Catalytic Ignition of Nitrous Oxide With Propane/Propylene Mixtures for Rocket Motors

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Presentation Outline

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- Experimental Setup
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  - Adsorption Studies on Shell-405
  - Activity Studies on Shell-405
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- Conclusions & Recommendations

Objectives

- **Feasibility of a Nitrous Oxide Propane (NOP) bi-propellant rocket engine for Orbital Express program**

- **Develop a low temperature catalytic rocket motor igniter using N_2O and C_3H_8/C_3H_6**
  - **Identifying and developing a suitable catalyst for the thermal decomposition of nitrous oxide and optimizing conditions under which this occurred**

Introduction

Why use nitrous oxide ?

Benefits

- Thermal decomposition temperature - 520ºC
- Storage density of liquefied gas - 745 psig. at 20ºC
- Decomposes exothermically - - 81.6 kJ/mol N_2O
- Adiabatic decomposition temperature - 1640ºC
- Generates free oxygen for combustion

$$N_2O(g) \rightarrow N_2(g) + \frac{1}{2} O_2(g) + \text{Heat.}$$

Barriers

- Heat input is required to initiate the reaction
- Activation energy barrier for N_2O is about 250 kJ/mole

Experimental

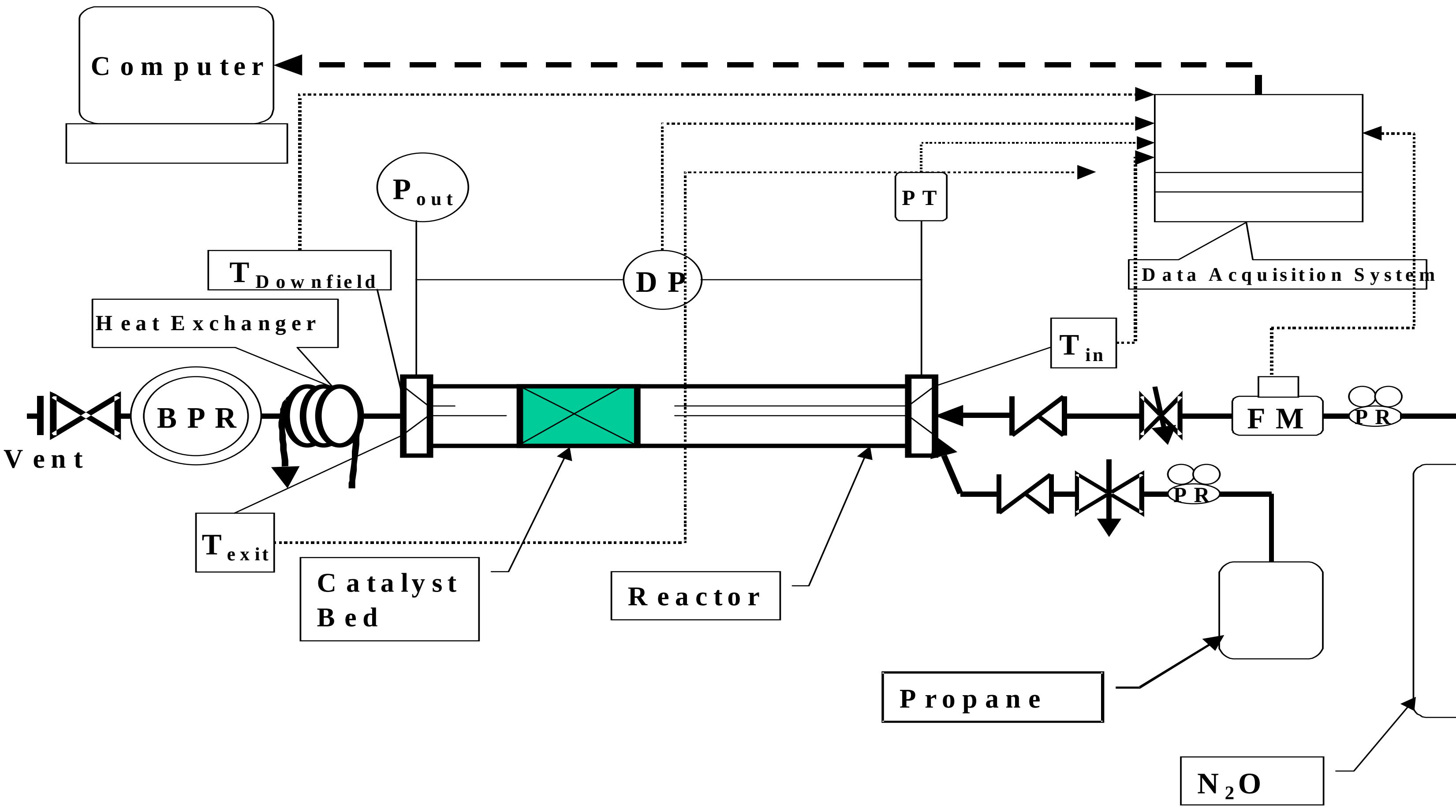
- **Lab tests for evaluating operating conditions for N_2O decomposition**

