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Catalyst Heating Operation Studies in a Single-Cylinder Optical Diesel Engine

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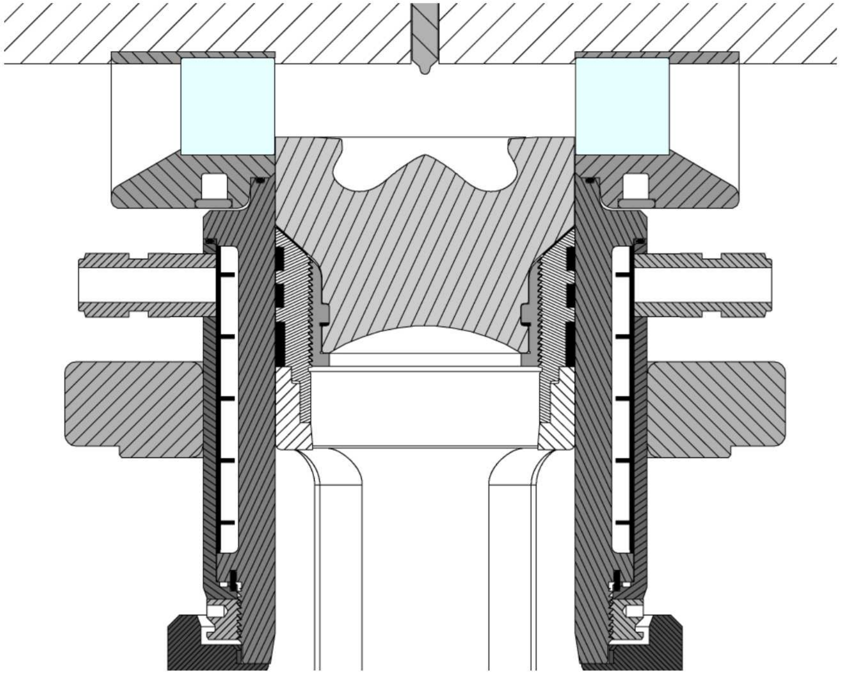
Outline

- Project introduction: diesel catalyst heating operation
- Experimental approach in a single cylinder optical engine
  - Engine operation
  - Load/injection quantity approach
  - Injection strategy / calibrations
  - Thermodynamic calculations
  - Variations
- Initial results
- Summary

Project introduction

- Collaborative discussions with Ford Motor Company, UW-Madison
  - Goal: develop set of well-controlled experimental conditions to study the ignition, combustion, and pollutant formation mechanisms of post injections
- Sandia's small-bore diesel will be used for initial thermal and optical catalyst heating studies
  - New MD-Diesel research platform: planned operation of thermal configuration in 2019



Engine operation

- Constant engine speed 1500 rpm
- Coolant temperature set point: 30°C
  - 20°C is not possible
- Intake mass flow rate is held constant
  - EGR is simulated with a fixed concentration of N_2 and CO_2
  - 18.7% O_2 corresponds to 30% EGR with an 11 mg total fuel quantity
- Intake temperature adjusted with EGR rate to maintain estimated motored TDC temperature
- Skip-fired operation (skip 4 fire 1)
  - No hot residuals
  - No exhaust temperature measurement
  - Emissions measurements corrected for dilution
- Measured data
  - Cylinder pressure: 50 cycles
  - Emissions: NOx, HC, CO, FSN

	0% EGR	30% EGR
Bore x stroke	82 mm x 90.4 mm	
Piston bowl	Re-entrant, no valve cutouts	
Swirl ratio	2.2	
Nozzle holes	7 x 139 µm 149° opening angle ks = 1.5	
EVO	0.1 mm @ 130 CAD ATDC	
Engine speed	1500 rpm	
Intake mass flow rate	8.51 g/s	
Intake composition (mole fractions)	O2: 21% N2: 79% CO2: 0%	O2: 18.7% N2: 79.36 CO2: 1.94%
Intake temperature	31 °C	49 °C
Coolant temperature	30 °C	
TDC temperature (est.)	723	
TDC density (est.)	21.2 kg/m³	
Injection pressure	500 bar	
Start of Pilot Injection	15 CAD BTDC	
Pilot quantity	2 mg	
Start of Main Injection	0 CAD ATDC	
Main quantity	3, 5, 7 mg	
Start of Post Injection	10, 14, 18, 22, 26, 30 CAD ATDC	
Post quantity	2, 4, 6 mg	

