The effect of fuel composition on particulate emissions from a highly boosted GDI engine - an evaluation of three particulate indices

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- Experimental equipment
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Background

• Boosted GDI increasing market penetration

• Fuel effects on PN
  • Dependent on mixture formation – evaporative performance of fuel
  • Avoid wall wetting / pool fires
  • Many particle formation pathways pass through aromatic / PAH components
Background – particulate indices

- PM index (2010) – Honda – good correlation between fuel composition and PM
  - Unable to calculate PM index without detailed compositional breakdown of fuels
- PN index (2012) uses industry standard measurements
  - DVPE
  - Blending by volume
- Moriya index (2016)
  - Requires only distillation information

\[
PM\ index = \sum_{i=1}^{n} \left[ \frac{DBE_i + 1}{VP_i} \right] W_i
\]

\[
DBE = \frac{2C^° - H^° + 2}{2}
\]

\[
PN\ index = \frac{\sum_{i=1}^{n} [DBE_i + 1]V_i}{DVPE(kPa)}
\]

\[
Moriya\ index = -0.0647 \times E170 - 0.0324 \times E130 + 9.92405
\]

\[
Simplified\ Moriya\ index = -0.0757 \times E150 + 7.8511
\]
Ultraboost engine

• Highly-boosted, heavily-downsized engine
• Torque curve and power output of the NA Jaguar Land Rover AJ133 5.0L V8 engine
• 35% improvement in fuel economy / CO₂ target
• 60% downsizing (2.0 litre i4)
• Driveability of the original V8 to be maintained
• Operation on 95 RON pump gasoline

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Inline 4 cylinder</td>
</tr>
<tr>
<td>Bore × Stroke</td>
<td>83 × 92 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>1991 cm³</td>
</tr>
<tr>
<td>Valves per cylinder</td>
<td>2 intake, 2 exhaust</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>9:1</td>
</tr>
<tr>
<td>Maximum fuel pressure</td>
<td>200 bar</td>
</tr>
<tr>
<td>Peak BMEP</td>
<td>35 bar</td>
</tr>
<tr>
<td>Peak cylinder pressure</td>
<td>150 bar</td>
</tr>
</tbody>
</table>

Turner et al. SAE 2014-01-1185
Particulate measurements

- Cambustion DMS500
Sampling location

- Approx 3m downstream of exhaust manifold
- Water cooled exhaust manifold
- Downstream of backpressure valve and one silencer
- No catalyst
Test points

Max BMEP curve

1. KLSA
2. EGR
3. KLSA
4. Limited Spark Swing

- S.C.
- Spark Swing SOI Swing
- Inlet T
- T.C.
- N.A.
Test fuels

- 10 fuels tested – 3 “market”, 7 “test”

- A-D – deconvolved RON/MON matrix
- E/F – High/Low laminar flame speed
- G – Artificially boosted RON
- H – minimum EN228 RON
- I – “Winter” gasoline
- Base – standard EN228

<table>
<thead>
<tr>
<th>Fuel</th>
<th>RON (-)</th>
<th>MON (-)</th>
<th>DVPE (kPa)</th>
<th>FBP (°C)</th>
<th>E150 (%)</th>
<th>C (% m/m)</th>
<th>H (% m/m)</th>
<th>O (% m/m)</th>
<th>PN index* (1/kPa)</th>
<th>PN index** (1/kPa)</th>
<th>PM index (1/kPa)</th>
<th>Moriya index*** (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>103.3</td>
<td>95</td>
<td>26.1</td>
<td>177</td>
<td>96</td>
<td>7.15</td>
<td>14.45</td>
<td>0.17</td>
<td>6.57</td>
<td>6.61</td>
<td>0.55</td>
<td>0.57</td>
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<tr>
<td>B</td>
<td>101.4</td>
<td>88.8</td>
<td>68.0</td>
<td>176</td>
<td>95</td>
<td>6.40</td>
<td>11.17</td>
<td>0.11</td>
<td>3.97</td>
<td>3.99</td>
<td>1.01</td>
<td>0.68</td>
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<tr>
<td>C</td>
<td>92.8</td>
<td>90.7</td>
<td>30.5</td>
<td>193</td>
<td>93</td>
<td>7.41</td>
<td>15.94</td>
<td>0.00</td>
<td>4.23</td>
<td>4.31</td>
<td>0.49</td>
<td>0.82</td>
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<tr>
<td>D</td>
<td>88.6</td>
<td>87.3</td>
<td>32.9</td>
<td>190</td>
<td>92</td>
<td>7.31</td>
<td>15.64</td>
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<td>4.03</td>
<td>4.12</td>
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<td>0.91</td>
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<td>E</td>
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<td>82.2</td>
<td>28.7</td>
<td>138</td>
<td>98</td>
<td>6.68</td>
<td>12.38</td>
<td>0.00</td>
<td>10.41</td>
<td>10.41</td>
<td>0.99</td>
<td>0.44</td>
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<tr>
<td>F</td>
<td>104.2</td>
<td>92.6</td>
<td>23.3</td>
<td>139</td>
<td>98</td>
<td>6.94</td>
<td>12.46</td>
<td>0.00</td>
<td>11.14</td>
<td>11.14</td>
<td>1.04</td>
<td>0.42</td>
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<tr>
<td>G</td>
<td>111.6</td>
<td>101.2</td>
<td>57.4</td>
<td>192</td>
<td>98</td>
<td>7.10</td>
<td>11.80</td>
<td>0.00</td>
<td>5.69</td>
<td>5.69</td>
<td>1.00</td>
<td>0.44</td>
</tr>
<tr>
<td>H</td>
<td>95.1</td>
<td>85.0</td>
<td>53.1</td>
<td>189</td>
<td>88</td>
<td>6.20</td>
<td>11.48</td>
<td>0.10</td>
<td>4.64</td>
<td>4.67</td>
<td>1.32</td>
<td>1.18</td>
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<tr>
<td>I†</td>
<td>98.7</td>
<td>86.5</td>
<td>97.4</td>
<td>173</td>
<td>95</td>
<td>6.28</td>
<td>11.23</td>
<td>0.00</td>
<td>2.64</td>
<td>n/k</td>
<td>n/k</td>
<td>0.66</td>
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<tr>
<td>Base</td>
<td>97</td>
<td>85.3</td>
<td>75.0</td>
<td>188</td>
<td>92</td>
<td>6.05</td>
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<td>3.30</td>
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<td>1.10</td>
<td>0.87</td>
</tr>
</tbody>
</table>

