

Additives to Increase Fuel Heat Sink Capacity

***41st AIAA/ASME/SAE/ASEE
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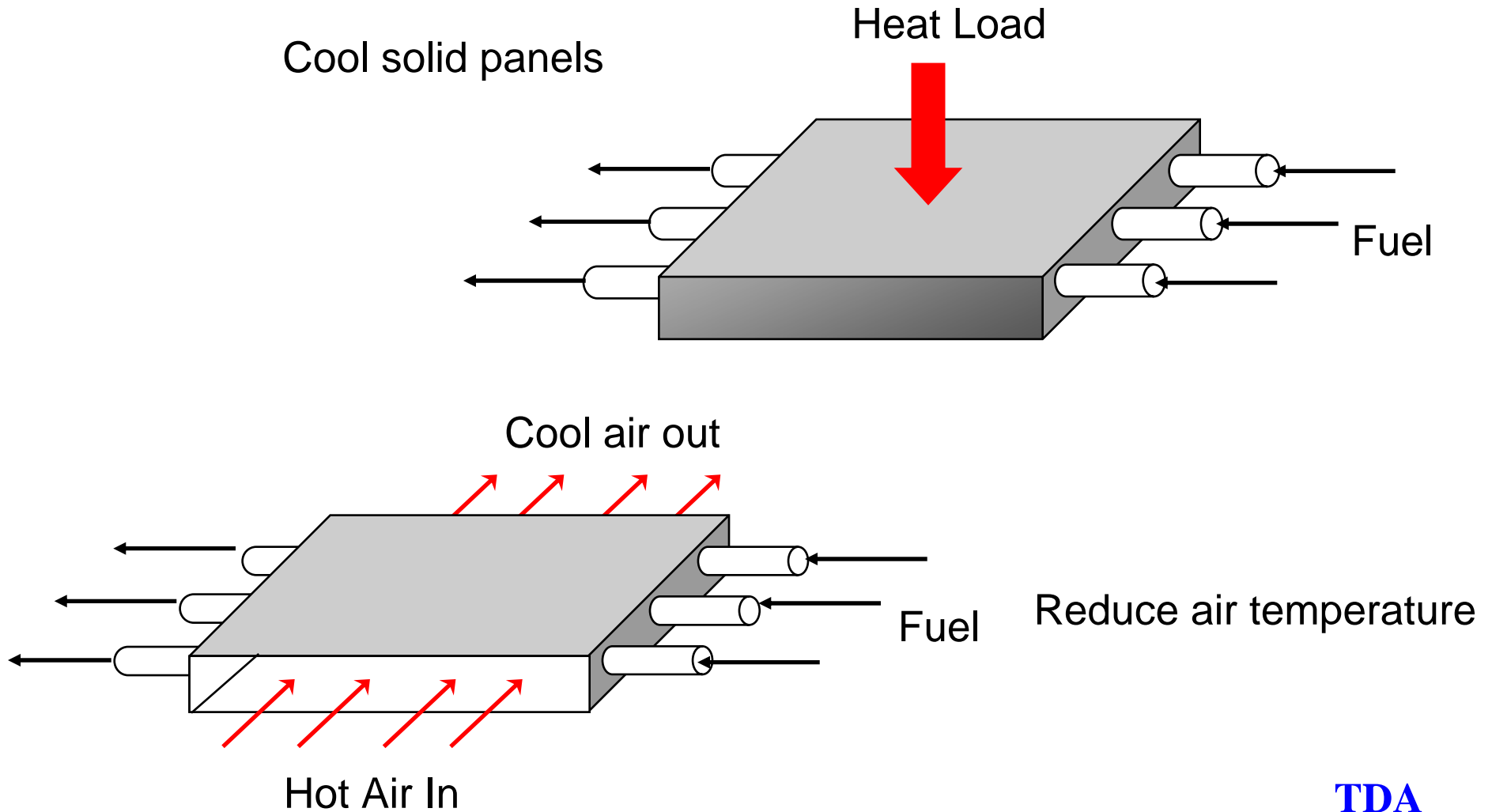
Overview

- Application of endothermic fuels.
- Initiated thermal cracking reactions.
- Results of laboratory experiments to measure initiated heat sink capacity.
- Results obtained with pilot scale fuel/air heat exchanger.

