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Effects of Boost Pressure and Fuel Composition on Combustion Knock Characteristics

Executive Summary

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COORDINATING RESEARCH COUNCIL, INC.
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This project investigated how boosted intake pressure affects the knock characteristics of fuels with varied levels of important hydrocarbon classes found in modern commercial gasolines. In addition, the work explored how boosting affects the operation of the RON Cooperative Fuel Research (CFR) test engine and what further information would be required to propose modifications to the octane test method to improve the correlation between octane number and knock propensity in modern spark ignition engines.

A highly instrumented CFR research octane number (RON) rating engine at Argonne National Laboratory was used to investigate how knock testing methodology and fuel chemical composition affects the knock propensity rankings of seven Coordinating Research Council (CRC) Fuels for Advanced Combustion Engines (FACE) gasolines (≈95 RON), primary reference fuels (PRFs), and a toluene standardization fuel (TSF).

While performing the standard ASTM D2699 RON test method, significant differences were observed between the fuels in terms of their lambda of highest knock intensity and cylinder pressure transducer based knock intensities (relative to the standard CFR knockmeter), which were correlated to fuel chemical composition. For instance, no correlation was found ($R^2<0.3$) between RON ratings and amplitudes of knock cylinder pressure oscillations. Highly paraffinic fuels tended to have a richer lambda of highest knock and higher pressure transducer knock intensities for a given knockmeter knock intensity. Since none of the FACE gasolines' RON ratings were evaluated at stoichiometry, or even similar lambdas as each other, their knock propensity rankings were re-assessed at stoichiometry with both the CFR knockmeter and cylinder pressure transducer based knock intensities.

To further explore the effects of discrepancies between the ASTM RON test method and how typical knock-limited spark advance (KLSA) tests are performed on automotive engines, the knock propensities of the test fuels were evaluated on the CFR engine using spark timing sweeps at fixed compression ratio (CR). A new knock propensity testing methodology was then developed utilizing the variable CR engine with intake pressure control. The fuels were rated based on the highest CR possible at stoichiometry, constant pressure transducer based knock intensity, fixed indicated mean effective pressure (IMEP), and spark timing of highest IMEP. The octane index (OI) and "K value" of the fuels were estimated under RON test conditions, but using varying degrees of commonality with automotive KLSA testing.

It was found that under standard RON test conditions (on the CFR octane engine), K can vary from -0.5 to +0.36, depending on the testing method (lambda, knock intensity measurement type, spark timing, etc.). Based on the large trend of downsized and boosted automotive spark ignition engines, the RON rating and fuels exploration was extended to light boost levels (up to 1.5 bar absolute). Other than fuel chemical composition, the variables examined included: knock intensity measurement method (knockmeter vs. cylinder pressure transducer), spark timing (fixed vs. KLSA), and compression ratio (fixed vs. knock limited CR). Contrary to previous findings, increased intake pressures caused high aromatic FACE gasolines, such as FACE D and FACE H (with 15 vol% ethanol added), to have higher knock propensity relative to the other FACE gasolines, PRFs, and TSF. However, the TSF (a high aromatic test

fuel) had a significant reduction in knock propensity with increased intake pressure. A distinct knock response from increased intake pressure was observed of the PRFs relative to some of the FACE test gasolines, including FACE B, FACE D, FACE F, and FACE H (with 15 vol% ethanol added). With increased intake pressure, the PRFs increased in knock propensity relative to the highly paraffinic gasolines FACE B and FACE F, and decreased in knock propensity relative to the highly aromatic gasolines FACE D and FACE H (with 15 vol% ethanol added). This could be concerning given the use of PRFs as the reference fuels for the octane scale. For the FACE gasolines that didn't show a statistically significant response to intake pressure relative to the PRFs, meaning FACE A (with 15 vol% ethanol added), FACE C (with 15 vol% ethanol added), and FACE G, it was concluded that in order to observe more statistically significant effects of intake pressure on these fuels' knock propensity, extending testing to higher intake pressure (e.g., 1.5-3 bar absolute) would be required.

The results of this work were published in three technical papers listed:

Hoth, A., and Kolodziej, C. P., "Effects of knock intensity measurement technique and fuel chemical composition on the research octane number (RON) of FACE gasolines: Part 1 – Lambda and knock characterization," Fuel, vol. 304, Nov. 2021, 120722, https://doi.org/10.1016/j.fuel.2021.120722

Effects of knock intensity measurement technique and fuel chemical composition on the research octane number (RON) of FACE gasolines: Part 1 – Lambda and knock characterization (Journal Article) | OSTI.GOV

Hoth, A., and Kolodziej, C. P., "Effects of knock intensity measurement technique and fuel chemical composition on the research octane number (RON) of FACE gasolines: Part 2 – Effects of spark timing," Fuel, vol. 342, Jun. 2023, 127694, https://doi.org/10.1016/j.fuel.2023.127694

Effects of knock intensity measurement technique and fuel chemical composition on the research octane number (RON) of FACE gasolines: Part 2 – Effects of spark timing (Journal Article) | OSTI.GOV

Kolodziej, C. and Hoth, A., "Effects of Critical Compression Ratio on Rating Gasoline Knock Propensity," SAE Technical Paper 2025-01-8451, 2025, https://doi.org/10.4271/2025-01-8451

Effects of Critical Compression Ratio on Rating Gasoline Knock Propensity (Conference) | OSTI.GOV