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Gas Supply System (HPCEF) for Studies on Combustion in Reactive Flows at Elevated Pressures

1 Statement of the Problem Studied

The U.S. Army Research Office (ARO) previously provided support to construct a "High Pressure Combustion Experimental Facility" (HPCEF), at the Combustion laboratory of the University of California at San Diego (UCSD), for carrying out experimental studies on combustion of a wide variety of gaseous and liquid hydrocarbon fuels, including commercial fuels for example JP-8 and Jet A, at pressures up to 25 bar. A notable feature of this facility is that it permits experiments to be carried out in nonuniform flows. In contrast, experiments conducted employing shock tubes and rapid compression machines, do not include the influence of flow on combustion. The HPCEF has been successfully employed to characterize combustion of many fuels in nonuniform flows at elevated pressures These studies have shown, for the first time, the influence of pressure on critical conditions of extinction of nonpremixed hydrogen, methane, ethane, and ethene flames, and the influence of pressure on critical conditions of extinction and critical conditions of autoignition of reference fuels, jet fuels, and surrogates. These studies have highlighted the influence of low temperature chemistry in promoting autoignition of high molecular weight hydrocarbon fuels. In view of the success of these previous studies at elevated pressures, additional funding was received from ARO to extend the maximum operating pressure of HPCEF from 25 bar to 60 bar. These studies provide fundamental knowledge that is relevant to the Army's need for high performance propulsion systems. High temperature and high pressure are encountered in these systems. The data at elevated pressures could be employed to test predictive models required to advance current understanding of fundamental chemical processes that characterize the combustion of jet fuels.

To complete a set of experiments significant quantities of nitrogen and air are required. Previously these gases were supplied from pressurized gas cylinders. For example for conducting one set of experiments, nitrogen from twenty-five pressurized gas cylinders and air from six pressurized gas cylinders were required. These gas cylinders need to replaced frequently. This was labor intensive and resulted in delay. The current support from ARO was used to upgrade the gas delivery system to allow higher supply of nitrogen and air to HPCEF with less frequent replacement of the pressurized gas cylinders. This improved gas delivery system has significantly enhanced current research capabilities and research-related education of our ARO supported research on combustion of jet fuels and surrogates at elevated pressures.

2 Summary of the Most Important Results

Figure 1 shows a photograph of the previous gas-handling system. One pressurized nitrogen gas cylinder holds 6450 liters of gas at STP. Experiments at 13 bar require 700 L/min of nitrogen. Therefore the run-time employing twenty-five pressurized nitrogen tanks is $6450 \times 25 \times 0.75 / (700 \times 60) = 2.8$ hrs including warm-up and shutdown. Here a flow factor of 0.75 is employed to account for the fact that the cylinder can only be depleted up to 500 psi. At 25 bar the experiments require 1500 L/min of nitrogen. A similar calculations shows that the run-time including warm-up and shutdown is 1.3 hrs.

Figure 2 is a schematic illustration of the high-capacity gas-handling system that was recently constructed using support from ARO. The key components are the liquid nitrogen storage tank and the "Suregas system" for gas delivery to the HPCEF. This system is made up of the cryogenic pump, vaporizer, and the cylinder-pack buffer. Liquid nitrogen is stored in a tank with a capacity of 1500 liters (roughly 390 gallons). It holds roughly 10^6 liters of nitrogen at STP. It allows a maximum flow rate of 50,000 liters per hour. It is placed on a stand that is roughly 1.5 m in diameter and 2.4 m high. The cryogenic pump is used to transport liquid nitrogen to a vaporizer. The vaporized liquid nitrogen is then introduced to a buffer that is made of twelve cylinders. The gaseous nitrogen from the cylinders are then introduced into the gas-handling system of the HPCEF. Figure 3 is a photograph of the liquid nitrogen tank, the vaporizer and the 12-cylinder buffer pack. Figure 4 is a photograph of the cryogenic pump and motor. Figure 5 is a photograph of the control panel. The main control panel features a PLC (Programmable Logic Controller) which monitors various sensor devices in the system (1.e pressure and temperature) and control various devices (i.e alarms and indicator lights). Two oxygen sensors with alarms are installed in the laboratory to monitor the concentration of oxygen. The alarms will switch on in the event of accidental leak of nitrogen from the tank.