NASA Application for Endothermic Fuels

- Improve commercial access to space.
 - Current cost is about \$10,000 per pound.
 - Goal is to reduce cost to \$100 per pound.
- Cost reductions will require:
 - Single stage to orbit (SSTO) vehicles.
 - Rocket-based combined cycle (RBCC) engines using hydrocarbon fuel.
- At speeds between Mach 5 and 10, heat loads exceed cooling available from sensible heating of the fuel.
- Thermal cracking reactions may provide the additional heat sink capacity.

Applications of Endothermic Fuel Cooling



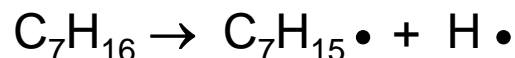
Thermal Cracking Reactions

- Heptane cracking.

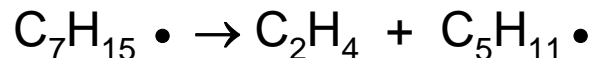


- Proceeds by a free radical mechanism.

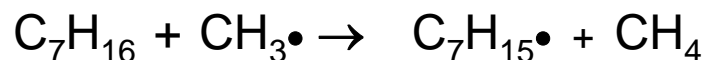
Initiation - slow step



Ethylene formation by β scission - fast



Chain propagation - fast



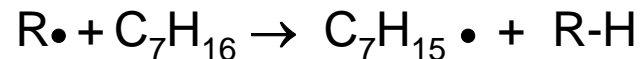
- The overall rate is limited by the initiation step, which is slow at working temperatures.

Addition of Chemical Initiator

- Increases the rate of radical generation because the R-R bond is weaker than the C-H bond.



- $R \cdot$ and $R_1 \cdot$ then react with the fuel.

