"X-Ray Vision" Allows Groundbreaking Engine Research

Challenge

To reduce environmental degradation caused by semi-trucks, sport-utility vehicles, light-duty trucks, trains, and, potentially, diesel-hybrid cars, manufacturers must improve the combustion process in diesel engines. For today's direct-injection engines, the key to improving diesel combustion is obtaining a better understanding of the mechanisms of the fuel spray: atomization, mixing with air, and initiation and maintenance of combustion. Current laser techniques provide a certain level of knowledge with qualitative images. But a deeper, quantitative understanding had to wait until someone could apply x-ray vision to a fuel spray injection chamber — providing a way to directly observe all the details of an engine at work and allowing further improvements in engine design, efficiency, and emissions reduction.

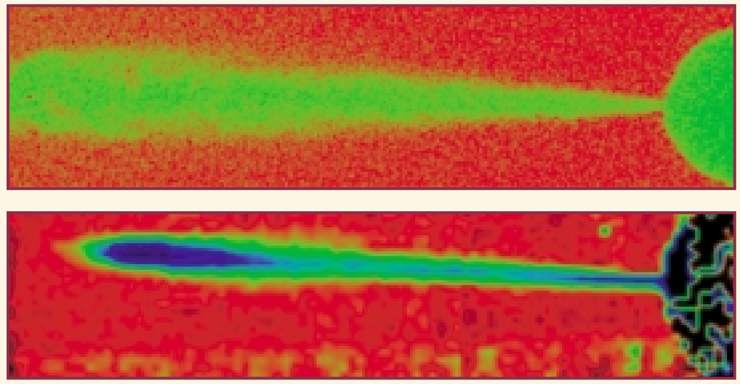

Figure 2. Unlike conventional optical techniques, x-rays provide quantitative data on the internal workings of an engine.

Argonne's Role

Argonne researchers are using x-rays to usher in a new era in engine research. Their work — which won the team the 2002 National Laboratory Combustion and Emissions Control R&D Award — makes it possible to use x-rays to penetrate gasoline and diesel sprays (Figure 1). This new diagnostic tool provides researchers with a new way of looking at heretofore unseen fuel spray regions. It allows detailed measurements of fuel injection systems for diesel engines, which in turn will help bridge the gap between applied research, with its emphasis on the inner working of engines, and basic research, with its emphasis on the physics and chemistry of droplet combustion.

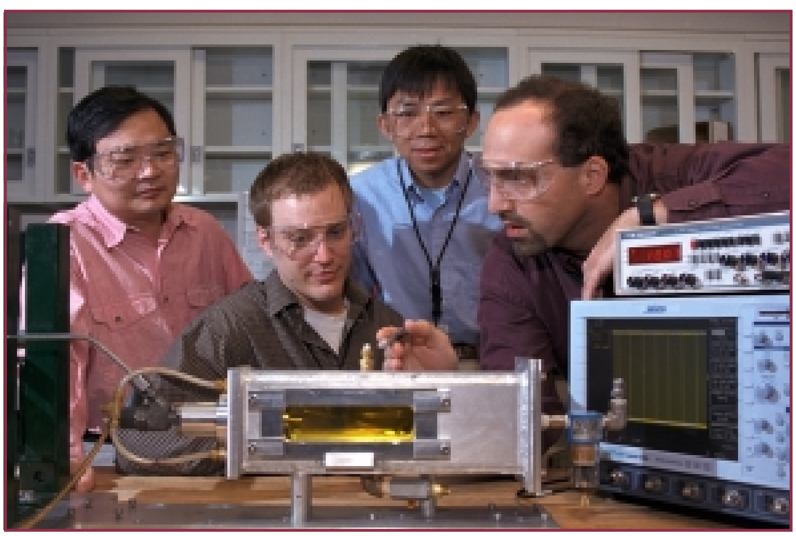

Figure 1. Recent DOE award-winning team with their fuel spray injection chamber.

Groundbreaking experiments at Argonne's Advanced Photon Source employ synchrotron radiation to allow scientists to see near-nozzle phenomena for the first time and to track the fuel mass of a spray, unlike the previous standard of optical-based techniques like lasers or photos, which illuminate only external functions. A newly designed fuel spray injection chamber provides researchers with more realistic engine operating conditions, accessible to x-rays and capable of achieving an environment that approximates the real-world conditions of an engine (Figure 2).

Approach

To study the fuel sprays, the researchers employ a high-pressure injection system (about 20,000 psi) similar to that of a modern diesel passenger car. The fuel is sprayed from the nozzle into a chamber filled with sulfur hexafluoride and nitrogen at atmospheric pressure and at room temperature. The density of the sulfur hexafluoride simulates the high-pressure environment inside an automotive diesel engine.

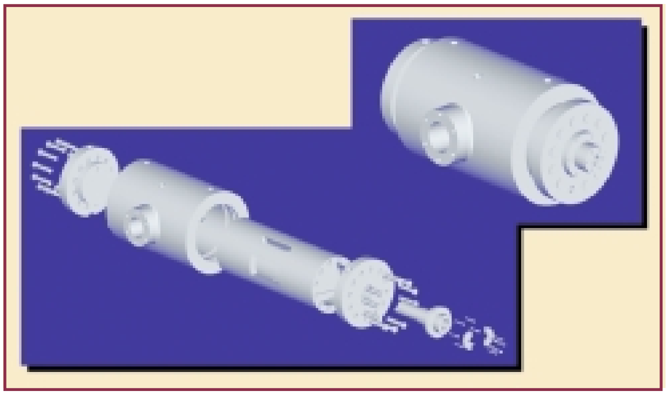

Figure 3. Isometric drawing of pressurized spray chamber with x-ray-accessible windows.

X-rays probe the fuel spray through windows on the side of the chamber (Figure 3). The highly penetrative nature of x-ray beams make them ideal for studying extremely dense droplets composed of materials with a low atomic number. Those that pass through are measured by the avalanche photodiode — a detector that maps the absorption of the fuel spray — and then they are transmitted to an oscilloscope that plots the voltage changes over time. The resulting graph is stored in a computer to be combined later with data from other sprays to create a picture. The x-rays that make it through are compared with the number that were sent into the chamber. The difference reveals the total mass of the fuel, which optical techniques cannot measure.

Accomplishments

- Argonne researchers made the first quantitative measurements of a shock wave in diesel fuel spray (caused by a liquid penetrating into a gas). The presence of shock waves challenges current assumptions about spray dynamics and may lead not only to more accurate modeling of spray fluid mechanics, but to precisely tuned injection systems.
- Spray characteristics can be correlated with experimental engine emissions data. Different fuel additives having different levels of x-ray absorptive quality allow the use of higher-energy x-rays and deliver more accurate results with fewer experimental runs.
- A pressurized chamber, tested at up to 1,800 psi, creates an experimental environment similar to that of an operating diesel engine.

Collaborators

Bosch Injector
Brigham Young University
Cornell University

Sponsors

U.S. Department of Energy, Office of Basic Energy Sciences
U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

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