Experimental Investigation of Endothermic Fuel Cracking for Cooling Hypersonic Vehicles

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MOTIVATION

The Air Force's scramjet (**s**upersonic **c**ombustion **ramjet**) is a jet engine in which combustion takes place in supersonic airflow. As scramjet flight speeds increase to supersonic and hypersonic regimes, the temperature of the ram air taken on board the vehicle becomes too high to cool the structure. Therefore, it is necessary to use a fuel that undergoes endothermic cracking as the primary coolant.

The primary focus of this project is to develop a fundamental understanding of the coupled homogeneous and heterogeneous reactions that occur during endothermic fuel cracking; which will be partly accomplished through the investigation of gas-phase and surface reaction interactions in a High Pressure Flow Reactor.

Figure 1. Boeing X-51 WaveRider [1]

BACKGROUND

Hydrocarbon fuels undergoing endothermic cracking before entering the combustor offer increased cooling capacity. A major obstacle is the formation of pyrolytic coke deposits on heat exchanger walls during extended runs at elevated temperatures; the formation of coke deposits degrades heat transfer and fuel flow characteristics.

The main focus for this project includes:

- The design and manufacture of a fuel pump and delivery system to study the breakdown of pentane
- The use of LabVIEW to control and operate the entire system
- The use of a Gas Chromatograph (GC) to analyze gas samples after pyrolysis

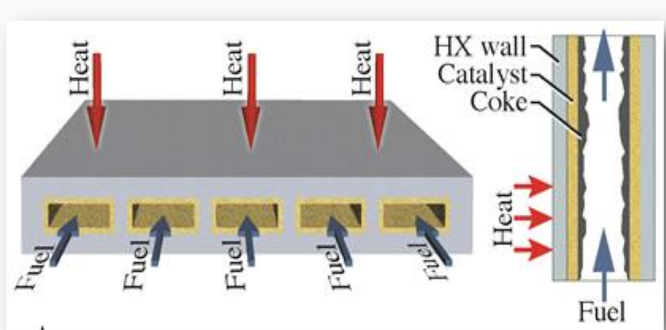

Figure 2. Coke Deposits within Heat Exchanger [2]

HIGH PRESSURE FLOW REACTOR

The High Pressure Flow Reactor (HPFR) is designed to study the chemical kinetics of various fuels.

Flow Rate Change:	55~500 SLPM
Temperature Range:	27~1100 °C
Pressure Range:	1~30 atm

- N_2 is preheated up to 850 °C
- Mixer ensures homogenous mixture
- Gas sample is sent through quartz tube (heated at 1100 °C) and to GC for analysis
- Water-cooling sampling probe used to cool gases for GC testing

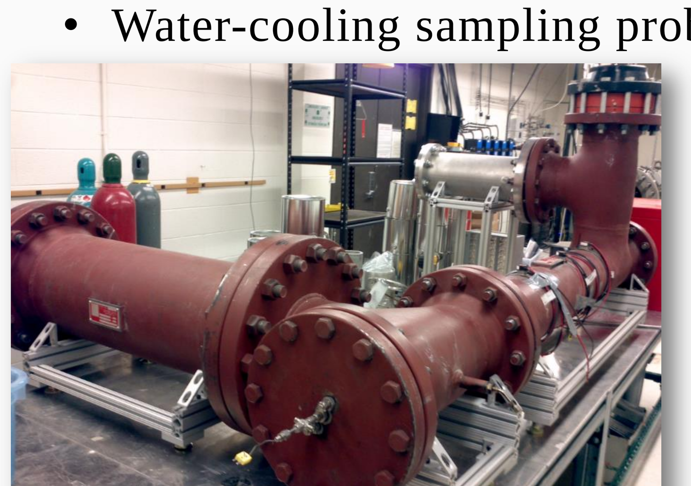

Figure 3. Experimental Apparatus of HPFR

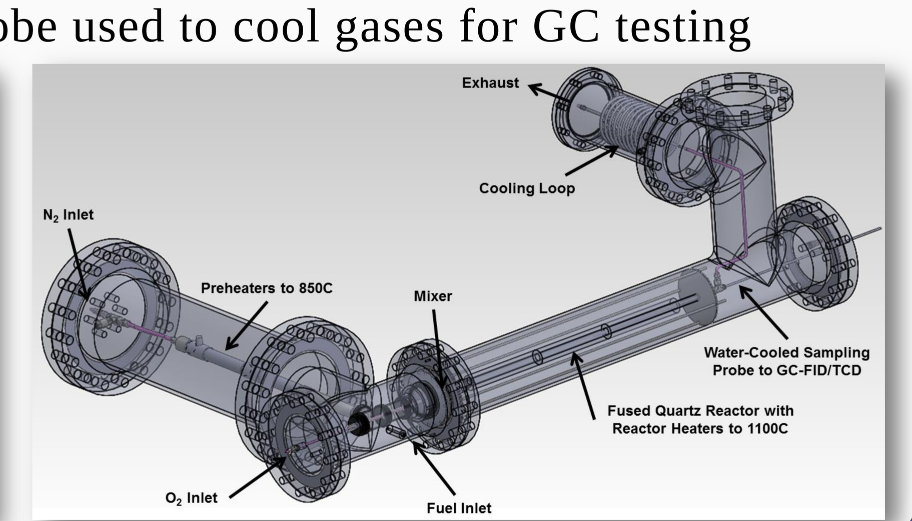

Figure 4. Schematic of HPFR [3]