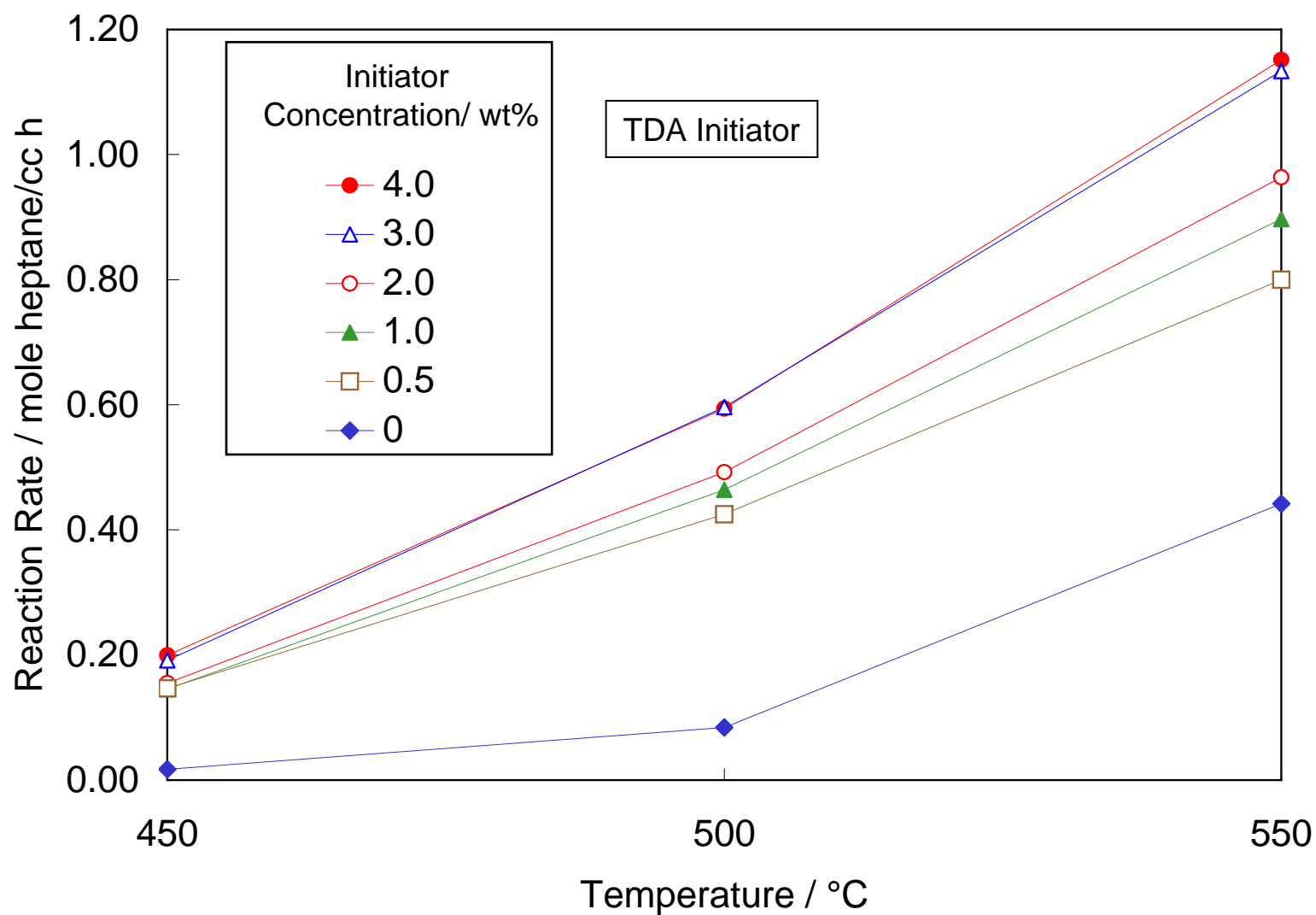


- The rest of the process is identical to the mechanism without the initiator.
 - The chemical initiator only starts the reaction - it has no effect on reaction stoichiometry.
- Low concentrations required (less than 3 wt%).

Characteristics of the TDA Initiator

- Consists of carbon, hydrogen, and oxygen.
- Is soluble in normal paraffin fuels.
- Is stable in its concentrated form at ambient temperatures.
- It is not a highly toxic chemical.