Load / injection quantity approach

- Option 1: maintain target BMEP
  - Adjusting main injection duration changes load
  - On-the-fly load adjustments are time consuming with a skip-fired optical engine
  - In-cylinder thermodynamic state is not well controlled for the post injection

- Option 2: maintain fueling
  - Fueling rate is held constant for a given post timing sweep
  - Load changes with post injection timing
  - In-cylinder state no longer depends on a changing main injection quantity for a given sweep

- Initial study: maintain fueling (option 2)
  - Focus on operation with one pilot, one main, and either one or two post injections
  - Fixed pilot quantity and timing, fixed main timing for three main quantities, variable post injection quantity and timing

Injection strategy/calibrations

- Pilot-main-post(s) strategy
  - Pilot quantity and timing fixed
  - Main timing fixed
  - Three main quantities
  - Three post quantities
  - Variations of main-post dwell

- Injection quantities depend on other injection quantities and dwells
  - Each calibration has been determined with a hydraulic flow bench at a fixed initial backpressure

Injected mass in mg/str

Total	Pilot	Main	Post1	Post2	
5	2	3			All injection schedules characterized; Main-post1 dwells of 10,14,18,22,26 and 30 CAD
7	2	3	<-2->	Not tested	
9	2	3	<-4->		
11	2	3	<-6->		
9	2	3	2	<-2->	Need to decide on Post1 timing
11	2	3	2	<-4->	
13	2	3	2	<-6->	
7	2	5			All injection schedules characterized; Main-post1 dwells of 10,14,18,22,26 and 30 CAD
9	2	5	<-2->		
11	2	5	<-4->		
13	2	5	<-6->		
11	2	5	2	<-2->	Need to decide on Post1 timing
13	2	5	2	<-4->	
9	2	7			All injection schedules characterized; Main-post1 dwells of 10,14,18,22,26 and 30 CAD
11	2	7	<-2->		
13	2	7	<-4->		
13	2	7	2	<-2->	Need to decide on Post1 timing

Thermodynamic calculations

- Heat release analysis
  - First law, ideal gas law
  - Specific heat ratio depends on mass fraction burned and bulk gas temperature; fuel vapor and unburned products are neglected
  - Woschni heat transfer model
- Bulk gas temperature is computed as part of the heat release analysis
  - Likely inaccurate, but at least consistent
- Temperature at EVO is used as a surrogate for exhaust temperature
  - For a constant air mass flow rate and total fueling rate, changes in exhaust temperature correspond to changes in exhaust enthalpy flow
- Temperature at SOI_{post} is another useful metric
  - Other temperature-based metrics are being evaluated

CRF

Variations for upcoming testing

- EGR / no EGR
- Cetane number
  - DPRF58 vs DPRF66: CN 50.7 vs. CN 43.9

Testing completed

- Fuel distillation properties
  - Cert diesel: CN 43.9
- Intake temperature
  - Bypassing the EGR cooler in production engines increases intake temperature
- Second post injection
- Bio-fuel components (CoOptima task)
  - Alcohols: expected negative impact on ignition
  - OME: expected positive impact on ignition
  - Fueling for equal quantity vs. equal fuel energy

