Investigation of RCCI Combustion in a Two-Stroke Engine

Scott R. Miles, Jaal B. Ghandhi

Motivation
Due to increasingly stringent emissions regulations, new ways to reduce engine-out emissions from two-stroke cycle engines are being investigated. Reactivity Controlled Compression Ignition (RCCI) has demonstrated the capability to reduce four-stroke diesel emissions while increasing thermal efficiency. This project is aimed at understanding if the same benefit can be obtained in a two-stroke engine.

Fuel Spray Characterization
In order to better understand the dynamic injection event and to enable computational modeling, both fuel injectors were characterized over their respective operating ranges.

- Backlit High Speed Imaging
  - Spray & Bend Angles
  - Footprint
  - Liquid Tip Penetration

Low Reactivity GDI

\[ P_{\text{inj}} = 50 \, \text{bar} \]

High Reactivity GDI

\[ P_{\text{inj}} = 80 \, \text{bar} \]

- Bosch Bench
  - Rate of Injection
  - Hydraulic Delay

Lab Implementation
A two-cylinder outboard engine was laid on its side to mate with a horizontal dynamometer and the lube oil injection system was adapted accordingly. A common throttle delivers intake air to independent crankcases before entering each cylinder. Each cylinder has a dedicated exhaust system, so relative isolation of the gas exchange process is achieved.

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Inline 2-Cylinder, Crankcase Scavenged, Oil Injected</th>
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</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>864 cm³</td>
</tr>
<tr>
<td>Bore / Stroke</td>
<td>91.5 mm / 65.7 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>10.4 (DISI), 15.0 (RCCI)</td>
</tr>
<tr>
<td>Boost Port (Open/Closed)</td>
<td>122° ATDC / 122° BTDC</td>
</tr>
<tr>
<td>Transfer Port (Open/Closed)</td>
<td>120° ATDC / 120° BTDC</td>
</tr>
<tr>
<td>Exhaust Port (Open/Closed)</td>
<td>90° ATDC / 90° BTDC</td>
</tr>
</tbody>
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A new cylinder head was developed to preserve the DISI configuration in one cylinder, enable RCCI operation in the other cylinder and accommodate pressure transducers. Each cylinder is independently controlled.

High Reactivity

Low Reactivity

Removable Plug

Adjustable CR with spacer thickness

In the RCCI cylinder, a higher compression ratio is required for compression ignition. A reduced squish height (relative to production) was implemented in order to increase high reactivity fuel penetration - promoting complete burning of the partially premixed, low reactivity fuel, and ultimately reducing unburned hydrocarbon emissions. An adjustable plug allows flexibility in compression ratio and injector orientation.

Results

Throttle Effects
- Throttle position (delivery ratio, DR) controls scavenging, which impacts \( \Phi \), internal EGR, and bulk gas temperature at exhaust port close to TDC.

- At 2.5 bar, optimum delivery ratio appears to be 0.75 for best gross indicated efficiency (deemed at map: \( \Phi = \max \) with injected max at \( \Phi_{\text{inj}} \)).

HCCI Combustion with Primary Reference Fuels
- CAS0 maintained at TDC
- Octane ‘appetite’ is mainly a function of load, but modified delivery ratio affects PRF number above 2 bar IMEP

- 2.5 bar IMEP Throttle Sweep

DISI Combustion Compared to RCCI Combustion with Gasoline and Diesel
- Late diesel injection results in high NOx emissions for RCCI
- Fast heat release provides higher efficiency for RCCI

21 g/kW-hr HC+NOx Comparison

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