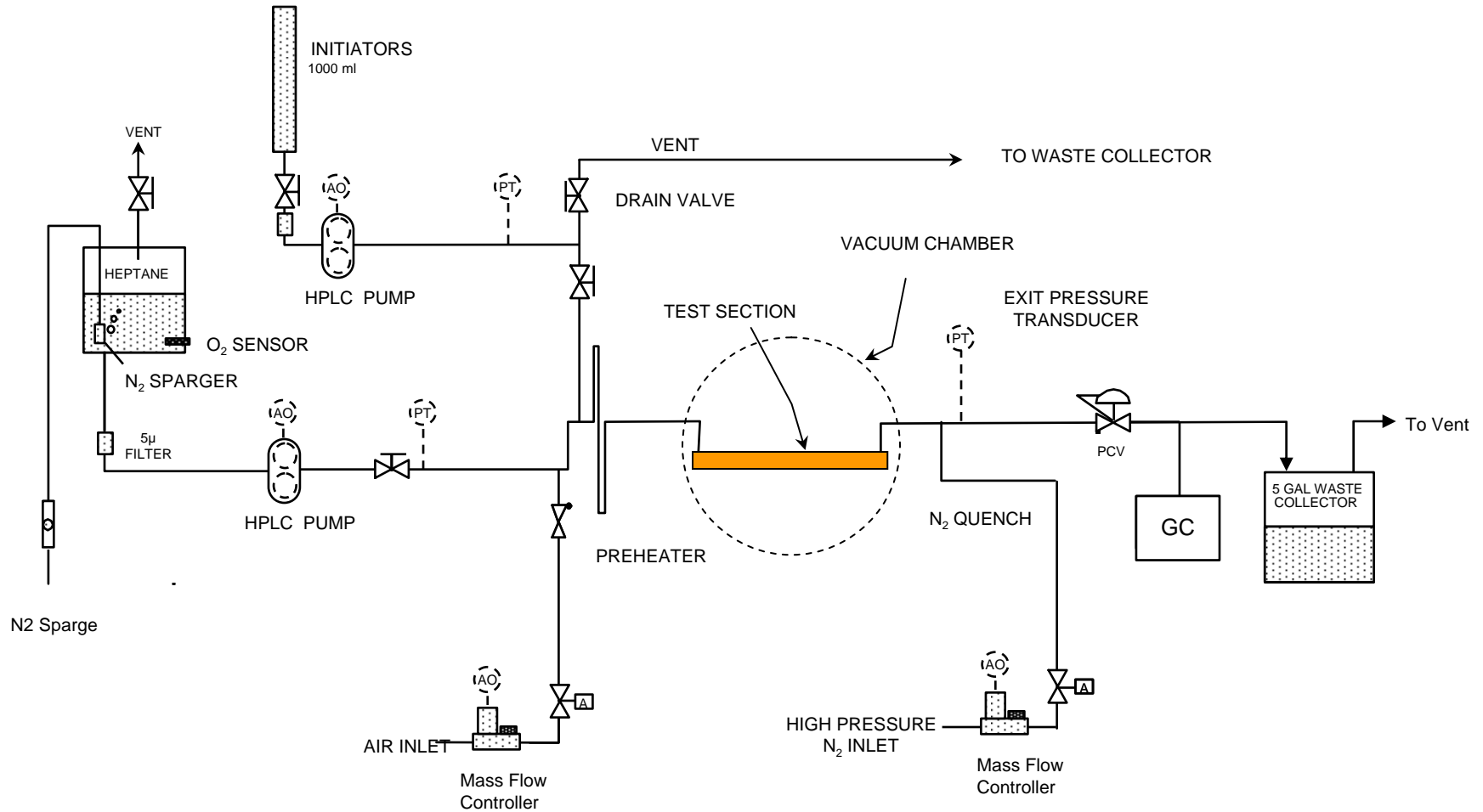
Previous Results with n-Heptane



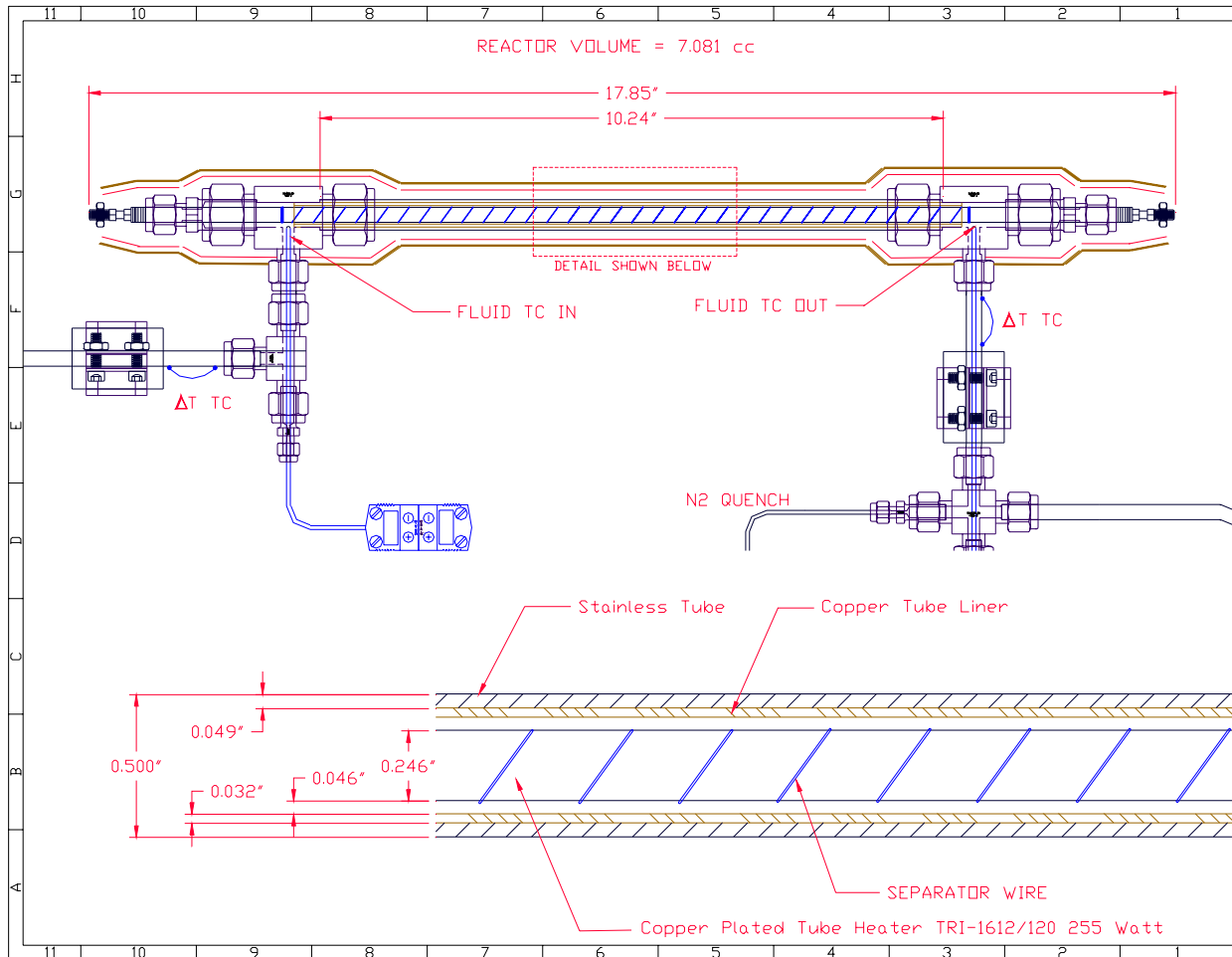
Objective of Current Project

- Measure heat sink capacity of real fuels such as JP-7 with and without initiator.
- Use kinetic data to design and construct a pilot scale heat exchanger and demonstrate initiator under realistic heat flux.