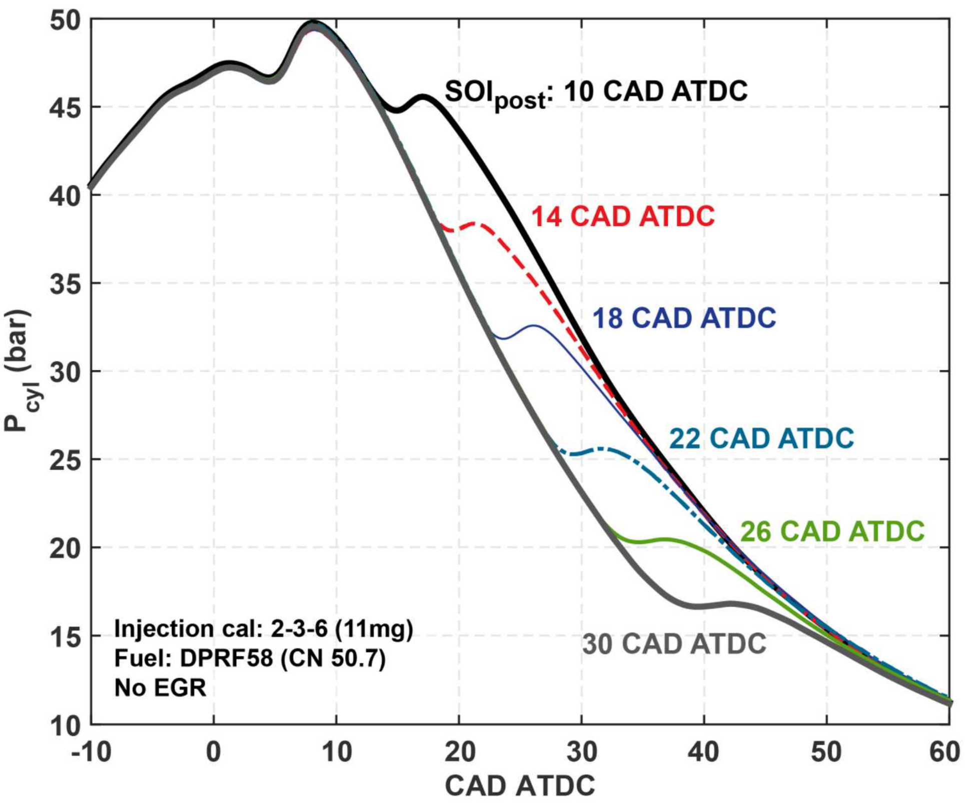
CRF

Initial results: cylinder pressure

- Naming convention
  - 2-3-6: 2 mg pilot, 3 mg main, 6 mg post
    11 mg total

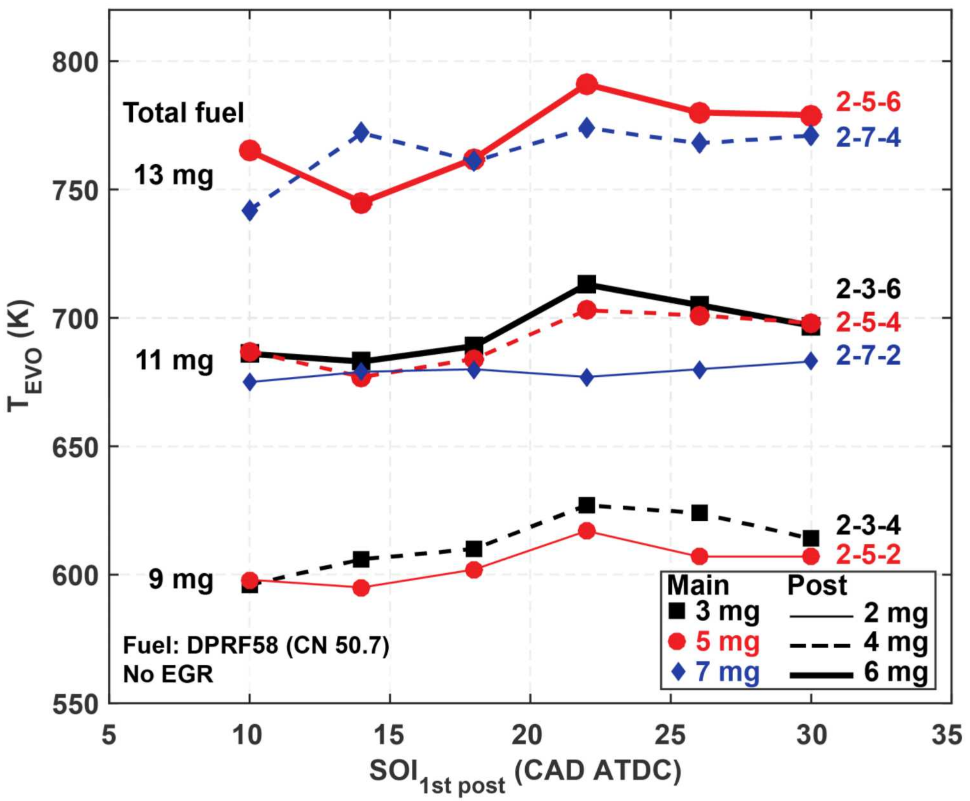
- Cylinder pressure is highly repeatable until the combustion of the post injection
  - This holds for all injection calibrations

