REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY) 13-12-2017	2. REPORT TYPE Final Report	3. DATES COVERED (From - To) 15-Aug-2015 - 14-Aug-2017

4. TITLE AND SUBTITLE Final Report: High Pressure Combustion Experimental Facility (HPCEF) for Studies on Combustion in Reactive Flows	5a. CONTRACT NUMBER W911NF-15-1-0341
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 611103
6. AUTHORS	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of California - San Diego Office of Contract & Grant Adm 9500 Gilman drive, MC 0934 La Jolla, CA 92093 -0934	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSOR/MONITOR'S ACRONYM(S) ARO 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 66931-EG-RIP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Kalyanasundaram Seshadri
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER 858-534-4879
UU	UU	UU	UU		

RPPR Final Report
as of 02-Jan-2018

Agency Code:

Proposal Number: 66931EGRIP **Agreement Number: W911NF-15-1-0341**

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DUNS Number: 804355790 EIN: 956006144
Report Date: 14-Nov-2017 Date Received: 13-Dec-2017
Final Report for Period Beginning 15-Aug-2015 and Ending 14-Aug-2017
Title: High Pressure Combustion Experimental Facility (HPCEF) for Studies on Combustion in Reactive Flows
Begin Performance Period: 15-Aug-2015 **End Performance Period:** 14-Aug-2017
Report Term: 0-Other
Submitted By: Kalyanasundaram Seshadri Email: kseshadri@ucsd.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0 **STEM Participants:** 0

Major Goals: The goal of this work is to construct an experimental facility for conducting experiments on combustion of Jet fuels at elevated pressures up to 60 bar. Using support provided previously by the U.S. Army Research Office (ARO) a ``High Pressure Combustion Experimental Facility'' (HPCEF) was constructed for carrying out 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 30 bar. In view of the success of these previous studies at elevated pressures up to 30 bar, additional funding was received from ARO to extend the maximum operating pressure of HPCEF from 30 bar to 60 bar. Several systems are integral to the facility. They include the flow control system, gas-supply system, the ignition system, the exhaust system, the cooling system, and the pressure control system. All these systems were successfully upgraded. The US Army is currently developing technologies to facilitate diesel-powered equipment and equipment employing spark-ignition combustion (for example Unmanned Aerial Vehicles) to be powered by JP-8. The HPCEF will make a significant contribution in providing fundamental knowledge on aspects of combustion at high pressures. This will provide the foundation for developing the technologies necessary for the conversion. The useful life of the HPCEF is estimated to be twenty years.

Further details are given in the attached report

Accomplishments: See attached

Training Opportunities: Nothing to Report

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

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Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
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Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

High Pressure Combustion Experimental Facility (HPCEF) for Studies on Combustion in Reactive Flows

Contents

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 30 bar. There was a need to extend the operating pressure of the HPCEF. To meet this need upgrades were made to the HPCEF to extend the operating pressure from 30 bar to 60 bar. Several systems are integral to the facility. They include the flow control system, gas-supply system, the ignition system, the exhaust system, the cooling system, and the pressure control system. All these systems were upgraded. The useful life of the HPCEF is estimated to be twenty years.

2 Introduction

The High Pressure Combustion Experimental Facility can be used to study non-premixed, premixed and partially premixed combustion. A notable feature of this facility is that it permits experiments to be carried out in nonuniform flows. The measurements that could be made include critical conditions of flame extinction and autoignition. Probes can be placed inside the pressure chamber to allow samples to be removed from the flame for analysis using gas chromatographs. Thermocouples can be placed inside the pressure chamber to allow measurements of temperature profiles. The facility has optical access to permit future nonintrusive, optical measurements of profiles of temperature and concentration of various species. Although the facility will be mainly employed for studies of combustion processes in nonuniform flow fields employing counterflow burners, it will be possible to house many different types of burners inside the pressure chamber. They include, for example, co-flow burners for studies on diffusion flames, and bunsen burners and flat flame burners for studies on premixed flames. The HPCEF is therefore a versatile facility that can be employed for experimental studies on non-premixed, premixed and partially premixed combustion using different burners and configurations.