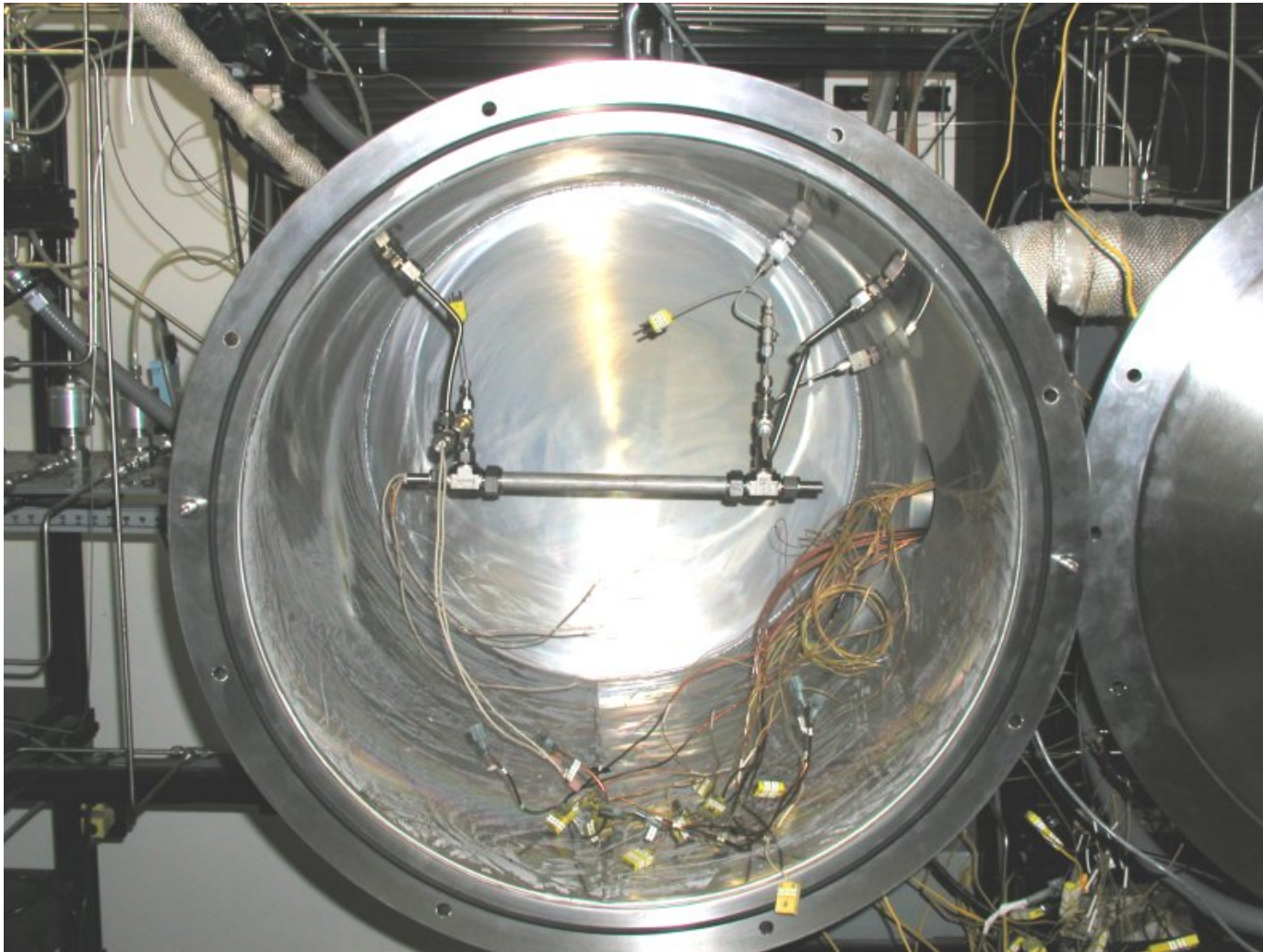
Laboratory Apparatus



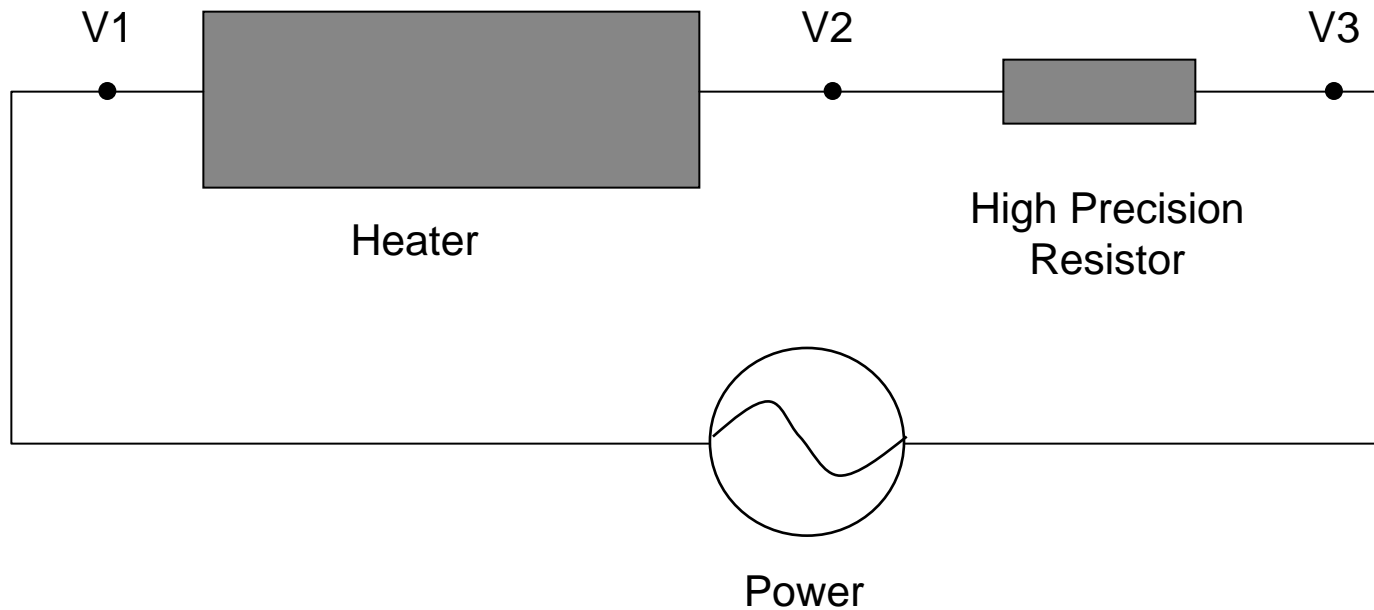
Test Section Used Annular Fuel Flow Path