- Cylinder pressure traces converge after ~60 CAD ATDC



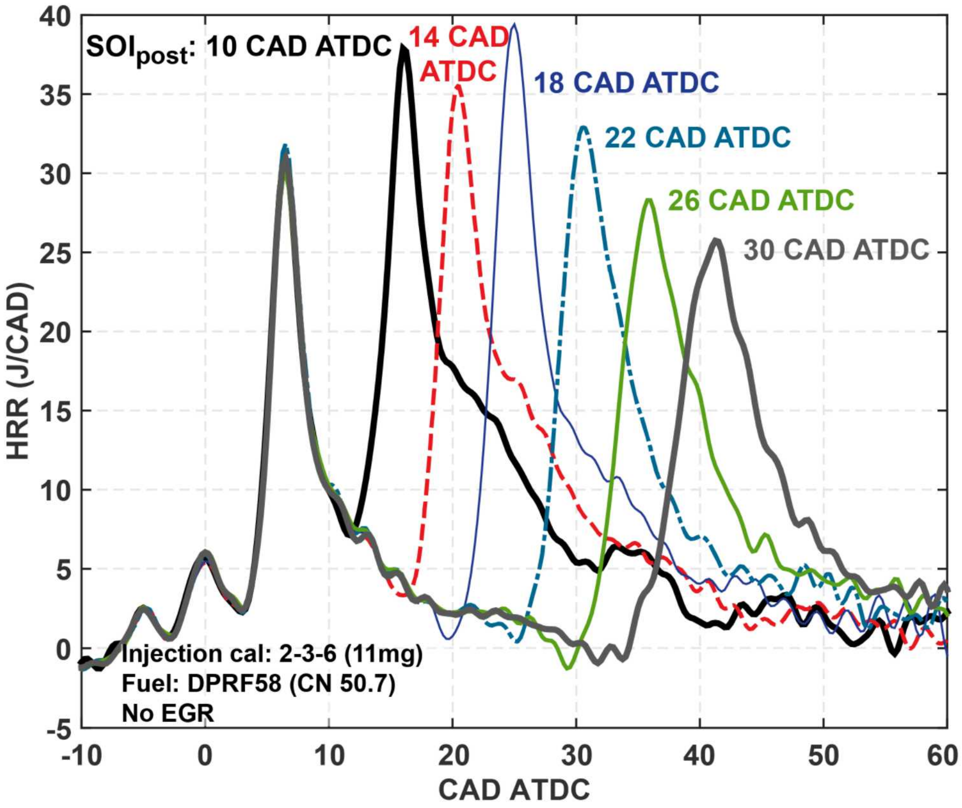
Initial results: T at EVO (no EGR)

- Bulk gas temperature at EVO is used to represent exhaust temperature
  - T_{EVO} is plotted as a function of post timing for each injection calibration
- T_{EVO} depends most strongly on the total amount of fuel delivered
- The post/main quantity ratio also impacts T_{EVO}
  - Higher post quantities tend to increase exhaust temperatures for post injection timings near 22 and 26 CAD ATDC
- T_{EVO} (and likely exhaust enthalpy) often peaks at a post injection timing of 22 CAD ATDC