The HPCEF has been successfully employed to characterize combustion of many fuels in nonuniform flows at elevated pressures [1–4]. These studies have shown, for the first time, the influence of pressure on critical conditions of extinction of non-premixed hydrogen, methane, ethane, and ethene flames [1, 2], and the influence of pressure on critical conditions of extinction [3] and critical conditions of autoignition [4] 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 [4]. 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 30 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.

The US Army is currently developing technologies to facilitate diesel-powered equipment and equipment employing spark-ignition combustion (for example Unmanned Aerial Vehicles) to be powered by JP-8. This conversion is a complicated process. Many issues with fuel properties and performance have to be considered. They include autoignition, combustion, fuel injection, lubricity, and spray characteristics. The HPCEF will make a significant contribution in providing fundamental knowledge on aspects of combustion at high pressures. This will provide the foundation for developing the technologies necessary for the conversion.

3 Description of HPCEF

3.1 The Pressure Chamber

The main part of the HPCEF is a cylindrical pressure chamber shown in Fig. 1. 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 viewports for optical access with an opening size of 3 inches. The thickness of the quartz windows in the viewports are 1 inch. Fig. 2 shows a photograph of the viewport. The bottom part of the HPCEF 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. The quartz windows successfully withstood a pressure of 100 bar.

3.2 Flow Control System

All gaseous streams are controlled by computer regulated analog mass flow controllers. Figure 3 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, that was added recently, are for experiments at higher pressures up to 60 bar. The HPCEF employs mass flow controllers with maximum flow rates in the range of 30 to 1500 slm. Mass flow controllers work on the principle of measuring the thermal dispersion in a flowing gas. Hence the heat capacity of the gas is the determining factor for the flow rate through the mass flow controller. In contrast to setting the volume flow rate, this method allows high accuracy independent of temperature or pressure of the supplied gas. Actual volume flow rates in the experiments are calculated based on mass flow rate and actual experimental conditions. The HPCEF uses significant amount of nitrogen because it is used to fill the HPCEF to the desired pressure, as a diluent of air, and "curtain flows" in the counterflow burner [1–4]. Nitrogen is also mixed with products of combustion and removed continuously from the HPCEF.

Gas Supply

Gases in the HPCEF are provided from standard compressed gas cylinders as shown in Figs. 4 and 5. To accommodate experiments at elevated pressures beyond 30 bar, the number of gas cylinders, manifolds have been increased to accommodate the higher flow rates at elevated pressures. The cylinders have a capacity of 228 ft^3 at 2200 to 2300 psig. A total number of fifteen standard compressed gas cylinders are required for experiments, 12 for nitrogen (see Figs. 4 and 5) and three for air (see Fig. 5). Each mass flow controller has its own supply unit, which consists of several cylinders, a manifold that merges the flows and a high-pressure regulator that provides gas at constant pressure. There are two quadruple manifolds and two double manifolds for nitrogen, one triple manifold for air. Depending on the mass flow requirements they are either connected through 1/4 inch or 3/8 inch stainless steel lines to the corresponding mass flow controller. Gas supply lines have been updated to accommodate the higher flow rates at elevated pressures. The lines have been tested.

3.3 Exhaust System:

The products of combustion enter an exhaust system where they are cooled before they are introduced into the exhaust treatment system in the laboratory. The exhaust system has been upgraded and tested to increase its operating pressure to 60 bar.

3.4 Water Separator Unit:

The purpose of the water separation unit is to separate exhaust gases from water and condensate. The unit and the chamber has been upgraded with new liquid-level sensors and a high-pressure drain valve. The control system has been upgraded to work with the new sensors.

3.5 Pressure Control System:

The pressure inside the chamber is held constant at a desired value by a PID controlled back-pressure valve. Figure 6 is a photograph of PID controlled back-pressure valves that can operate at pressures up to 1500 psi.

3.6 Safety Measures:

A high capacity relief valve has been mounted on top of the chamber to vent gases if the chamber is accidentally over-pressurized. The relief valve was calibrated to vent gases at the desired pressure. A new burst disc has been installed. An appropriate system has been installed for emergency depressurization, venting and draining water.

3.7 Counterflow Burner:

All counterflow burners were upgraded to operate at pressures up to 60 bar. Figure 7 shows a photograph of condensed-fuel counterflow burner. It shows oxidizer duct (1), the liquid-pool assembly (2), and the water collector unit for cooling exhaust gases (3). The counterflow burner is made up of two concentric quartz tubes. The inner tube has an inner diameter of 25.4 mm and an outer diameter of 27.4 mm.

