Onboard Fuel Reforming for High-Efficiency, Clean Heavy-Duty Generators

Innoveering, LLC develops technical solutions for energy, defense and aerospace markets, focusing on designing and building advanced power generation and propulsion systems. In the market of power generation, Innoveering focuses on flex-fuel combustion, distributed power generation, reduction of greenhouse gas emissions, fuel cells, catalysis and energy storage.

Innoveering has been present in this market since 2012, when it was founded by former technology leaders from Alliant Techsystems (ATK) and General Applied Science Laboratories (GASL).

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Brand: Innoveering
Industry: Power Generation & Propulsion
Location: Ronkonkoma, NY
Website: http://innoveering.net/

MOTIVATION

Natural gas is an abundant domestic fuel and has been increasing its market share compared to conventional petroleum fuels because of its lower price and lower CO_2 emissions per unit energy. Also, its expanding infrastructure has increased its popularity for power generation.

Figure 1: A Caterpillar 3520C stationary generator

Lean-burn spark-ignition engines can be a promising solution for increased efficiency and reduced emissions in propulsion and power generation. Burning natural gas in them provides an opportunity to capitalize on the benefits of both. However, natural gas-air mixtures are difficult to ignite under lean conditions that are beneficial for thermal efficiency. A proposed solution is partial substitution of natural gas by hydrogen (H_2), which increases the flammability of lean mixtures. However, hydrogen is not readily available and it has to be derived from other sources.

Along with the expansion of natural gas, markets have turned to alternative (non-fossil) fuels for power generation. Locally harvesting biogas or waste for commercial or industrial use has been proposed and it has received increased scientific and commercial attention.

NEW SOLUTIONS

Innoveering is developing a robust catalytic reformer that takes any hydrocarbon fuel as an input and creates synthesis gas or syngas (a mixture of CO and H_2), which can be used to improve the combustion characteristics of heavy-duty engines used for stationary power generation. The reformer design includes a continuous feed tubular reactor and novel feed system that help to achieve significant energy density advantages over existing solutions.

Stony Brook University (SBU) has been amongst the first to realize the potential of the advancements in parallel computing to improve computational modeling and contribute to the design of new products. The foundation of the Institute of Advanced Computational Science (IACS) in 2012 and its close collaboration with the Computational Science Center of Brookhaven National Laboratory (BNL) have increased the available computational resources enabling complex and detailed simulations.

The opportunity to cooperate with Innoveering appeared based on a practical application of fuel reforming that is not completely understood: How does syngas affect the combustion process of heavy-duty engines and how can fuel reforming be optimized for use with natural gas as the fuel? SBU was able to respond with expertise in combustion modeling and high performance simulations.

MODELING AND SIMULATION

Accurate production of a natural gas-syngas generator requires a computational fluid dynamics (CFD) model of an engine cylinder, which was created in Converge CFD. This model solves the conservation equations for fluid flow, heat transfer, and species concentrations in a variable volume (piston motion) using a time-dependent grid and advanced numerical schemes. These features require significant computing power, which is available at IACS.

Converge CFD is a commercial CFD code distributed by Convergent Science, Inc. and represents the industry standard for internal combustion engine simulations. It was selected based on its automatic mesh generation, advanced numerical schemes, and large parallelization capability. The software also offers adaptive mesh refinement, which is key in capturing gradients of critical quantities such as species concentration and temperature.

Converge uses chemical kinetics mechanisms as inputs to simulate combustion with different fuel-air mixtures. Its advanced numerical schemes can decouple the solution of the flow field from chemistry calculations, which enables optimization for computational efficiency. Converge also utilizes a load balancing algorithm to balance the computational load between processors and further increase computational efficiency.

RESULTS

With support through New York's High Performance Computing Consortium (HPC^{NY}) and IACS, Stony Brook Mechanical Engineering is working closely with Innoveering to investigate the effect of catalytic reforming on heavy-duty natural gas combustion. The IACS computational resources enable detailed simulations towards understanding the combustion process and the potential benefits from syngas addition.

Figure 2 shows an example of CFD results that indicate flame propagation and temperature in the combustion chamber (top), and subsequent NOx formation in the high-temperature burned gas (bottom). The high level of analysis provided by SBU has enabled a thorough understanding of the associated physical processes and accelerated system design.

