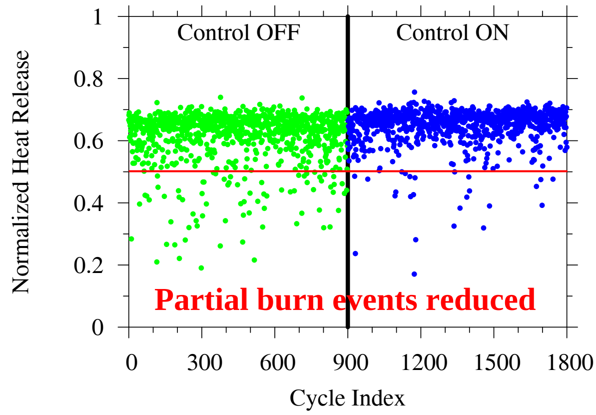
ORNL Adaptive Control Shows Potential for Extending Practical Lean Combustion Limit

Improved Engine Operation Further Reduces NOx Emission Levels

Background & Benefits

Nitrogen oxide (NO_x) emissions can potentially be reduced in spark-ignition (SI) engines by creating ultra-lean-burn conditions. The air-to-fuel ratio during combustion can be increased by introducing fresh air to the cylinder. The diluted mixture results in lower combustion temperatures that inhibit NO_x production. Dilution is also a key component in achieving advanced combustion modes such as homogeneous-charge compression-ignition (HCCI) combustion, which also produces low NO_x levels.



In this example, application of adaptive control to a small NG engine operating at lean conditions results in a 70-75% reduction in the occurrence of extreme partial burns and misfires.

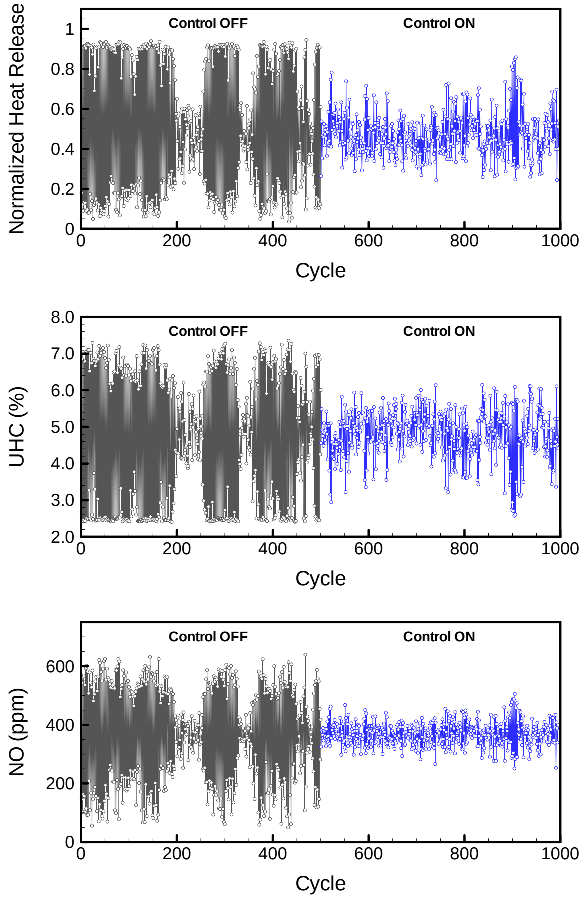
As dilution is increased, however, combustion becomes more and more unstable with increased cycle-to-cycle variability. These instabilities are responsible for decreased engine performance, decreased fuel efficiency, and increased emissions of unburned fuel and NO_x. Subsequently, SI engine operation becomes impractical at dilution levels well within the theoretical limit for sustainable combustion. The goal of this ORNL Advanced Reciprocating Engine Systems (ARES) Program project is to maintain stable combustion using adaptive controls while extending the lean limit as much possible.

Technology

Cycle-to-cycle variations observed in lean-burn conditions occur in a predictable pattern where performance in any given cycle directly effects the performance of the following cycle. The primary feedback between cycles is the residual exhaust gas trapped inside the cylinder when the exhaust valve closes. Following a suppressed combustion cycle, the residual exhaust gases contain significant quantities of unburned fuel which mix with the fresh charge to produce an extra-rich mixture and subsequent enhanced combustion event. ORNL emissions measurements confirm that, in addition to the emission of large amounts of unburned fuel (UHC) during the suppressed combustion events, high levels of NO_x are produced during the enhanced, high-temperature combustion events that follow.

The alternating suppressed and enhanced combustion cycles occur in a predictable pattern that can be controlled through a proactive control strategy. Adaptive controls resolve cycle-to-cycle combustion fluctuations in lean burn engines with active feedback control to make small, but precisely timed, changes to one or more engine parameters. Adaptable parameters include fueling, ignition timing, and possibly valve timing.

ORNL data shows that adaptive controls can indeed reduce the severity of cycle-to-cycle variation in an SI engine operating under lean conditions and allow the practical operating range to be extended. To better estimate the gains in fuel efficiency and emissions reductions which may be achieved through the application of these controls, ORNL researchers developed an analytical SI engine model by adding a detailed combustion model to commercially available engine-modeling software – specifically, WAVE from Ricardo, Inc. The resulting model can predict the development of combustion instabilities and evaluate adaptive control strategies for specific lean-burn SI engine platforms (including large, reciprocating, natural gas engines of interest to the ARES program) without costs associated with actual engine operation.



ORNL analytical model shows reduced cyclic variations and emissions levels using adaptive control and fuel perturbations..

Future Work

HCCI combustion is being aggressively pursued as a promising alternative for the reduction of NO_x production in internal combustion engines, however, it may not be possible to operate in HCCI mode over an entire load range due to dilute combustion instability. One of the most important developments needed to achieve wide-spread HCCI utilization is the ability to rapidly and smoothly switch between HCCI and SI combustion as the power demand changes.

Recent work conducted at ORNL has been focused on operating a single-cylinder research engine in SI and HCCI modes by varying the amount of exhaust gas recirculation. During the transition from SI to HCCI combustion, there are complex but predictable patterns of unstable combustion which can be stabilized with adaptive control strategies. In FY 2006, ORNL will install a state-of-the-art, ARES-representative, single-cylinder engine to further explore the potential benefits of adaptive control to SI and HCCI combustion.

Points of Contact:

Dean Edwards, Oak Ridge National Laboratory, 865-946-1213, edwardskd@ornl.gov
Robert Wagner, Oak Ridge National Laboratory, 865-946-1239, wagnerrm@ornl.gov

UT-BATTELLE