Upgrades were done to the oxidizer duct of the counterflow burner used for heating air and nitrogen for use in autoignition experiments. Figure 8 is a photograph of the oxidizer duct. The air mixed with nitrogen flows through the inner tube and nitrogen through the outer tube. Three 200 mesh fine wire Inconel 600 screens are placed at the exit of the quartz tube to achieve plug-flow conditions at the exit. The screens are held with inconel rings and are recessed by 1 mm. A silicon carbide heating element, 381 mm long with a diameter of 33.1 mm and a output of 3600 watts, is placed inside the inner quartz tube. The distance between the end of the heating element and the exit oxidizer duct is 80.0 mm. The surface of the heating element can reach a temperature of 1900 K. To minimize heat losses to the environment the duct is surrounded by a 2260 watt cylindrical ceramic heating furnace that can reach a surface temperature of 1200 K. Three 750 watt process heaters are used to preheat the oxidizer up to 700 K before it enters the quartz tube.

List of Figures

References

[1] U. Niemann, K. Seshadri, and F. A. Williams. Effect of pressure on structure and extinction of near-limit hydrogen counterflow diffusion flames. *Proceedings of the Combustion Institute*, 34:881–886, 2013.

[2] U. Niemann, K. Seshadri, and F. A. Williams. Methane, ethane, and ethylene laminar counterflow diffusion flames at elevated pressures: Experimental and computational investigations up to 2.0 MPa. *Combustion and Flame*, 161:138–146, 2014.

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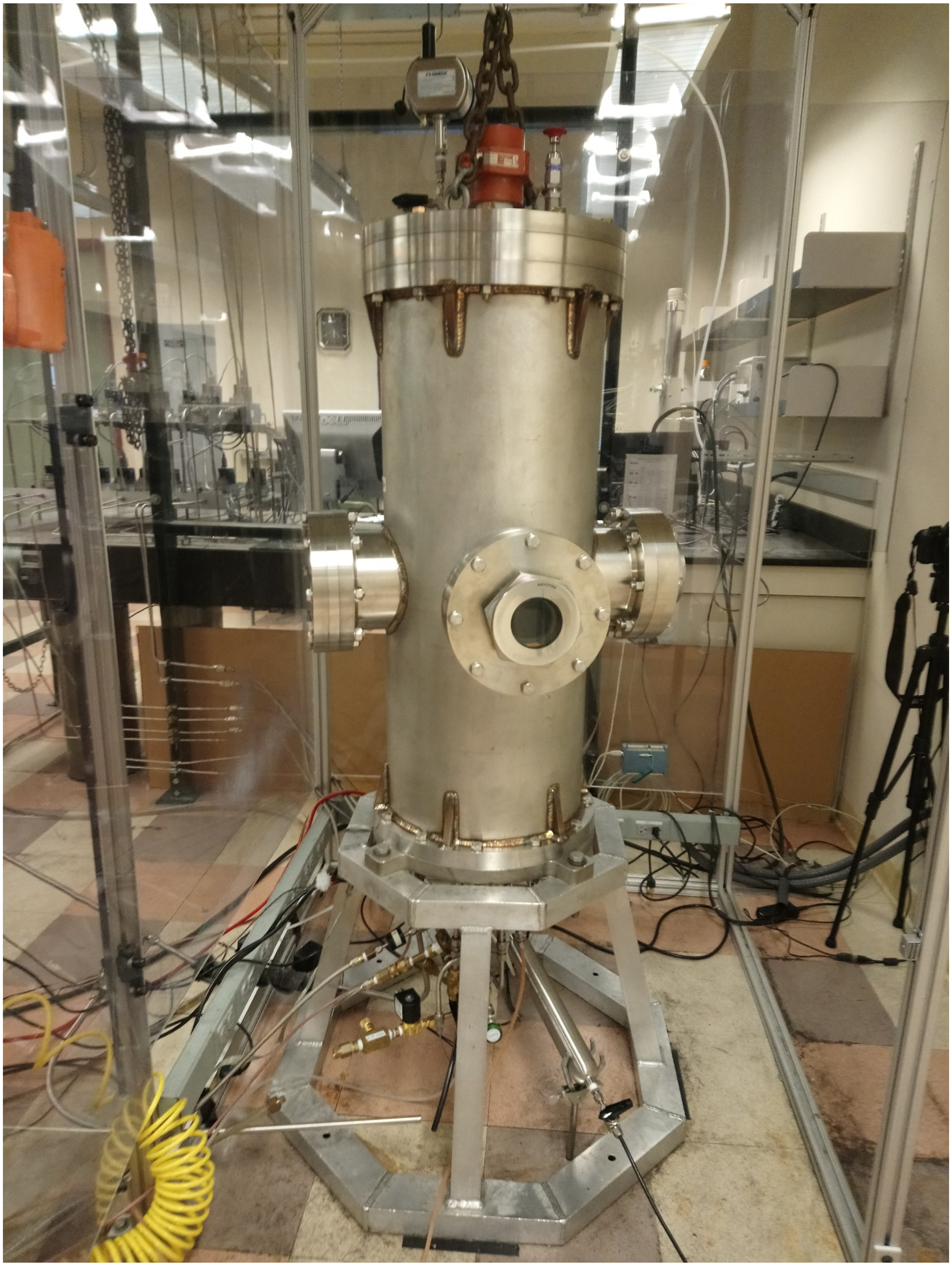