  - **N_2O used was of 98.5% purity. C_3H_8 used initially was 99.999% pure. C_3H_8/C_3H_6 mix used later composed of 89.924% mole C_3H_8 and 10.076% mole C_3H_6**

- **Optimizing tests performed on the Combustion Reactor Setup**

- **Field tests with the atmospheric igniter for integration with the rocket motor.**

Experimental Combustion Reactor Setup

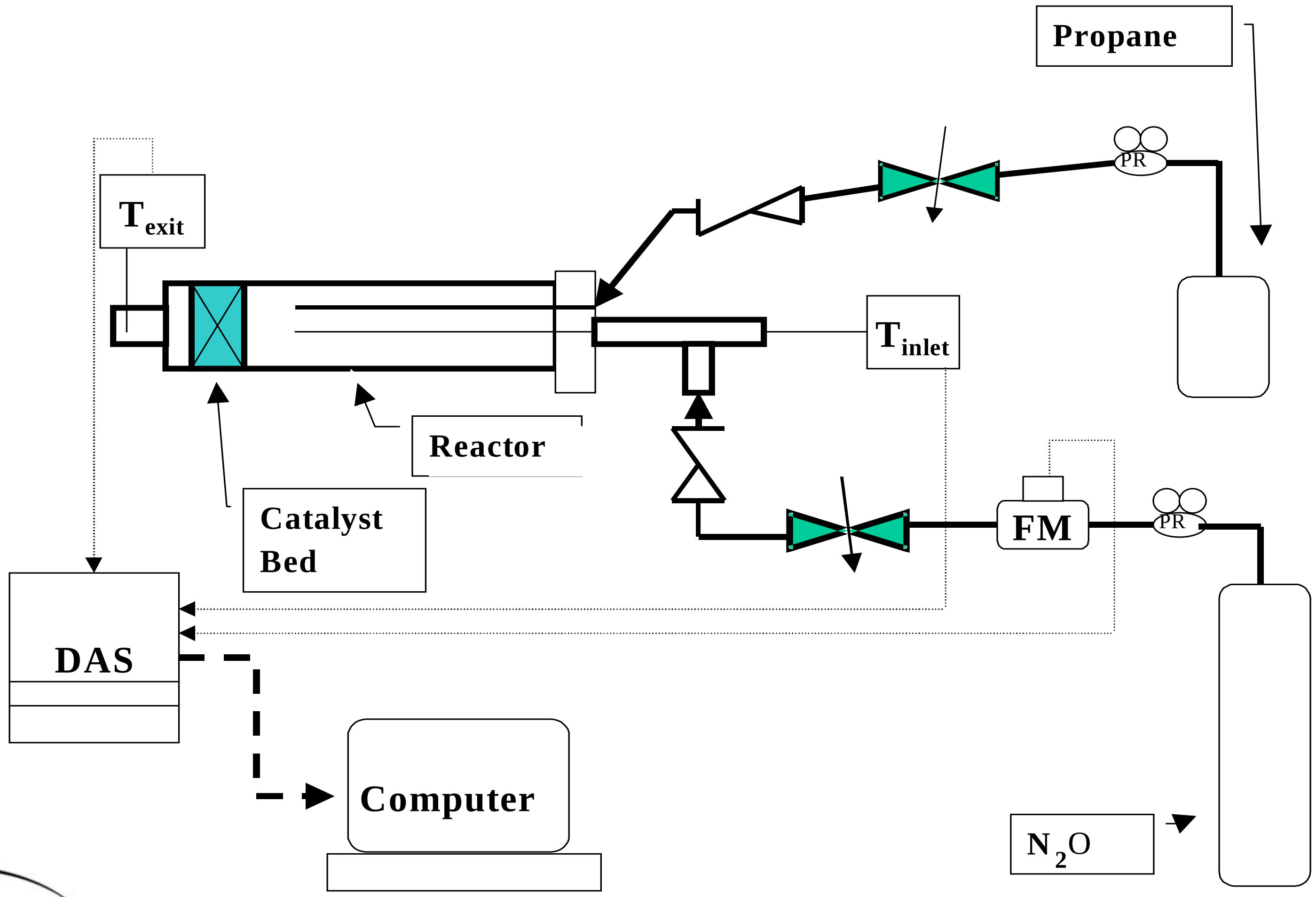


Experimental Procedure

- **Operating pressure between 30 to 150 psig**
- **Specific flow rate - 0.005 to about 0.03 SCFM**
- **Gas mixtures flowed through the catalyst bed between 2-4 minutes**
- **Exit temperature as a measure of catalytic activity**
- **Established N_2O optimum pressure was 80-95 psig. and the flow rate between 0.01-0.025 SCFM**