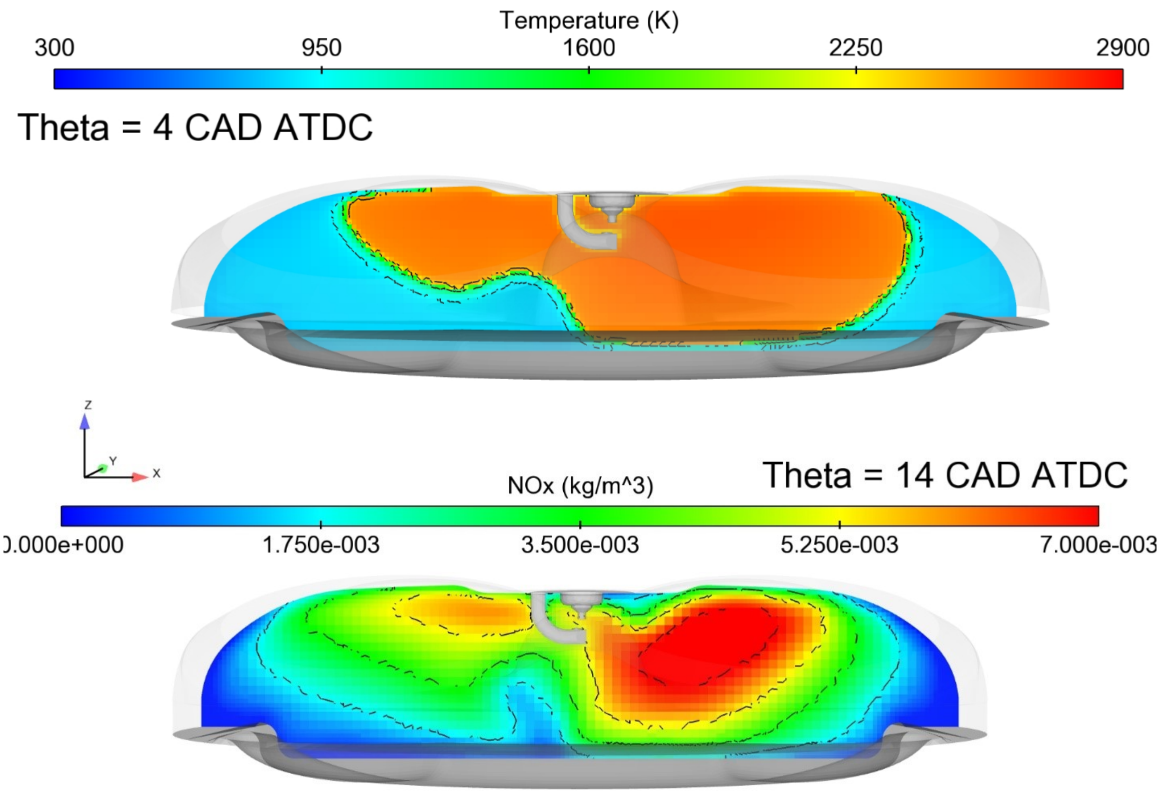

Figure 2: Temperature and NOx formation predicted by the CFD model

Recent progress in understanding combustion processes has enhanced the collaboration between SBU and Innoveering and paved the way for the design of generators operating on a mixture of natural gas-syngas. Key to this success has been the IACS' ability to work with commercial software such as Converge CFD while also leveraging research software tools and other open source platforms. Such activities are providing multiple benefits for job creation in New York State, adoption of the technology by larger commercial partners, utilization of alternative and renewable fuels, and economic growth on a regional and national level.

"High performance computing and our partnership with the Institute for Advanced Computational Science at Stony Brook University is accelerating innovation and technology deployment for Innoveering. These efforts will advance the state of the art in next generation power and propulsion technology." — Dean Modroukas, Ph.D., President, Innoveering LLC.

ABOUT HPC^NY

Funded by ESD Division of Science, Technology & Innovation, HPC^NY is a partnership between NYSERNet, a private not-for-profit corporation created to foster science and education in New York, and three supercomputing centers: the Rensselaer Polytechnic Institute Center for Computational Innovations, Stony Brook University/Brookhaven National Laboratory's New York Center for Computational Sciences, and the University at Buffalo's Center for Computational Research.

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HPC^NY provides businesses and research organizations with access to world-class advanced computing expertise through accelerating the engineering and development path of complex, ground-breaking designs to reliable, accurate, innovative product and process performance that can provide a distinct competitive advantage.

ABOUT IACS

The mission of IACS is to make sustained advances in the fundamental techniques of computation and in high-impact applications, with a vision that by 2017 it will be an internationally recognized center having vibrant multidisciplinary research and education programs, and demonstrated economic benefit to New York State. The aim is to approach 100 people by 2018 including students and staff. IACS currently has about 30 affiliated faculty from chemistry, materials science, physics, astrophysics, atmospheric science, nano-science, sociology, applied mathematics, engineering and computer science.

The IACS computational infrastructure features two HPC clusters including the LIRED and Handy Clusters. LIRED is a 10 TFLOP Cray cluster funded by the Long Island Regional Economic Development Council. "LIRED" is outfitted with 100 compute nodes from Cray, each with two Intel Xeon E5-2690v3 CPUs. These Intel CPUs are codenamed "Haswell" and offer 12 cores each, and operate at a base speed of 2.6 Gigahertz. The system also highlights a large memory node that spotlights 3 TB of DD4 RAM and 4 Intel E7-8870v3 processors with 18 cores each operating at 2.1 Gigahertz, for a total of 72 cores and 144 threads (via Hyper-Threading). Handy is a cluster from Lenovo that includes 40 compute nodes (each with dual socket 2.6 GHz Xeon E5-2670 processors, 16 cores per node, and 128 GB of memory), two of which are configured with larger memory (256 GB) to support data analysis and software development. One of these nodes are also equipped with two Intel Xeon Phi co-processors, and the other with two NVIDIA Tesla K20s.

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