Figure 1: Photo of the stainless steel pressure chamber mounted to an aluminum stand. Flanges connecting the cylindrical part to bottom and top are reinforced with gussets. All gas lines enter the chamber through the bottom part. Top and cylindrical part of the chamber can therefore be lifted off without 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.

Figure 2: Photo of the viewport with and the quartz window.

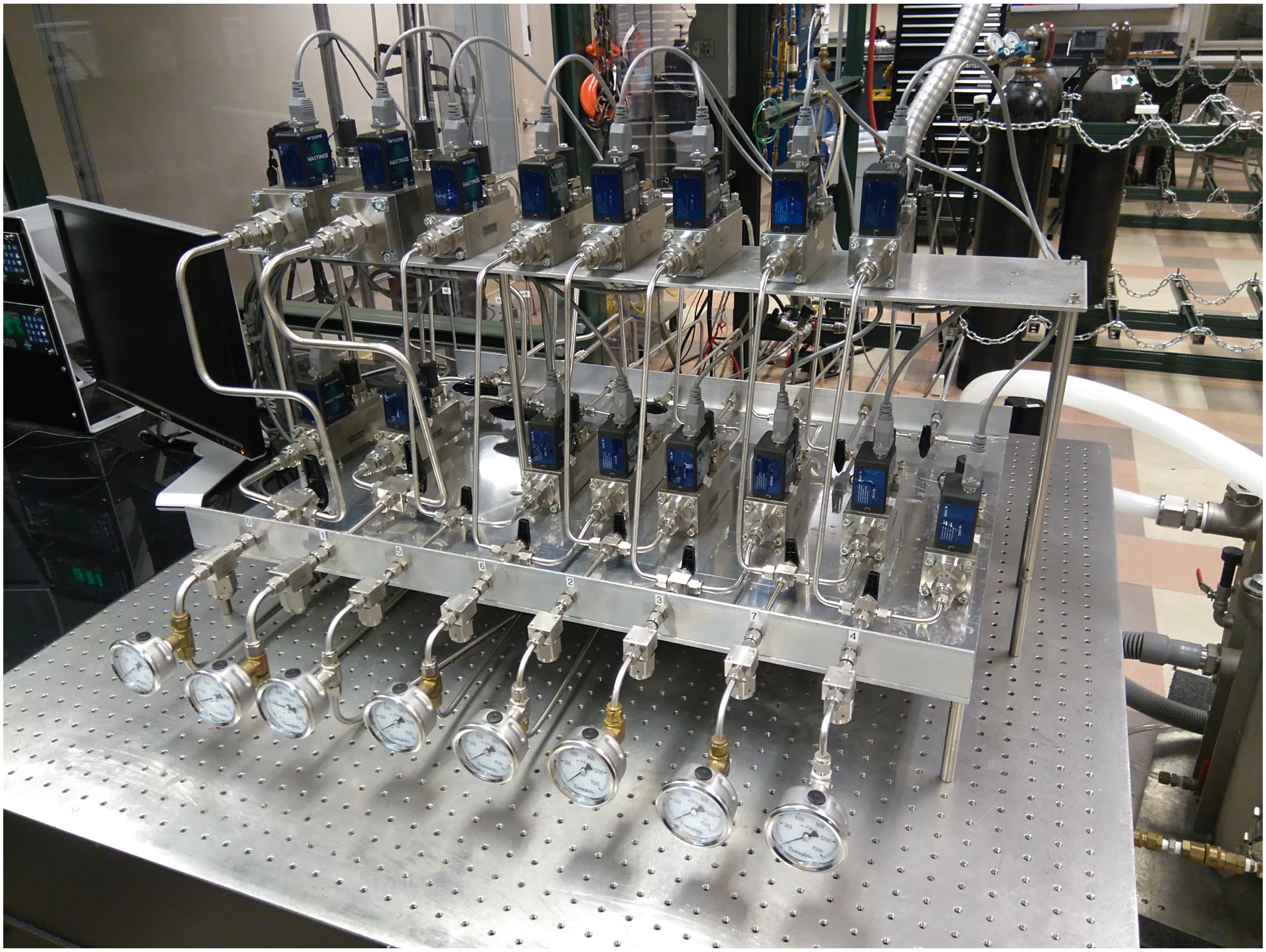

Figure 3: Photo of the flow control station featuring two sets of eight mass flow controllers in the range of 30 slm to 1500 slm for operational pressures of up to 1000 psi. Inlet pressure gauges allow easy monitoring of the gas supply pressure. Valves protect sensitive parts of the mass flow controller 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 4: Photo showing 10 nitrogen gas cylinders attached to two quadrapole manifolds and one double manifold. Two cyliders that supply gaseous fuel are placed in the cabinet.

Figure 5: Photo showing two nitrogen gas cylinders attached to a double manifold and three air cylinders attached to a triple manifold.