Test Section Installed in a Vacuum Chamber to Reduce Convective Losses



Power Measurement



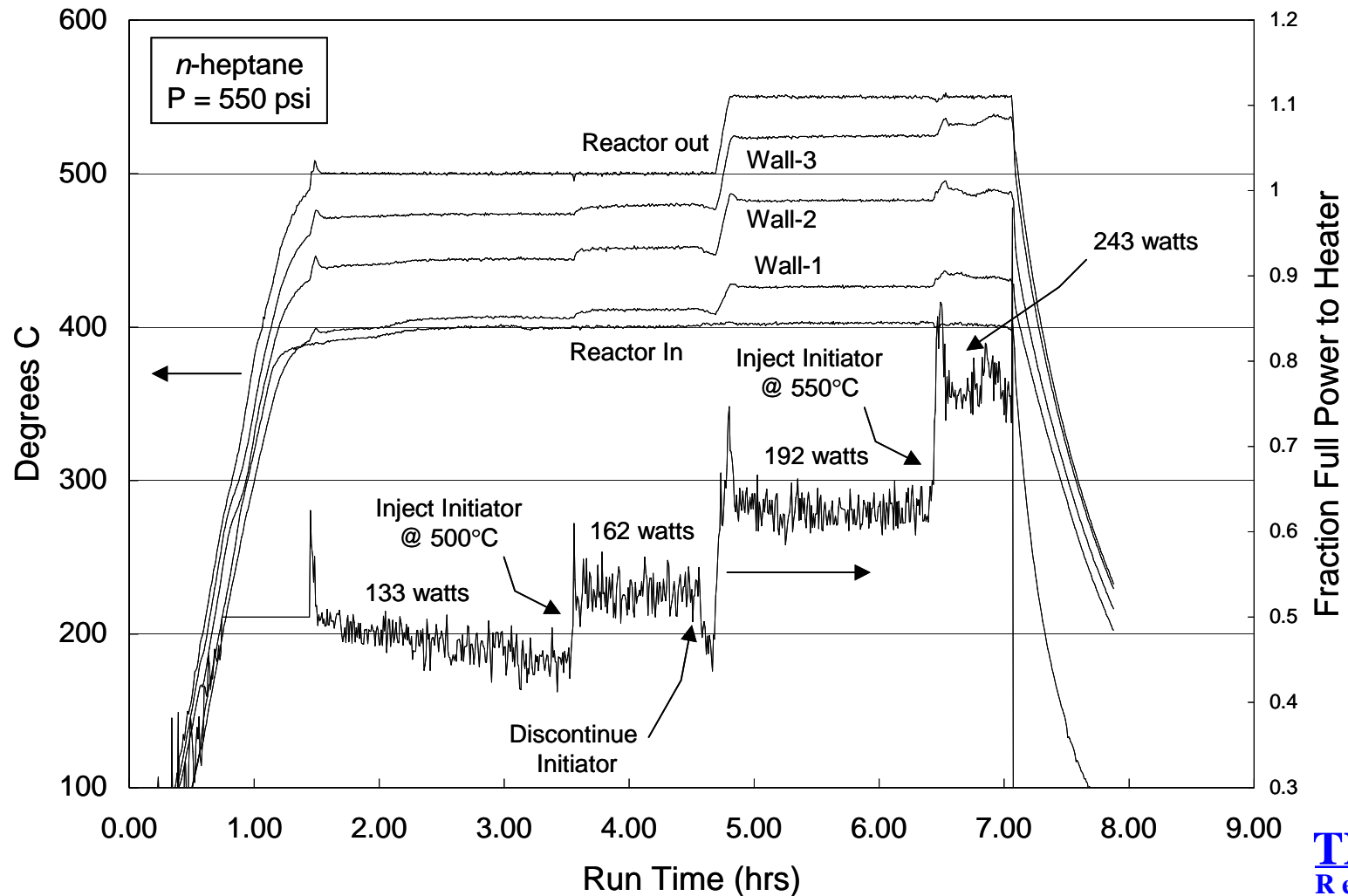
$$\text{Power} = V * I$$