The nitrogen from the 12-cylinder buffer pack flow into a system of computer regulated analog mass flow controllers to the pressure chamber of the HPCEF. Figure 6 is a photograph of the mass flow controllers. The system consists of two separate set of eight mass flow controllers placed in two levels and two four channel digital to analog (D/A) signal converters. The mass flow controllers at the lower level are for experiments for pressures up to 30 bar and the mass flow controllers on the upper level are for experiments at higher pressures up to 60 bar. Figure 7 shows the pressure chamber. It is made from stainless steel, is 40 inches tall and has a diameter of 15 inches with a wall thickness of 5/8 inch. The chamber is designed to withstand a pressure of 150 bar. It features four view-ports for optical access with an opening size of 3 inches. The bottom contains a number of through-puts for gas lines and electrical wiring. Threads for safety equipment and lifting hooks are incorporated in the top. The bottom is mounted to an aluminum stand, while the chamber cylinder and top can be lifted off, for easy access to the chamber inside. All flanges are sealed with o-rings and retained by bolted connections. Tempered quartz windows are employed in the view-ports. Tension and slight impurities can have a significant impact on such a brittle material. A special test bomb was designed to pressurize the windows in a safe environment to verify the ability to withstand desired operating conditions. The quartz windows successfully withstood a pressure of 80 bar.

The high-capacity gas-handling system has significantly increased the run-time. At 13 bar the run-time is $10^6/(700\times60)\approx23$ hrs, at 25 bar it is 11 hrs and at 50 bar it is 5 hrs.