ATMOSPHERIC COMBUSTION REACTOR

- Catalytic rocket igniter exhausted directly to the atmosphere



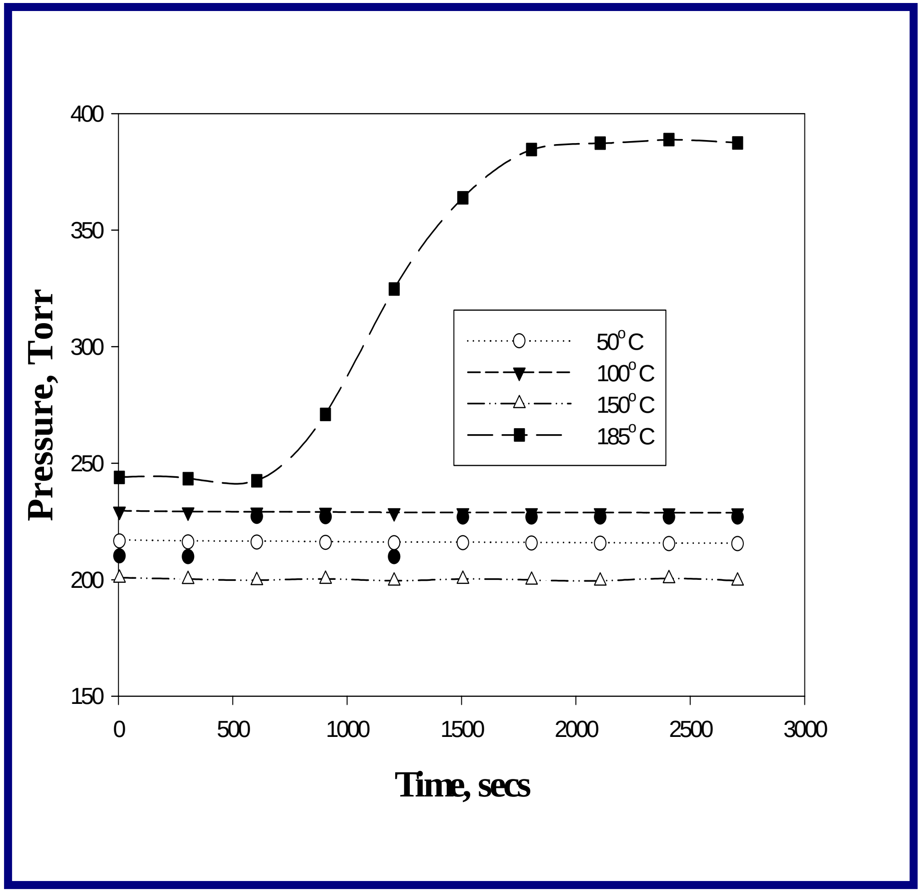
ATMOSPHERIC COMBUSTION REACTOR

- N_2O operating pressure established at 60 psig
- Catalysts
  - Iridium (Shell 405)
  - Hybrid catalyst bed of Shell-405 and platinum monolith
- Inlet and exit temperatures and flowrates were measured
