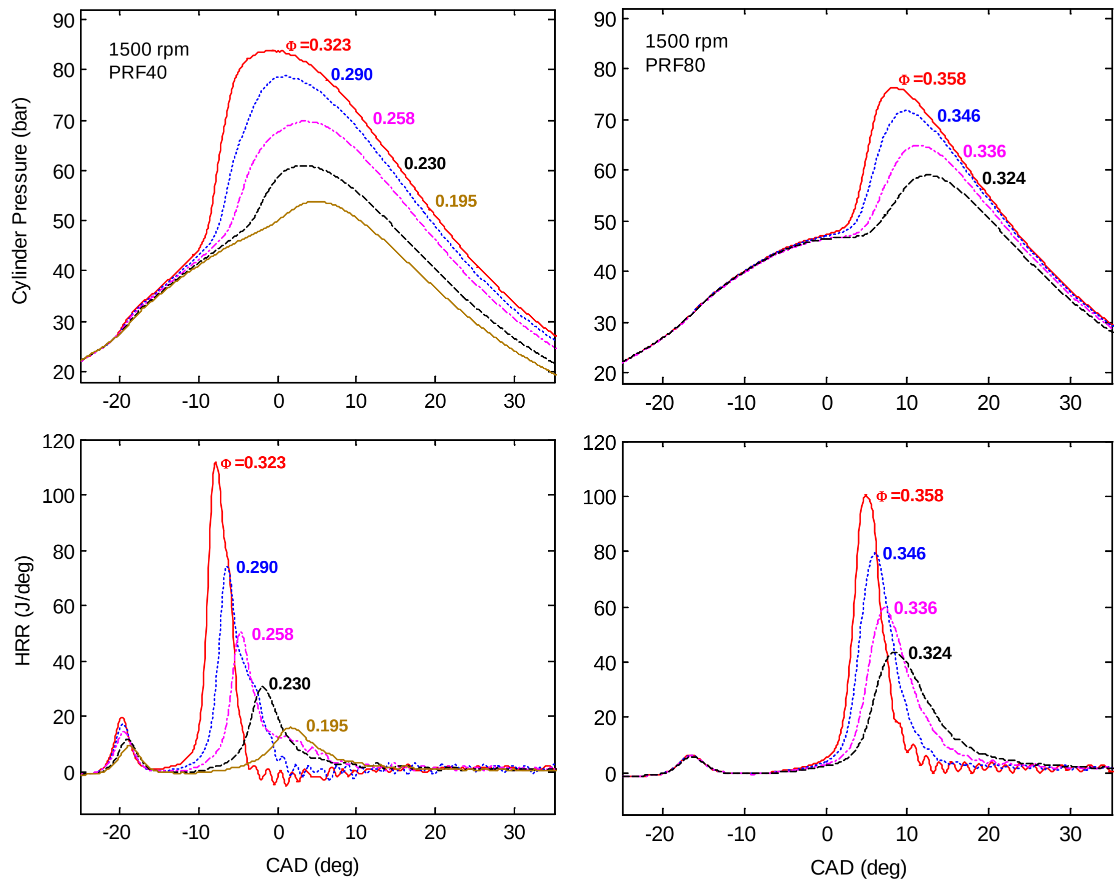
- Examine effects of fuel reactivity on HCCI operating limits, and overall feasibility of the dual-approach for extending HCCI operating range
- Intake air temperature effects on engine operation stability and lower load limit, and feasibility of combining intake air heating with dual-fuel approach

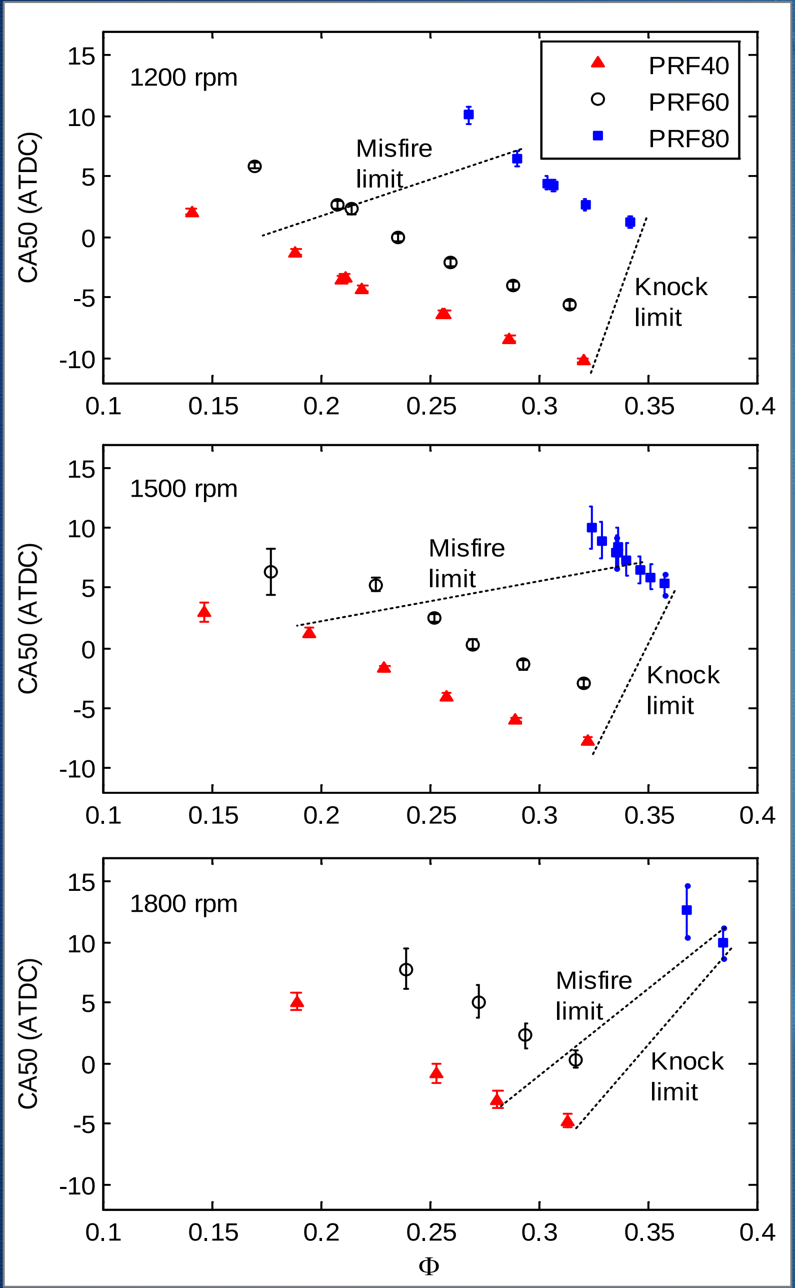
Experimental Detail

- Single-cylinder engine – 0.5 L PFI –
- PRF (iso-octane and n-heptane) fuels of 40, 60, 80 ON
- Intake pressure and back pressure fixed at 1.5 bar abs.
- Two intake temperatures - 75˚C and 90˚C
- Three different speeds, 1200, 1500 and 1800 RPM
- Different equivalence ratios
- Pressure data for 300 consecutive cycles
- Emissions – averaged over 60 s at 0.1s interval