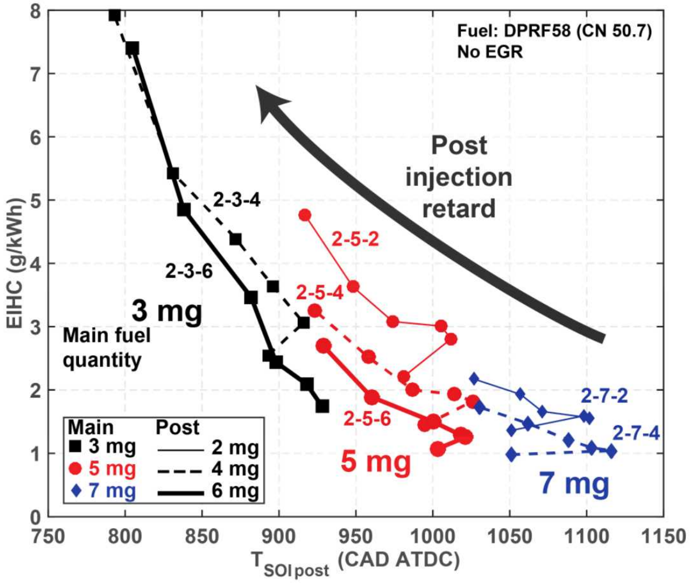
Initial results: heat release rate (no EGR)

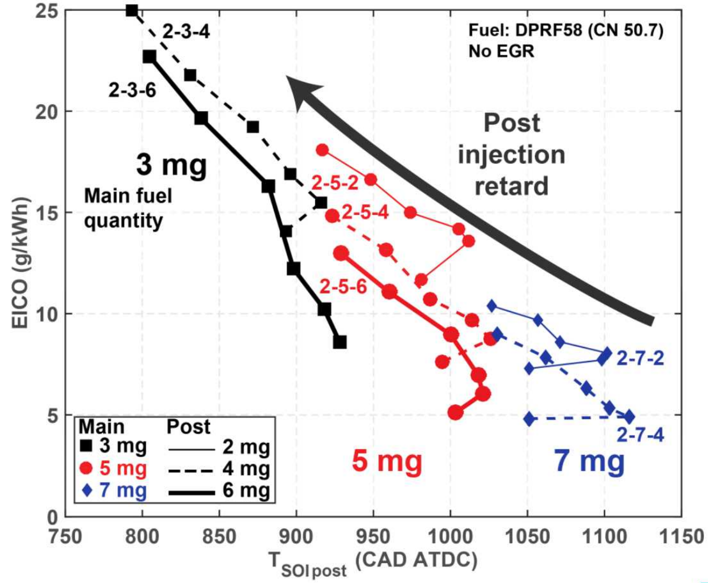
- Pilot heat release: distinct double-peak
  - Believed to be low- and high-temperature heat release; high-temperature heat release is likely suppressed by the main injection
- Pilot and main heat release are the same regardless of main-post dwell
- Post heat release peaks decrease for post injections starting after 18 CAD ATDC



Initial results: CO and HC (no EGR)

- EIHC and EICO are plotted against the computed bulk gas temperature at the start of the post injection, $T_{SOIpost}$
  - The results collapse fairly well
  - Exception: earliest post injection timing – interaction between post and main?
- Bulk gas temperature has a strong impact on HC and CO emissions
  - In this study, the main fuel quantity controls $T_{SOIpost}$
- Post quantity is the second most important factor in determining engine-out HC and CO emissions
  - Larger post injections reduce HC and CO for a given post injection timing





Summary

- An experimental approach to studying catalyst heating operation has been developed for Sandia's small-bore optical diesel engine
- Experimental objective: build fundamental understanding of mixture formation, ignition, combustion, and pollutant formation for catalyst heating operation
- Experiments are performed for discrete fueling levels with a fixed intake charge flow rate
- Experiments and analysis are ongoing

Thank you for your attention

Questions?

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