Working towards clean energy

Fundamental research is taking place at the University of Central Florida, with a focus on clean energy. Erik Ninnemann, a second-year Ph.D. student in the Department of Mechanical and Aerospace Engineering, studies combustion science—in particular the *ignition delay times* of high-temperature carbon dioxide-diluted mixtures—with the goal of aiding in clean energy development.

As a member of Dr. Subith Vasu's laboratory, Mr. Ninnemann and others have been expanding the knowledge of how CO_2 concentration impacts ignition delay times. The experimental apparatus revolves around an 8.54 m shock tube divided by a diaphragm into two sections containing different gases at different pressures. When the diaphragm is removed, a shock wave is created as the gases in the tube attempt to reach equilibrium. Ignition occurs when the shock wave reaches the end of the tube. The ignition delay time is then the time between the shock wave reaching the test location at the end of the tube and when ignition occurs. It is on the microsecond time-scale. Using CO_2 in these measurements is important, since the majority of previously available data does not use CO_2 as the primary diluent.

The collected data is instrumental for knowledge about supercritical carbon dioxide (sCO_2) cycles, which simulations show have the ability to be as efficient as current state-of-the-art energy cycles with a 99% decrease in CO_2 and NO_x emissions. While widespread CO_2 power plants are still an idea of the future, data collected has lead to real-world technology development. In Texas, a carbon dioxide-based power plant is in progress using technology that Dr. Vasu's laboratory helped develop.

CO_2 is both the working fluid in the combustion and one of the emitted by-products. For example, when an oxy-methane mixture with carbon dioxide combusts, carbon dioxide and water are the resultant by-products. The carbon dioxide can then be re-captured by condensing the water, and used in later cycles. In this way, the supercritical CO_2 cycle is extremely efficient without major greenhouse gas emissions.

Time measurements

To measure the ignition time delay accurately, the time zero of the combustion needed to be well defined. CO_2 dilution causes difficulties, due to the shock wave becoming bifurcated. This non-ideal shock wave makes using traditional methods of defining time zero difficult. In the past, pressure sensors were used to determine when the shock wave arrived at the test location. However, with a non-uniform shock wave, the pressure is no longer a reliable time of arrival indicator.

To avoid this, the Schlieren peak of a continuous wave laser (emitting around 3400 nm) was used to define the time zero. The Schlieren peak is seen when the gas density in the beam path changes sharply, indicating a passing shock wave.

To determine the delay between time zero and ignition, multiple methods are available. There are methods that involve statistical analysis of the emission, studying the rise of the emission signal, and the slope (with respect to time). Doing this allows an extrapolation of the onset of ignition. Other options involve using high-speed cameras and image analysis to define ignition time. A final option involves using a laser to interrogate the gaseous mixture in the tube, searching for absorption trends of specific molecules throughout the experiment. A quantum cascade laser (QCL) from mirSense is used for this interrogation. The discreet QCL emission line matches the absorption features of the molecules well. In the event of interfering molecules in the reaction, the QCL can be slightly tuned away from this interference.

Results

The ignition delay time varies with CO_2 concentration, pressure, and temperature. With the shock tube apparatus, experimental temperatures ranged from 1000 – 2000 K, with pressures reaching 30 atm. CO_2 concentrations were tested up to 85% of the gas concentration. Ignition delay times ranged from sub-100 μs to approximately 1 ms, depending on the experimental configuration. The wide variety of tunable parameters and gathered data is aiding greatly in the understanding of how a supercritical CO_2 cycle functions, and leading to the development of cleaner energy production.

Moving forward, Mr. Ninnemann plans to graduate in the summer of 2021. While working towards his Ph.D. he will continue increasing the pressure and CO_2 concentration of the ignition time delay measurements. This will continue to add valuable information to the sCO_2 database, while improving the models to simulate such cycles.