Pressure Trace and Heat Release

- Heat release curves of PRF40 exhibit two-stage ignition characteristics
- First-stage heat release becomes weaker as the iso-octane ratio increases
- Load range becomes narrower and sensitivity of pressure history to equivalence ratio becomes stronger as iso-octane ratio increases



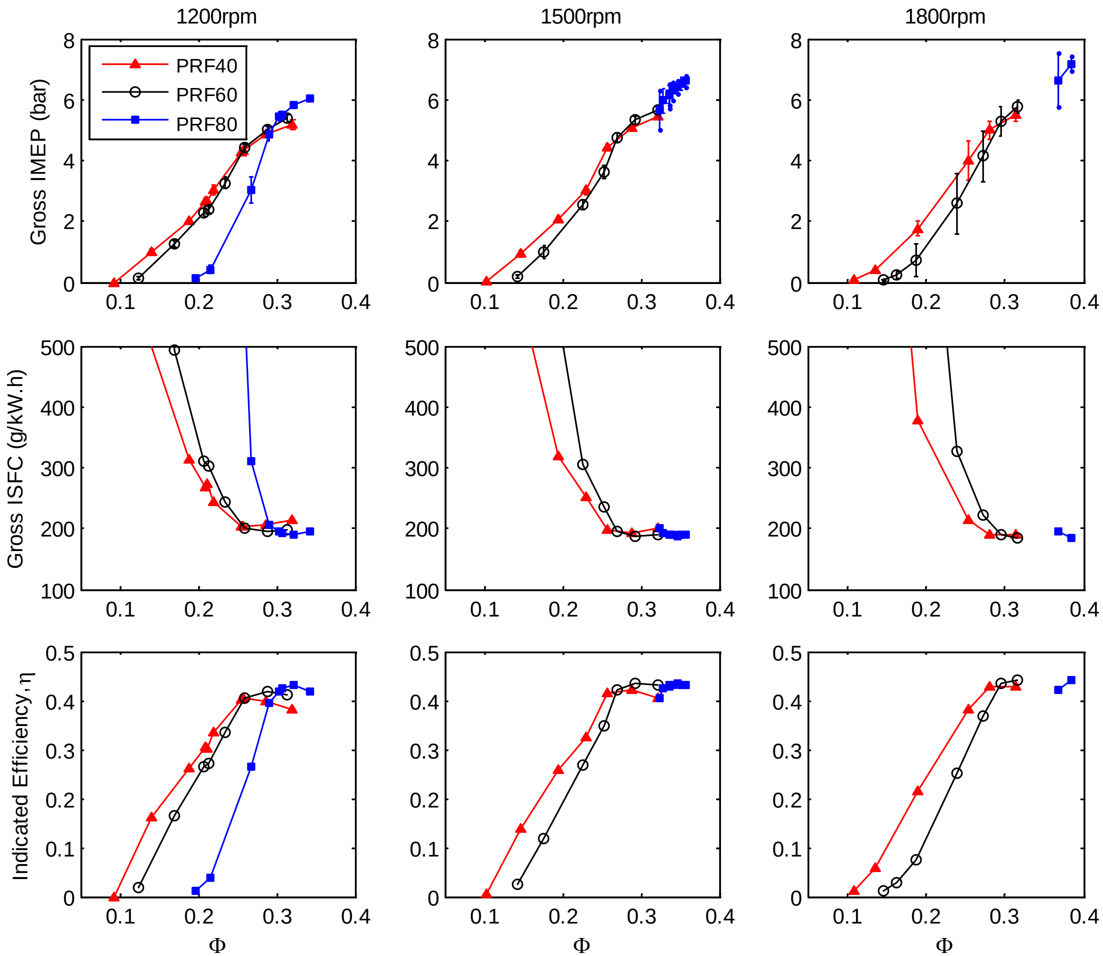


Combustion Phasing

- Misfire and knock limits are set following the definitions of HLL (7 MPa/ms) and LLL (5.0% IMEP COV)
- Combustion phasing advances (almost linearly) with increasing load until reaching the knock limit – Not constant
- The operating window becomes narrower with increasing speed