- Video observation

Results & Discussions

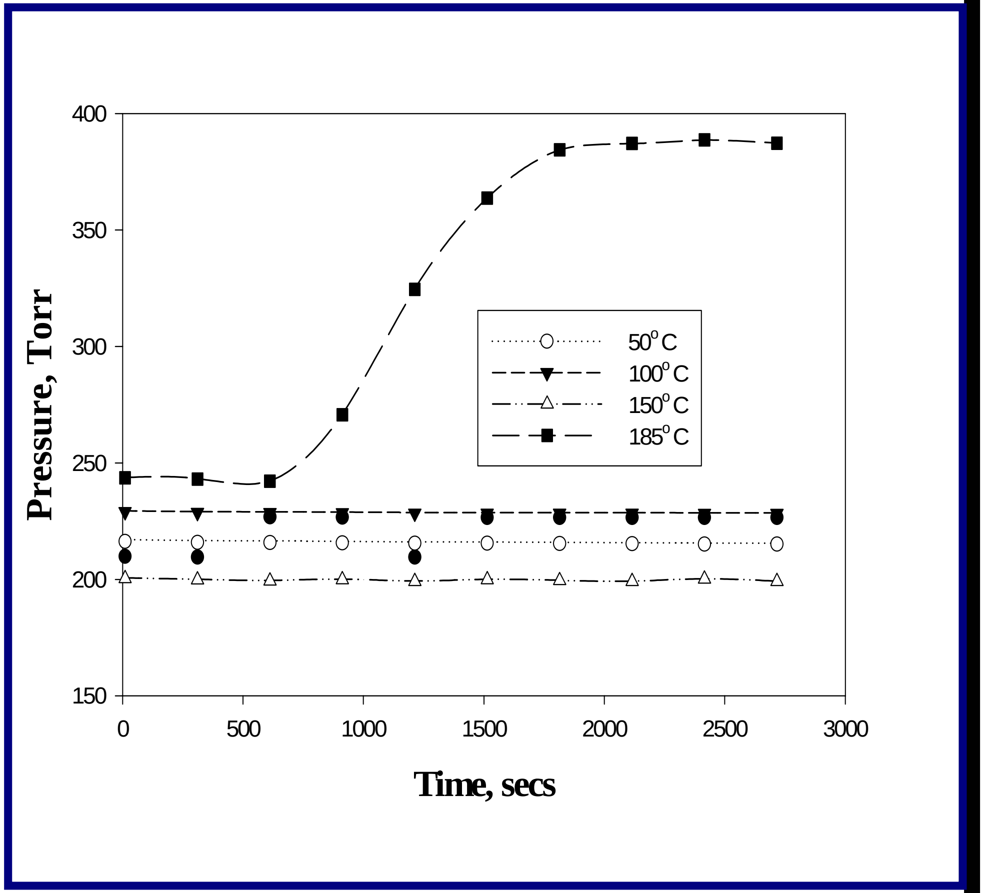
Adsorption Studies

- Dissociation leads to an increase in pressure
- Two states of catalytic activity with respect to the decomposition of N_2O
- Amounts of N_2O decomposed and O_2 formed correspond to the stoichiometry of reaction



Adsorption Studies (cont.)