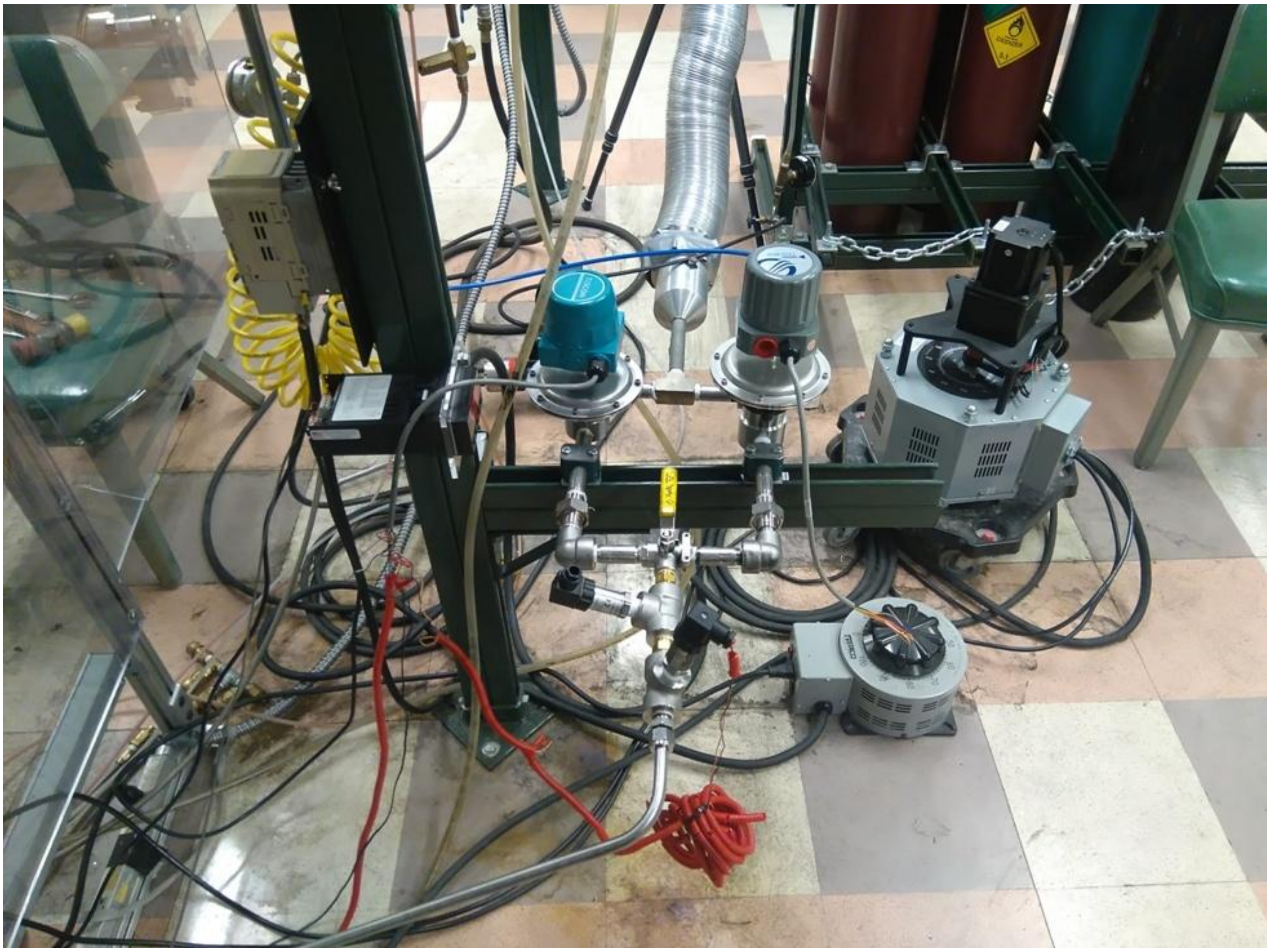

Figure 6: Photo of the backpressure valve.