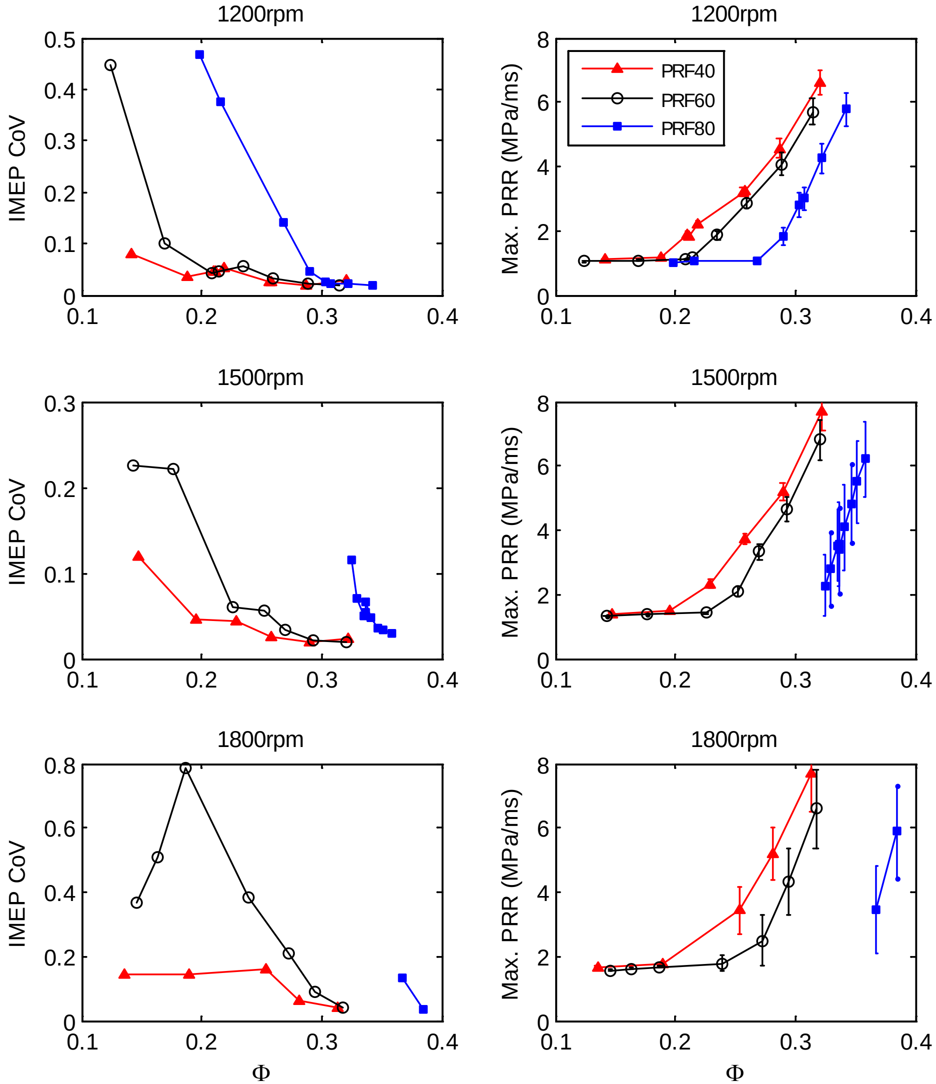
Effects on Load Range and Efficiency

- Decreasing fuel reactivity expands upper load limit and the plateau where ISFC is low and indicated efficiency is high
- This effect becomes more noticeable as engine speed increases
- Maximum IMEPg of 7.2 bar, maximum indicated efficiency of 44%, and minimum ISFCg of 185.5 g/kW.h are obtained with PRF80 at 1800 RPM



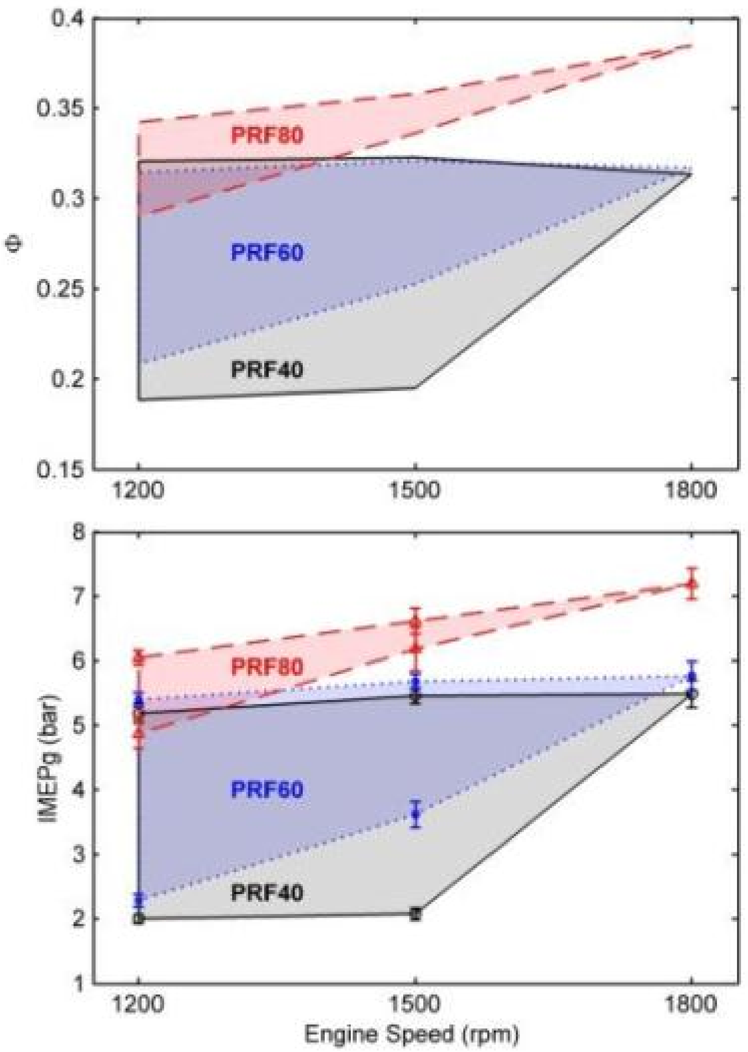
High and Low Load Limits

- Increasing fuel reactivity increases engine stability at low load but makes the engine more susceptible to knock at higher loads
- Boundaries of efficiency plateau generally correspond to MPRR of aprox. 7 MPa/ms on high load side and 3.5% IMEP COV in low load side
- Variations in MPRR increase sharply with increasing speed