- **At higher temperatures, overshooting of the oxygen concentration occurs when the catalyst changes the state of activity**
- **Demonstrates that the catalyst is able to store and release oxygen**
- **At higher preheats, desorption of O2 from the catalyst surface occurs leading to pressure rise**



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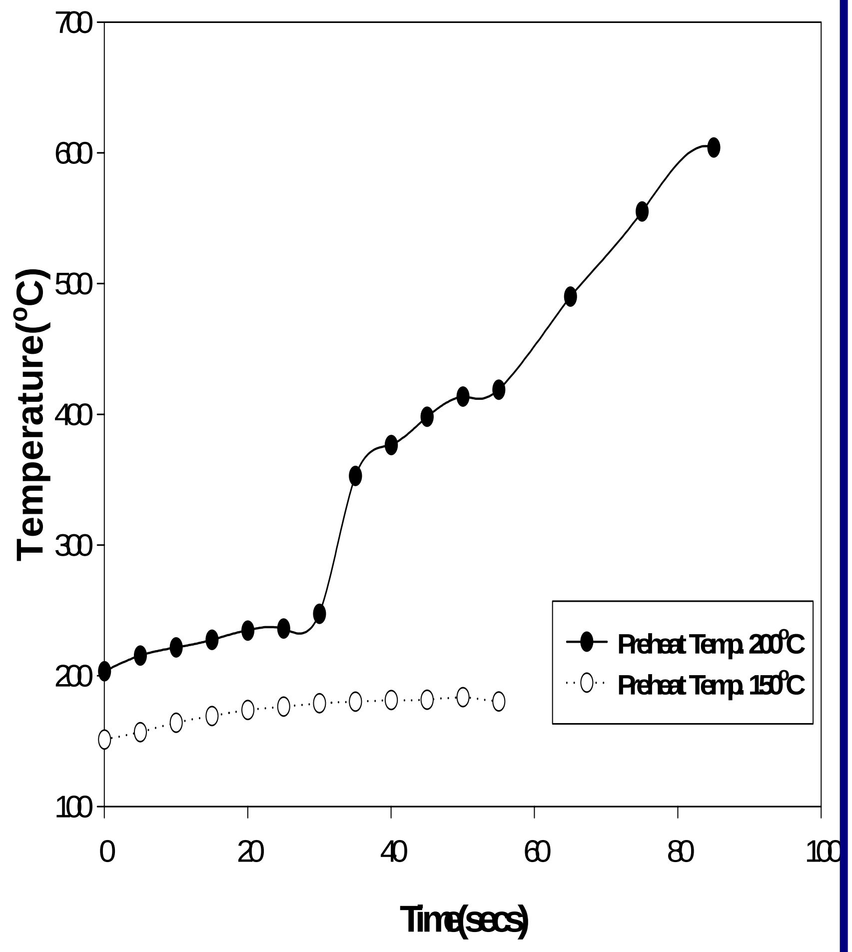
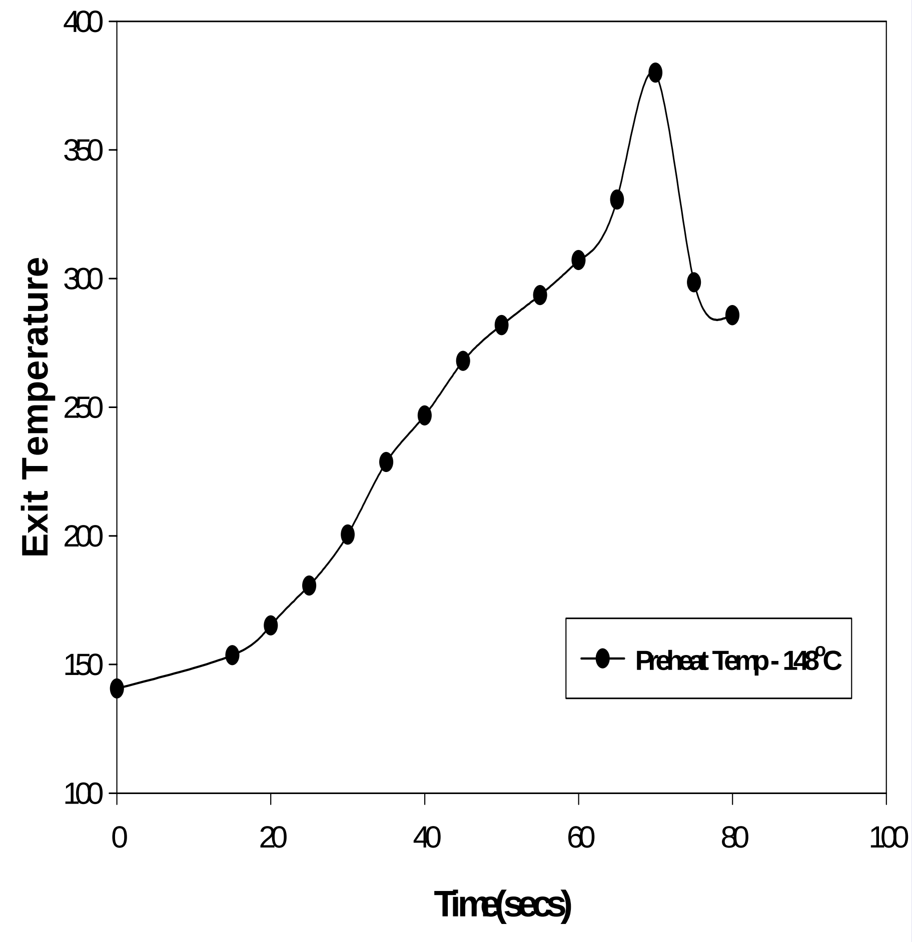
Activity Studies on Shell-405