List of Figures

Figure 1: Photograph of previous gas-handling system

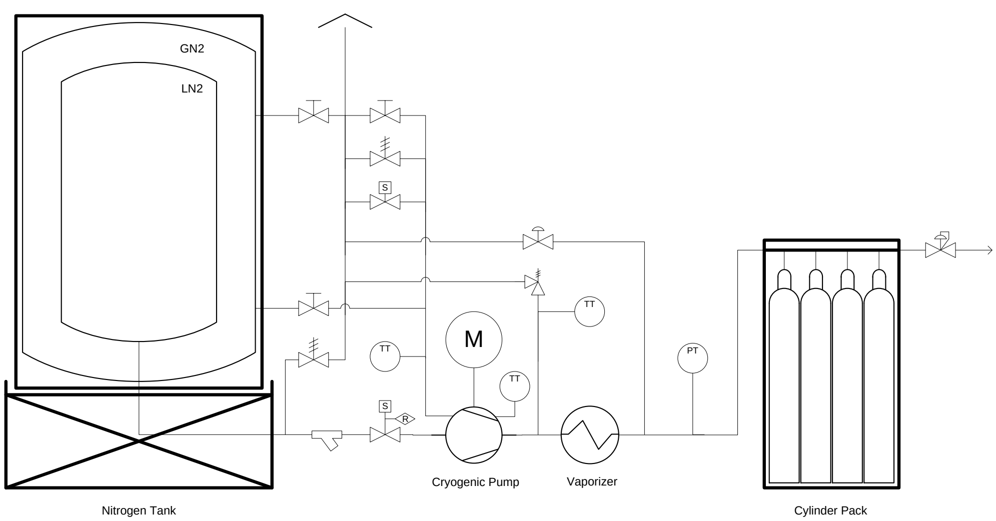

Figure 2: Sketch of the high-capacity gas-handling system

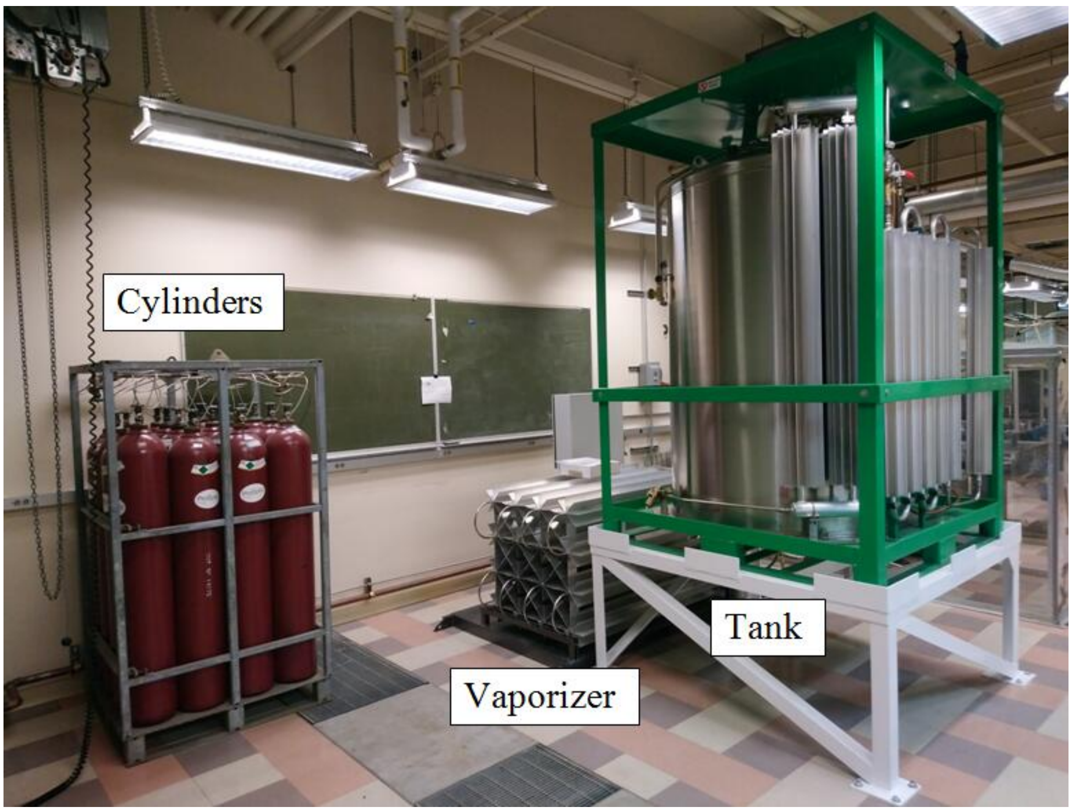

Figure 3: Photograph of the high-capacity gas-handling system. The photograph shows the liquid nitrogen tank and the 12-cylinder buffer pack

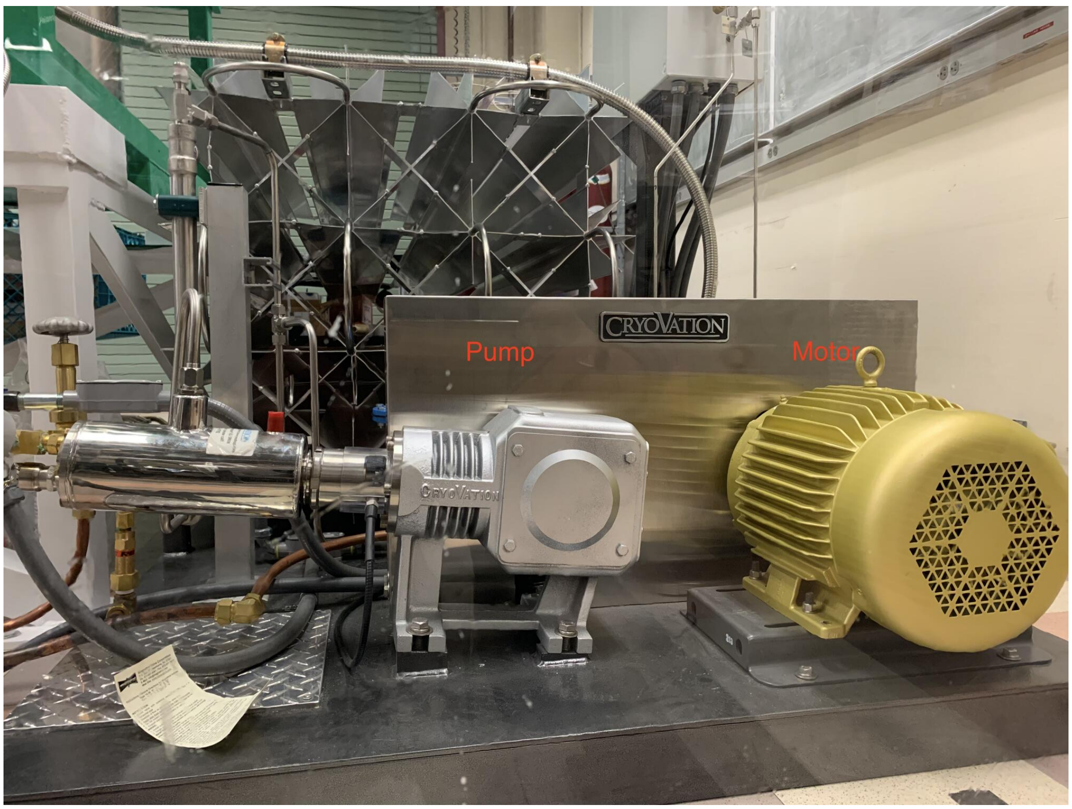

Figure 4: Photograph of cryogenic pump and motor. The vaporizer is behind the pump and motor

Figure 5: Photograph of the control panel.