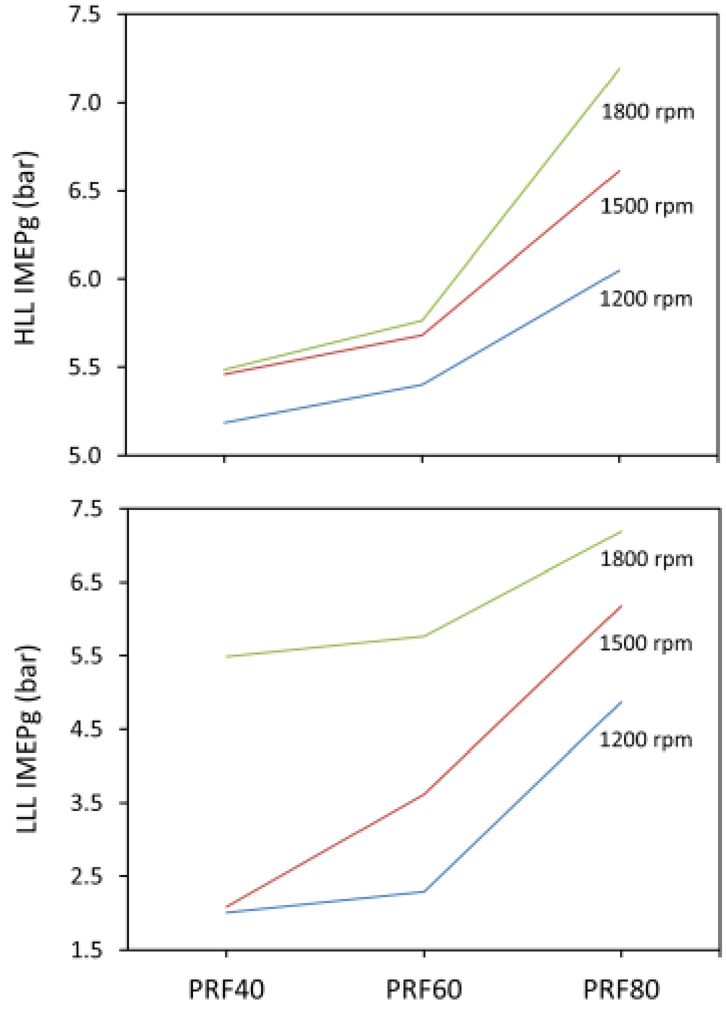
Operating Envelopes for Different Fuels

- Clear potential for variable reactivity approach
- Operating envelopes shrink with decreasing fuel reactivity and increasing engine speed
- More reactive fuels allow engine to operate with leaner mixtures
- Fuel effects are not linear with octane number



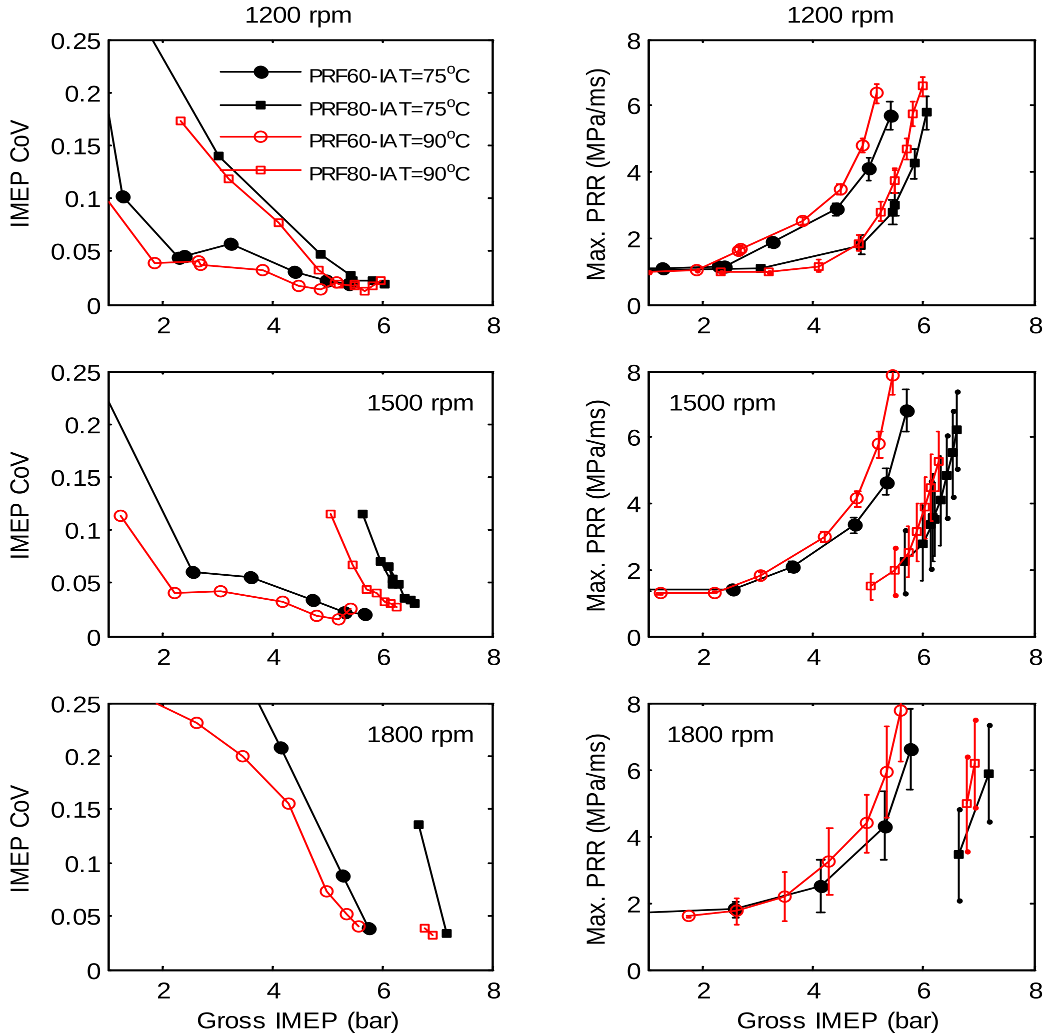
Fuel Effects on Operating Limits

- LLL and HLL are less sensitive to changes in octane rating between 40 and 60 than between 60 and 80
- This means that decreasing fuel reactivity below certain limit does not help in controlling load or extending LLL
- This nonlinear effect necessitates use of other combustion control means to complement dual fuel approach during low load operation