*Calculated from PIONA (ASTM D1319) analysis  ** Calculated from DHA  *** Simplified Moriya index by Equation 5 † A DHA was unavailable for Fuel I
Test fuels – spread of indices

- PN index identical (~1%) from two calculations
- Little correlation between three indices
Results – Market fuels

• Trends from previous work followed

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect on PN emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine load</td>
<td>Load ↑ Particulates ↑</td>
</tr>
<tr>
<td>Fuel injection pressure</td>
<td>P ↑ Particulates ↓</td>
</tr>
<tr>
<td>EGR</td>
<td>EGR ↑ Particulates ↑</td>
</tr>
<tr>
<td>Inlet air temperature</td>
<td>T ↑ Particulates ↓</td>
</tr>
<tr>
<td>Exhaust back pressure</td>
<td>Back pressure ↑ Particulates ↓</td>
</tr>
<tr>
<td>λ (AFR)</td>
<td>λ ↓ Particulates ↑</td>
</tr>
<tr>
<td>Spark timing</td>
<td>Ignition ← Particulates ↓</td>
</tr>
<tr>
<td>Fuel injection timing</td>
<td>Injection → Particulates ↓</td>
</tr>
</tbody>
</table>
Results – Market fuels

- All fuels – accumulation mode peak at ~30nm when boosted
- At part load – Fuel I (high DVPE) lowest PN
- At 2000rpm / max BMEP – fuel H highest PN
- Base fuel repeatable
Results – Test fuels

- Fuel G (artificially boosted RON) – very high PN + very small $d_p$.
  - Atypical distillation curve
  - High THC emissions (& BSFC)

- Fuels B & F high PN – B: high DVPE

- Fuels B&F “wide” accumulation mode (30–100 nm)
Results – Evaluation of indices

• PM index matches fairly well for all fuels (lower correlations than seen in literature)

![Graphs showing PN emission (#/cc) vs PM index (1/kPa) for different conditions.]

- TP1: 0% EGR vs 10% EGR, R² = 0.6367, R² = 0.5943
- TP2: 20C Inlet air T vs 40C Inlet air T, R² = 0.2825, R² = 0.4272
- TP4: λ = 1.0 vs λ = 0.875, R² = 0.4305
- TP3: 2.2 bar A EBP vs 1.7 bar A EBP, R² = 0.8287, R² = 0.6632
Results – Evaluation of indices

- PN index does not match that well for all fuels
Results – Evaluation of indices

• Moriya index does not match well for all fuels
Results – Evaluation of indices

• PN index – market fuels

• Good(ish) correlations from PN index with market fuels – best at boosted conditions
Results – Evaluation of indices

• Moriya index – market fuels

• Good(ish) correlations from Moriya index with market fuels – best at boosted conditions
Conclusions

- PN emissions from 10 different test fuels
- Fuel composition remains important factor
- PM index good predictor of emissions at all test conditions
  - Heavy aromatics
- PN index & Moriya – good for market fuels in this work
- All indices strongest correlations when boosted
- More complex index ➔ better match
  - DHA very useful
- Small (~30nm) accumulation mode particles seen from all fuels
Ultraboost consortium
Oxford Air Quality Meeting

Drawing together experts in vehicle emissions, air quality measurement, public health, and policy

Friday 10 January 2020, 9:00am - 5:00pm
Keble College, Oxford

www.oaqm.org

Kindly supported by:

[Logos of CAMBUSTION and EMISSIONS ANALYTICS]
Thank you


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