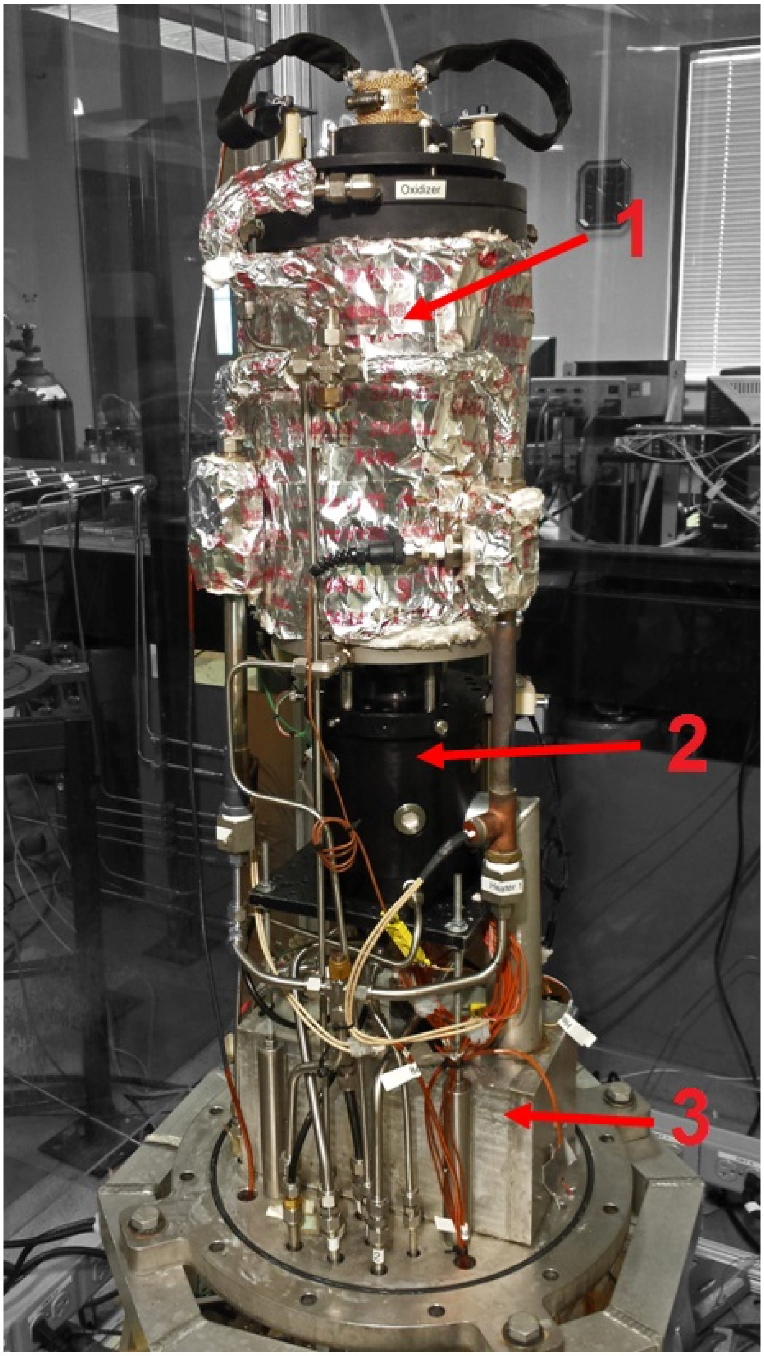

Figure 7: Photograph of the burner. It shows the oxidizer duct (1), the liquid-pool assembly (2), and the water collector unit for cooling exhaust gases (3).

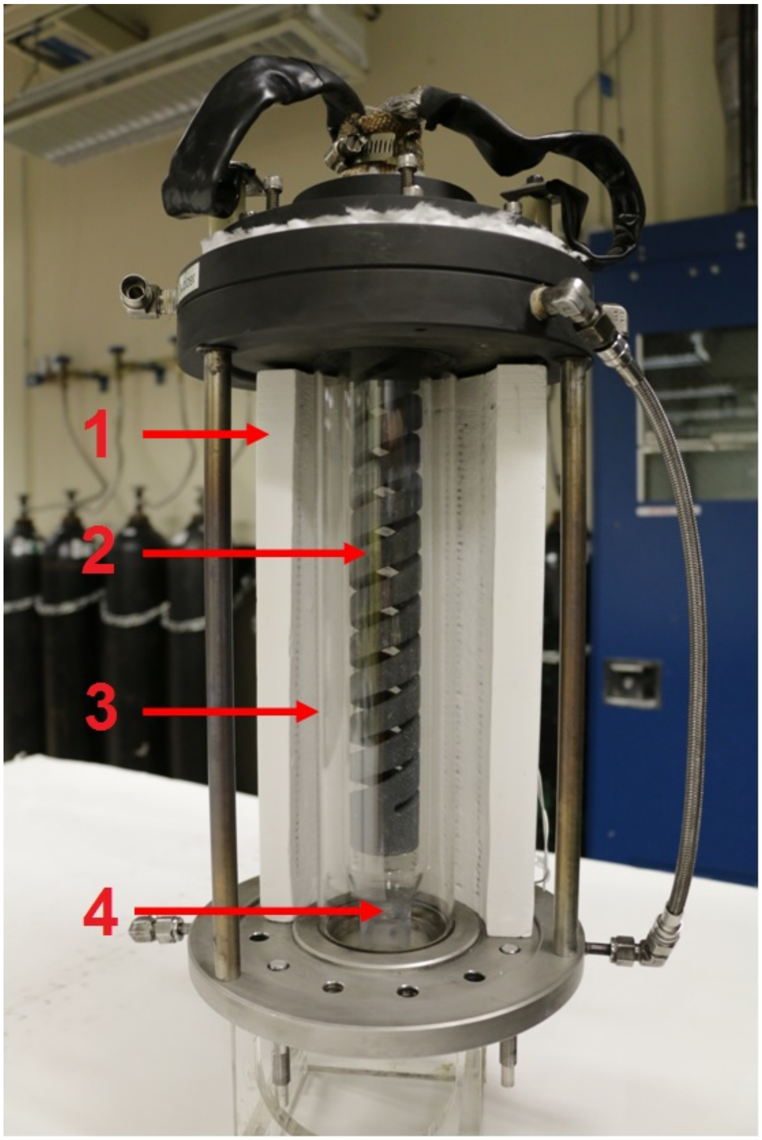

Figure 8: Photograph of the oxidizer duct of the counterflow burner used for heating air. It shows the ceramic heater (1), the silicon carbide heating element (2), the concentric quartz tube for nitrogen shield (3), and quartz tube for oxidizer (4).