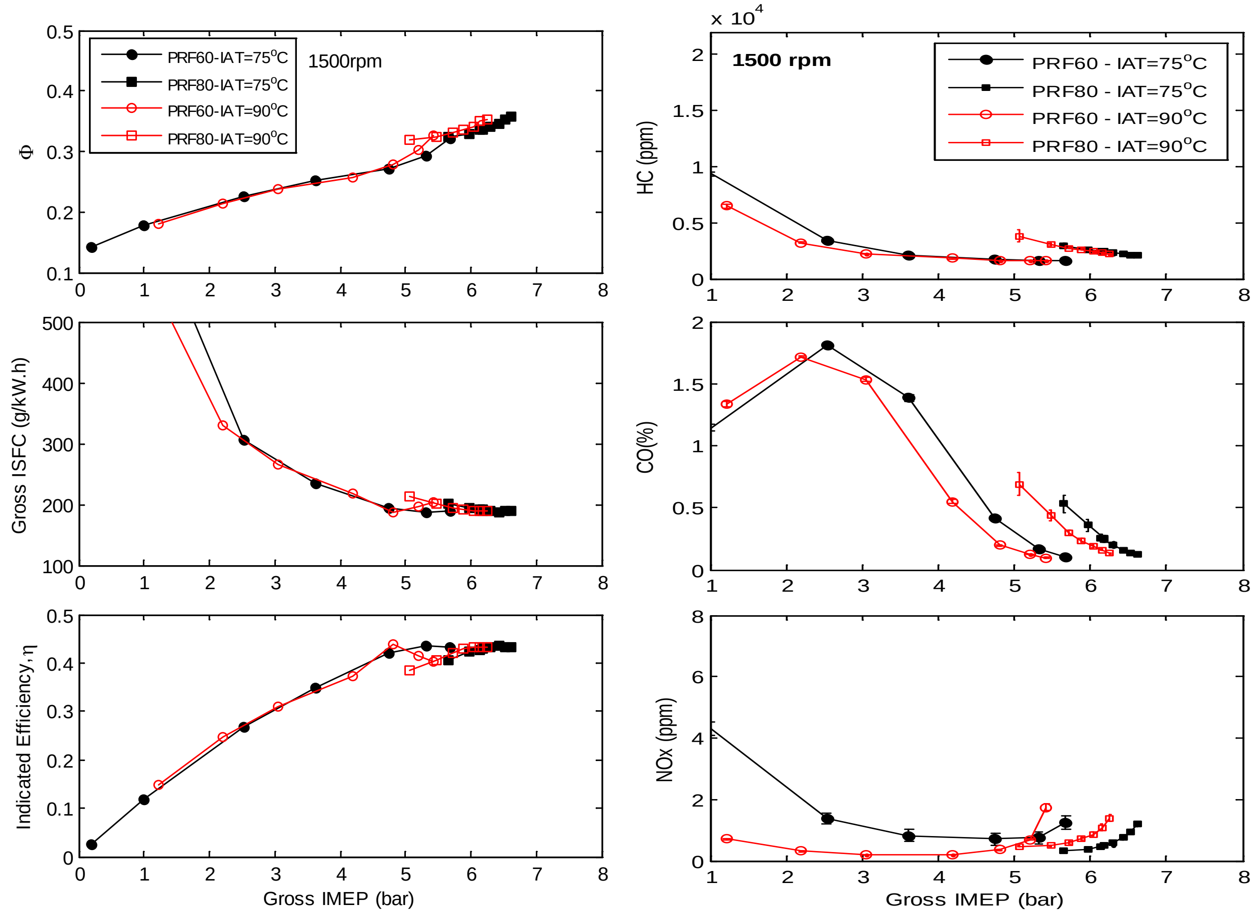
Intake Temperature Effects

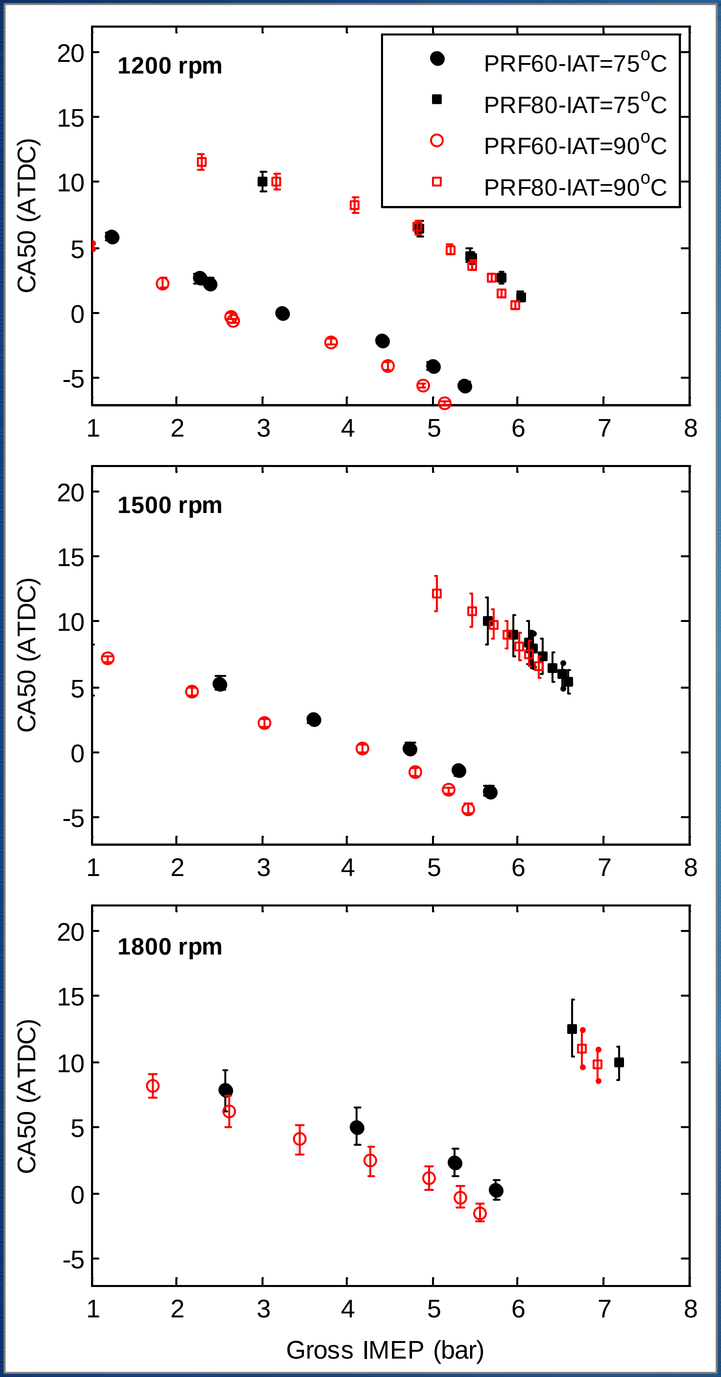
- Increasing intake temperature improved the engine operating stability at low and intermediate load but increased pressure rise rate at high load.
- Operating envelope shifts at each speed to lower load side and operation becomes more stable in general



Intake Temperature Effects

- Increasing intake temperature caused a slight decrease in efficiency at higher loads
- Increasing intake temperature resulted in consistent reduction in CO emissions
- HC emissions decreased at low load