LIQUID FUEL DELIVERY SYSTEM

The design and manufacture of the fuel pump and delivery system is needed to deliver a homogenous fuel vapor to the system:

- Liquid fuel is injected and vaporized due to high temperatures
- Fuel becomes gas and is mixed with N_2
- Fuel Pump allows continuous flow of high pressure fuel

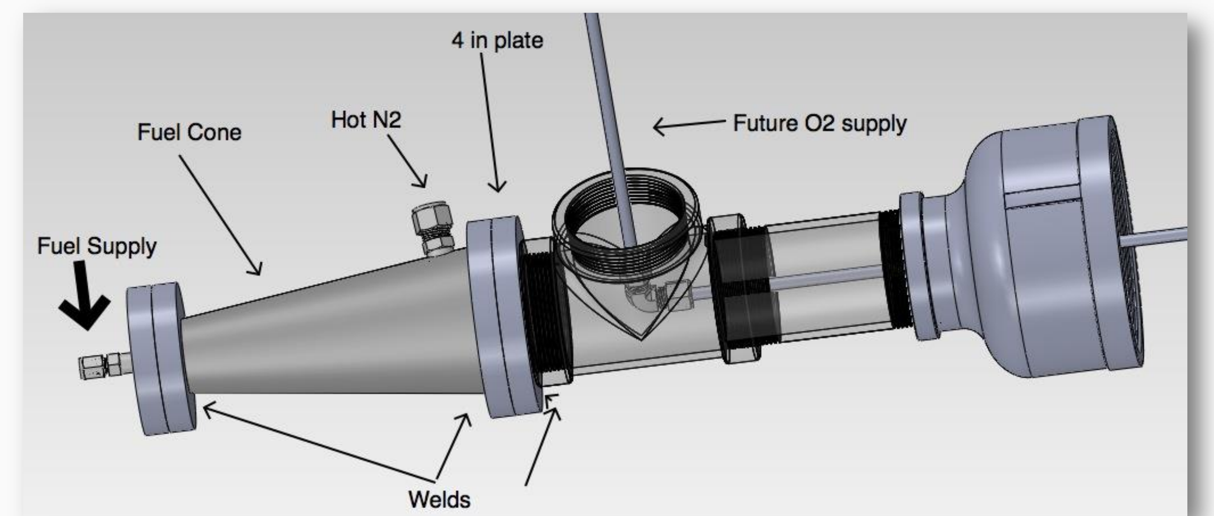

Figure 5. Schematic of Fuel Delivery System

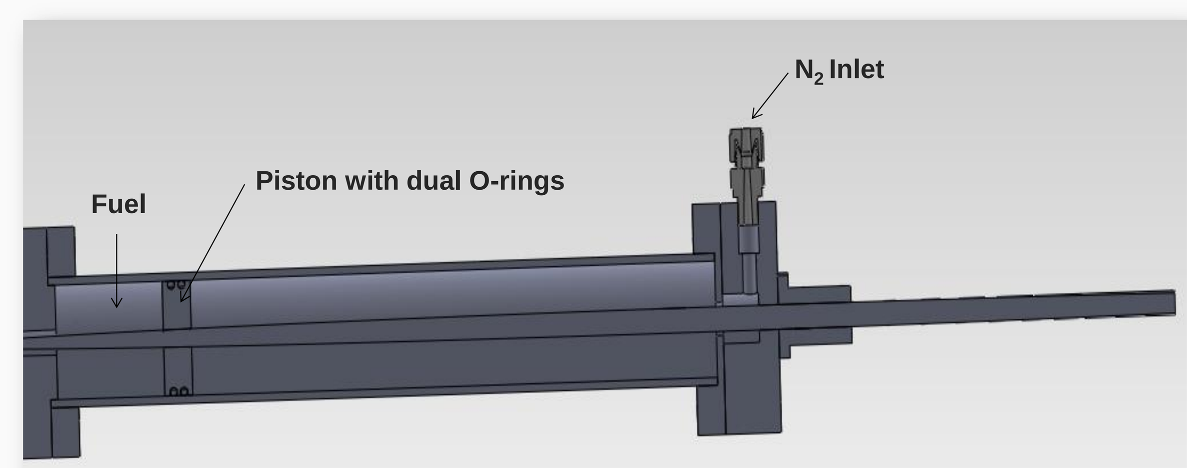

Figure 6. Schematic of Fuel Pump

AUTOMATION OF SYSTEM

LabVIEW (a visual programming language) is integrated with National Instruments' real time controllers to operate the entire system more efficiently and precisely.