- Flow of fuel to oxidizer (C_3H_8: N_2O) for optimum catalytic activity, 1:14
- Thermal decomposition of N_2O occurred at a catalyst preheat temperature of about 210^oC
- To reduce the light-off temperature, a premix of 90% mol C_3H_8 and 10% mol C_3H_6 was used



Activity Studies on Shell-405 (cont.)

- In C_3H_6,C=C bond is nonsymmetrical increasing surface reactivity relative to C_3H_8
- Exit temperature restricted to below 600°C as a safety precaution
- Addition of 10% propylene reduces light-off temperature by 62°C

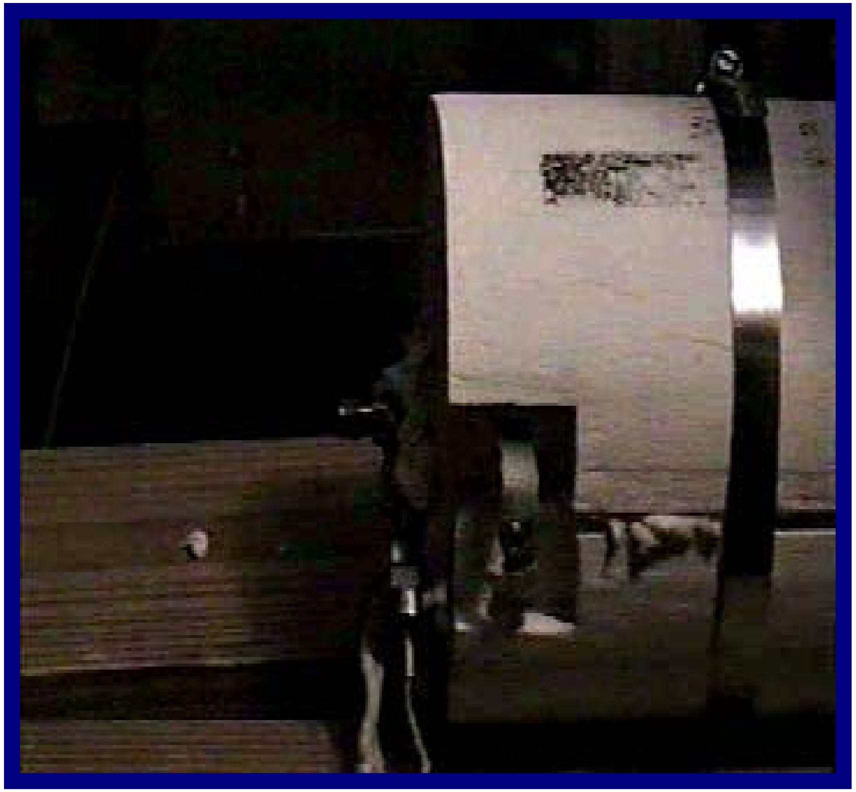


Atmospheric Igniter

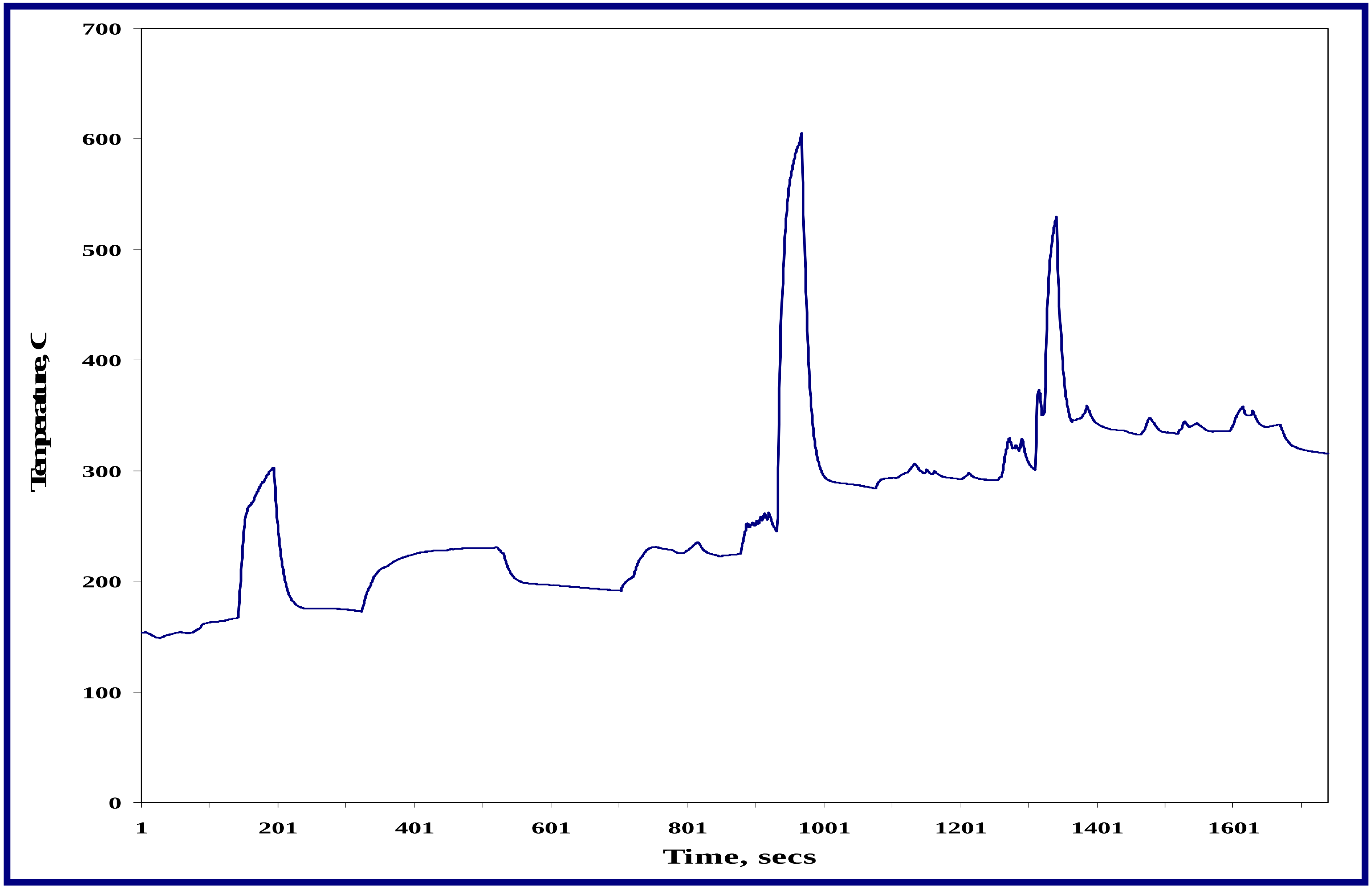
- N_2O flowed at 0.02 SCFM at the preheat temperature
- Shell 405 preheated to 125^oC , the instant a C_3H_8/C_3H_6 mix was added at 4-9 cc/sec, a flame was established and sustained for over 60 seconds
- Termination of C_3H_8/C_3H_6 flow and continued combustion (decomposition) of N_2O alone, indicated its functioning as a mono-propellant