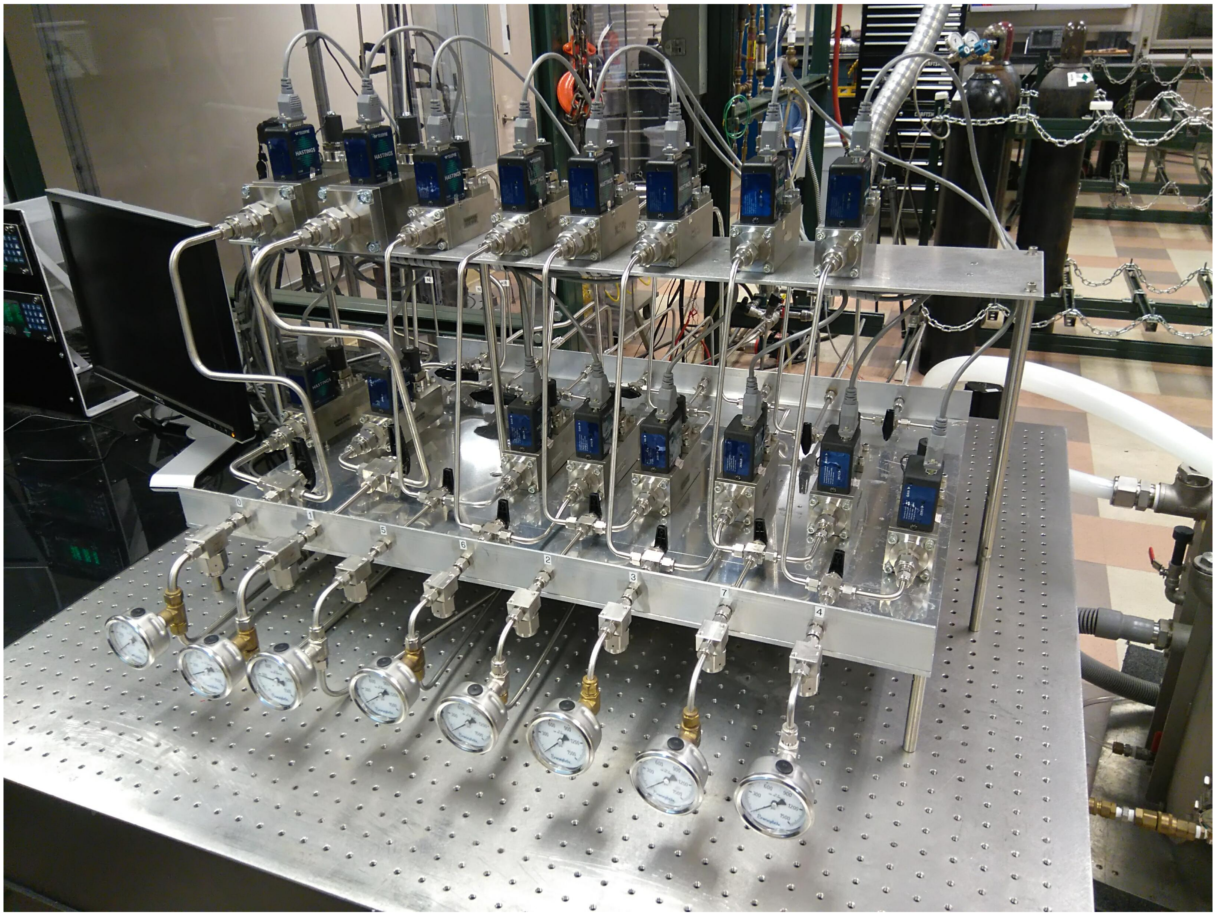

Figure 6: Photo of the flow control station featuring two sets of eight mass flow controllers in the range of 30 slm to 1500 slm for operational pressures of up to 1000 psi. Inlet pressure gauges allow easy monitoring of the gas supply pressure. Valves protect sensitive parts of the mass flow controller from pressure waves during start up procedure. Mass flow controllers are mounted horizontally to minimize the influence of natural convection on the accuracy for high pressure flows.

Figure 7: Photo of the stainless steel pressure chamber mounted to an aluminum stand. Flanges connecting the cylindrical part to bottom and top are reinforced with gussets. All gas lines enter the chamber through the bottom part. Top and cylindrical part of the chamber can therefore be lifted off without dismantling any connections. The chamber is enclosed in a high-impact polycarbonate cubicle that provides an increased degree of safety in case of malfunction or accident.