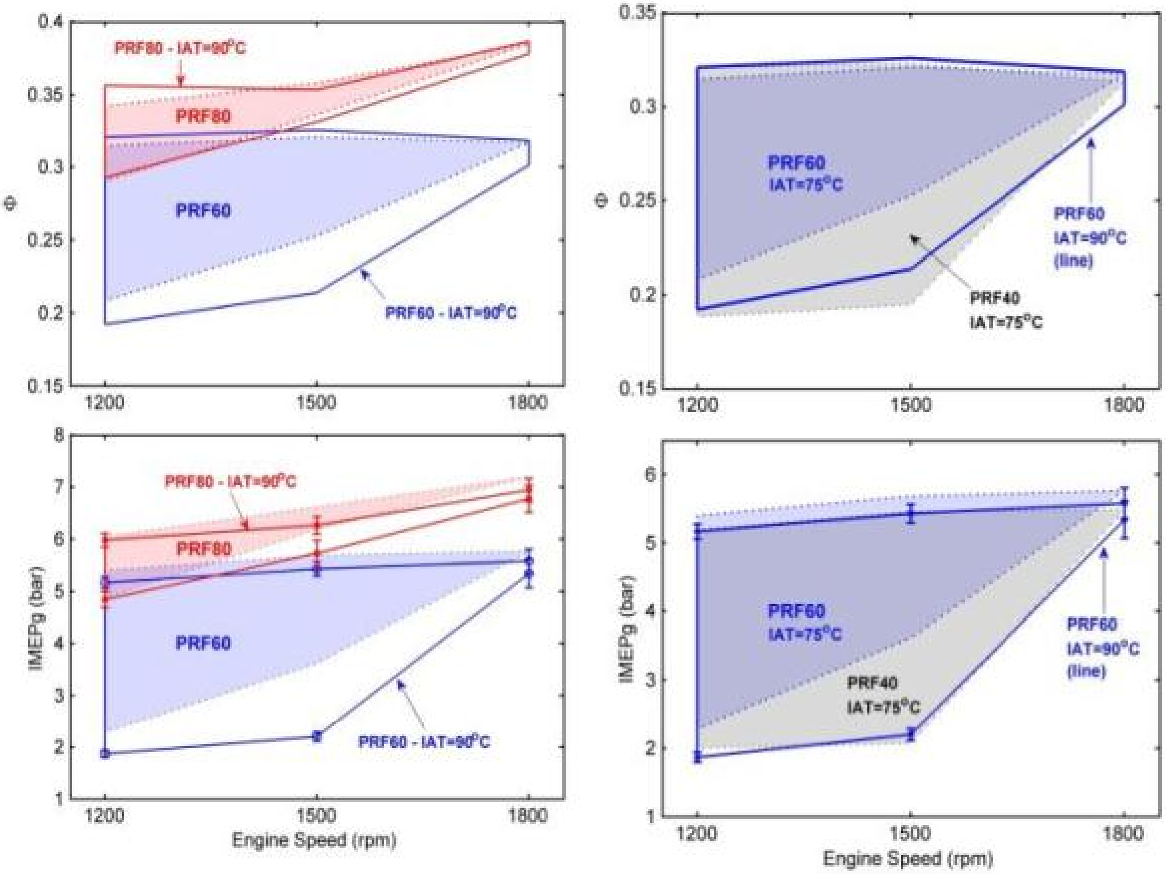
Combustion Phasing

- Increasing intake temperature caused a slight advance in combustion phasing, especially with PRF60
- This may explain the slight decrease in efficiency at the higher load

Intake Temperature Effects

- Increasing intake temperature extended LLL but slightly decreased HLL. Operating envelope, therefore, was expanded more towards the low load region

- Increasing intake temperature from 75°C to 90°C resulted in an operating range equivalent to that obtained by decreasing the PRF octane rating from 60 to 40.



Summary

- Decreasing fuel reactivity results in narrower operating window but expands high load limit and shifts operation towards higher equivalence ratio. These effects became more prominent as speed increased
- Increasing fuel reactivity becomes increasingly less effective in controlling HCCI combustion as engine load decreases. This nonlinear effect renders reactivity-base control not effective for extending low load limit
- Increasing intake temperature extended low load limit and enabled a more stable operation in general
- Increasing intake temperature resulted in some positive, but generally not significant, effects on engine performance and exhaust emissions. Most noticeable effect was the consistent reduction of CO emissions within the low to intermediate load region