Field Tests with the Atmospheric Igniter

- **Time delay of about 4 seconds given before mixing C_3H_8/C_3H_6 at about 1 cc/sec and 103 psig.**
- **Flows of the C_3H_8/C_3H_6 mix and N_2O shut-off, reactor purged with N_2**

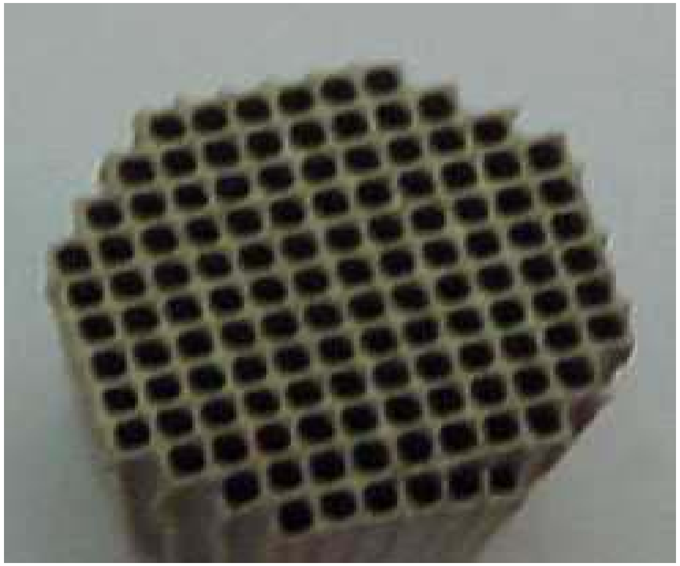


Flows restarted 6 times and a flame observed at the exit



- **Shell 405 deactivated at extreme combustion temperatures**

- **Results from the excessively long exposure time to the reactive flows and oxidation of the iridium**



Conclusions

- Replacing 100% C_3H_8 with a 90% C_3H_8/10% C_3H_6 mix as fuel reduced the N_2O light-off temperatures by about 25% (62^oC)
- In the case of Shell-405 catalysts exit temperatures exceeding 450^oC caused sintering of the catalyst particles, thereby deactivating the catalyst
- Hybrid catalyst bed led to cleaner combustion of reaction mixtures.

Recommendations

- The fuel composition can be changed by using different C_3H_8/C_3H_6 mix ratios like 80: 20, 75: 25, etc., to observe changes in activity levels
- Replacement of C_3H_8/C_3H_6 as fuel with other alkanes like ethane and alcohols such as methanol, etc.
- Off-stoichiometric mixtures should be investigated to develop reaction kinetic parameters
- Chromatographic analysis of the vent gases to understand reaction mechanisms occurring on the catalyst surface

Acknowledgements

This research was conducted in support of a DARPA–Tactical Technology Office study on Small Scale Propulsion Systems, funded by Micro Craft, Inc.