LabVIEW is used to log and control:

- Temperature and pressure
- Mass flow rate of gases
- Heaters used to heat the gas mixture
- Translation of the gas-sampling probe

Figure 7. LabVIEW User Interface

GAS ANALYSIS

The Gas Chromatograph is an analytical device that measures the various components of a gas sample.

- Used to analyze samples of gas mixtures after pyrolysis
- Currently testing ethane pyrolysis at high temperatures
- Future tests include the pentane pyrolysis across a wide range of temperatures and pressures

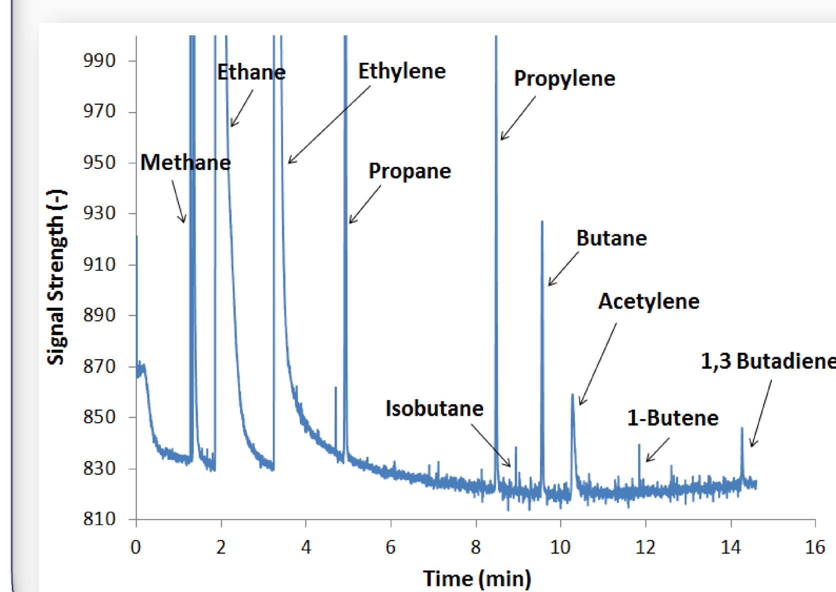

Figure 8. GC Run of Ethane (~850°C, 4 bar, 364 ms , 4% ethane)

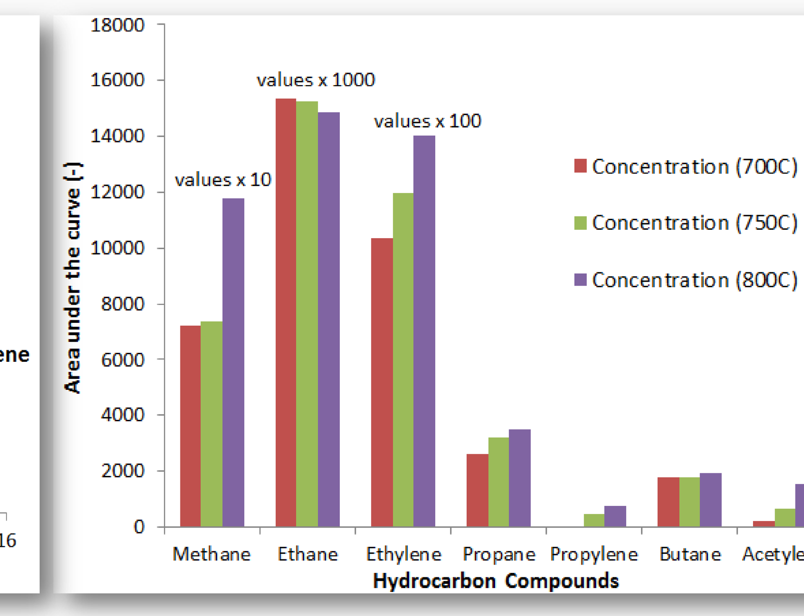

Figure 9. Relative Concentration at Various Temperatures (~3 bar, 273 ms, 4% ethane)

CONCLUSIONS/FUTURE WORK

- Fuel delivery system and pump was successfully designed and tested
- Initial validation of the high pressure flow reactor was performed using ethane
- Pentane will be used as the base fuel for studying endothermic fuel cracking under the conditions experienced on the scramjet
- The HPFR will continue to be operated and monitored using LabVIEW
- The gas samples will be analyzed using the Gas Chromatograph with interest in molecular weight growth species

REFERENCES

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2. Dean, A.; Bogin, G.; Kee, R.; Lobo, R.; Vlachos, D.; Zare, R.; Colket, M.; Opalka, S. "Heterogeneously Catalyzed Endothermic Fuel Cracking." Proposal.
3. Croxall, Jeffrey. *Design of a High Pressure Flow Reactor for Gas Phase Kinetics*. M.S. Thesis. Colorado School of Mines, 2013.

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