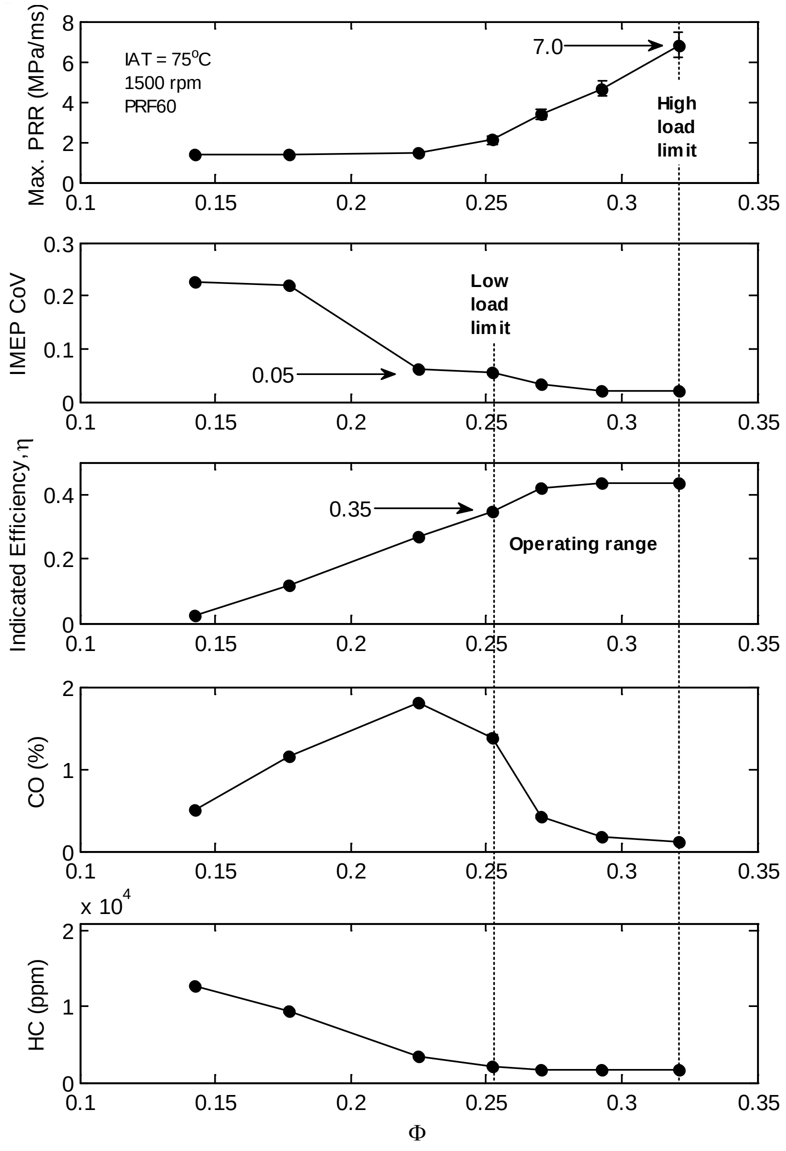
Back-up slides

Operating Window

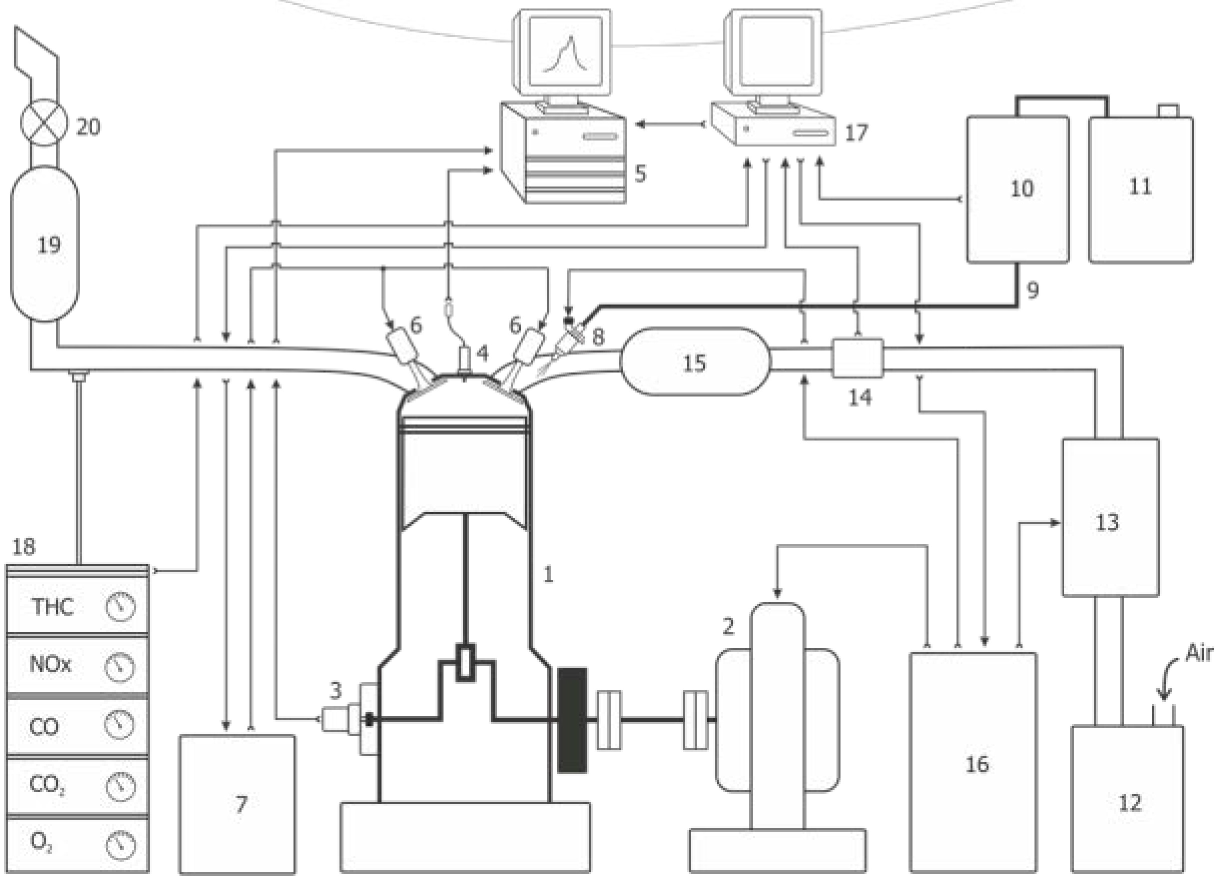
- Boundaries of efficiency plateau were generally found to correspond to an MPRR of about 7 MPa/ms on high load side and 3.5% IMEP COV in low load side

- Clear correlation between indicted efficiency and CO and HC emissions

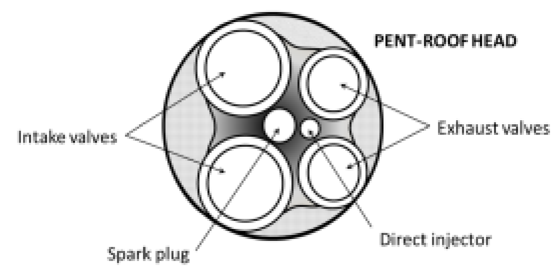
- HLL is set at 7 MPa/ms and LLL is set at 5% IMEP COV, accepting some penalty in thermal efficiency and CO emissions



