Controlled Combustion

Investigators
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Objective
This project aims to extend kinetic models of combustion to the "controlled combustion" regime of high-temperature, pressure and dilution ratio.

In conventional combustion devices, the chemical conversion of fuel and oxidizer to products occurs rapidly in an uncontrolled and highly irreversible process (flame). Kinetic models of conventional combustion processes have been used successfully to design more efficient, less polluting and more durable combustors. However, the controlled combustion regime lies outside the regime of conventional combustion processes and the chemical processes in the controlled combustion regime are poorly understood at the fundamental level needed for design optimization, especially for high-pressure combustion systems such as gas turbines and diesel engines. This project seeks to gain such an understanding by measuring the reaction progress of highly dilute, high-pressure combustion.

Background
In controlled combustion, the rate of the fuel conversion process is varied by imposing prescribed initial conditions (temperature and mass fractions of oxidizer and diluents), leading to potential reductions in irreversibilities in energy conversion and to reduced emissions of pollutants and greenhouse gases. One example of controlled combustion is the "flameless" oxidation process in which exhaust heat recovery and exhaust gas recirculation are employed to cause combustion to occur in a more homogeneous fashion. In the present project, this concept is being extended to include diluents such as nitrogen and carbon dioxide that could be produced in separation processes and delivered to the combustion system. Carbon dioxide is particularly interesting in that it can have both a thermal and chemical effect on the combustion reaction. The regime of controlled combustion is illustrated in Figure 1.

Figure 1: Controlled Combustion Regime

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Flameless oxidation systems have been engineered for high-temperature, highly irreversible processes (furnaces and process heaters), however very little is understood about this combustion regime. For example, there are no data on reaction rates, although there is theoretical evidence to suggest that the rate constants should be dependent on temperature and pressure under these conditions.

**Approach**

The regime of controlled combustion is being investigated experimentally in a high-pressure flow reactor facility, (Figure 2), in which important parameters, such as preheat and dilution, can be independently controlled. Fueling is controlled by a primary layer of injectors, while dilution and temperature trim are controlled by a secondary layer of injectors. The fuel can be hydrogen, methane or a synthetic blend of methane/ethane to simulate natural gas. The diluent can be carbon dioxide or nitrogen.

![High-Pressure Flow Reactor](image)

**Figure 2:** High-Pressure Flow Reactor

The spatial evolution of the chemical reaction is monitored by probe-extractive sampling for key reactant and intermediate product species, as well as by temperature.

Detailed modeling of the data will yield chemical models for use in the design of controlled combustion systems and particularly for use in modeling low-irreversibility combustion engines, which is another project being funded by the Global Climate and Energy Project.

To date, significant progress has been made on the characterization of the reactor. The effectiveness of the mixing process has been examined through measurements of injected tracer species. The reactor has been run on hydrogen fuel, and the probe extraction system has been designed and fabricated.