Engine Test Cell

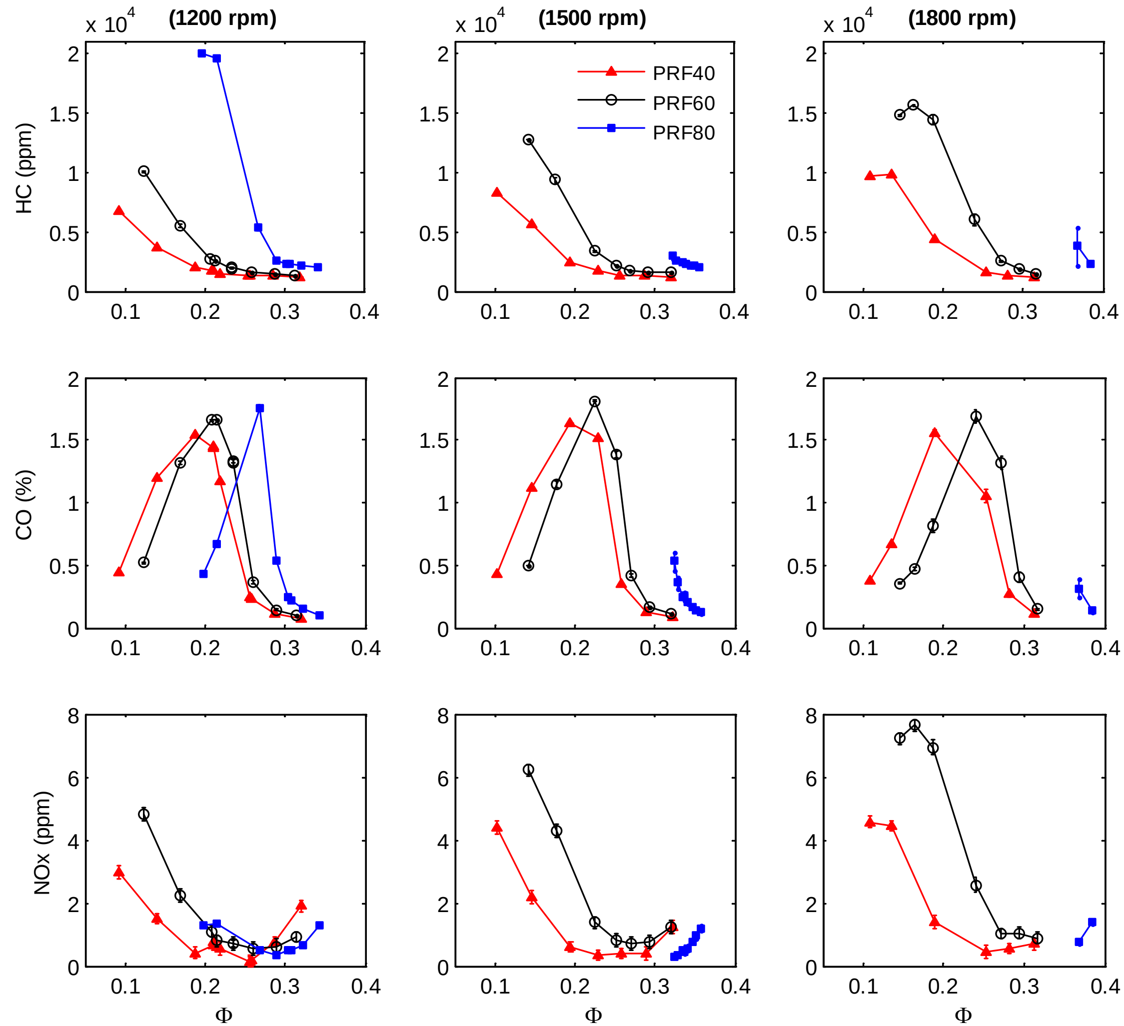


Displacement	499 cm^3
Stroke	90 mm
Bore	84 mm
Connecting rod	159 mm
Compression ratio	12:1
Fuel delivery system	PFI



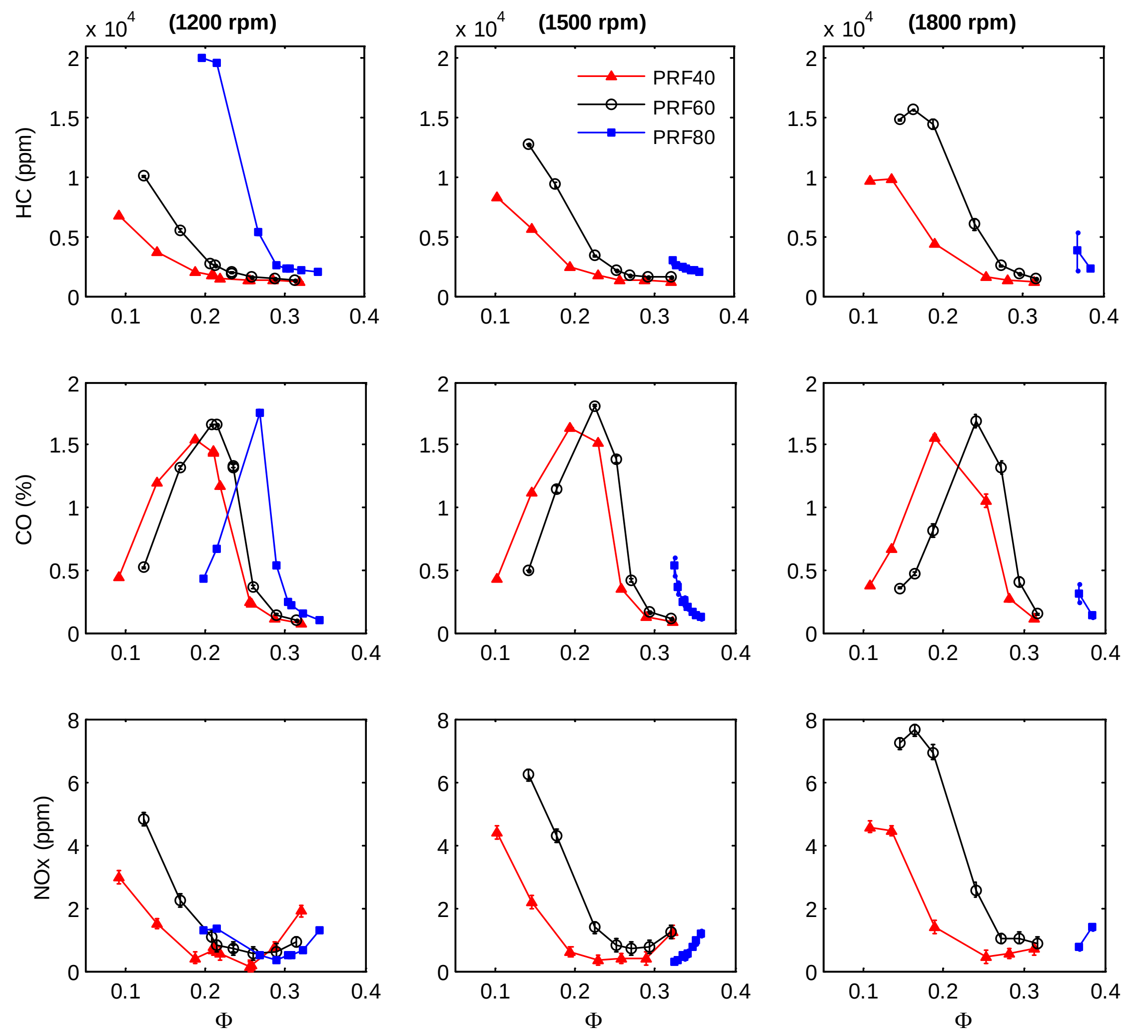
Effects on Emissions - I

- HC emissions plateau around 1500 ppm, but increases sharply as the engine approaches misfire region
- CO emissions show very strong sensitivity to operating conditions, reach a climax quickly after the misfire starts to occur, and then decreases sharply
- NOx emissions ranged from less than 1 ppm to 2 ppm in normal operation, but slightly increased close to motoring limit – Reason not clear



Effects on Emissions - II

- Expansion of high load limit while maintaining almost same emissions levels is possible
- Boundaries of practical operation ranges can be inferred from emissions trends, especially CO
- CO inflection point correspond to the start of increase in HC and NOx



Thank You