$$V = V1 - V2$$

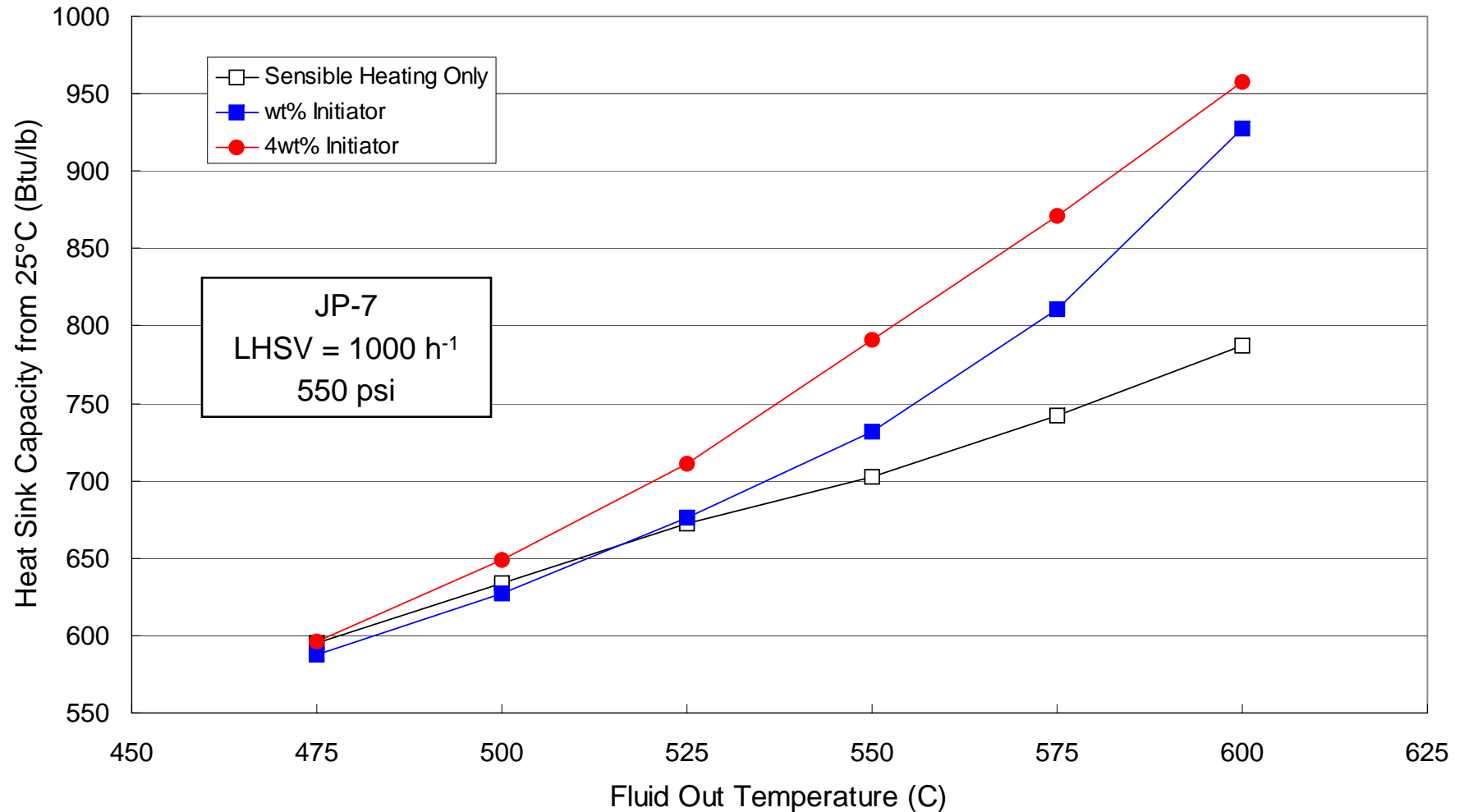
$$I = (V2 - V3) / r$$

Measurements were made at 1000 Hz with a digital oscilloscope

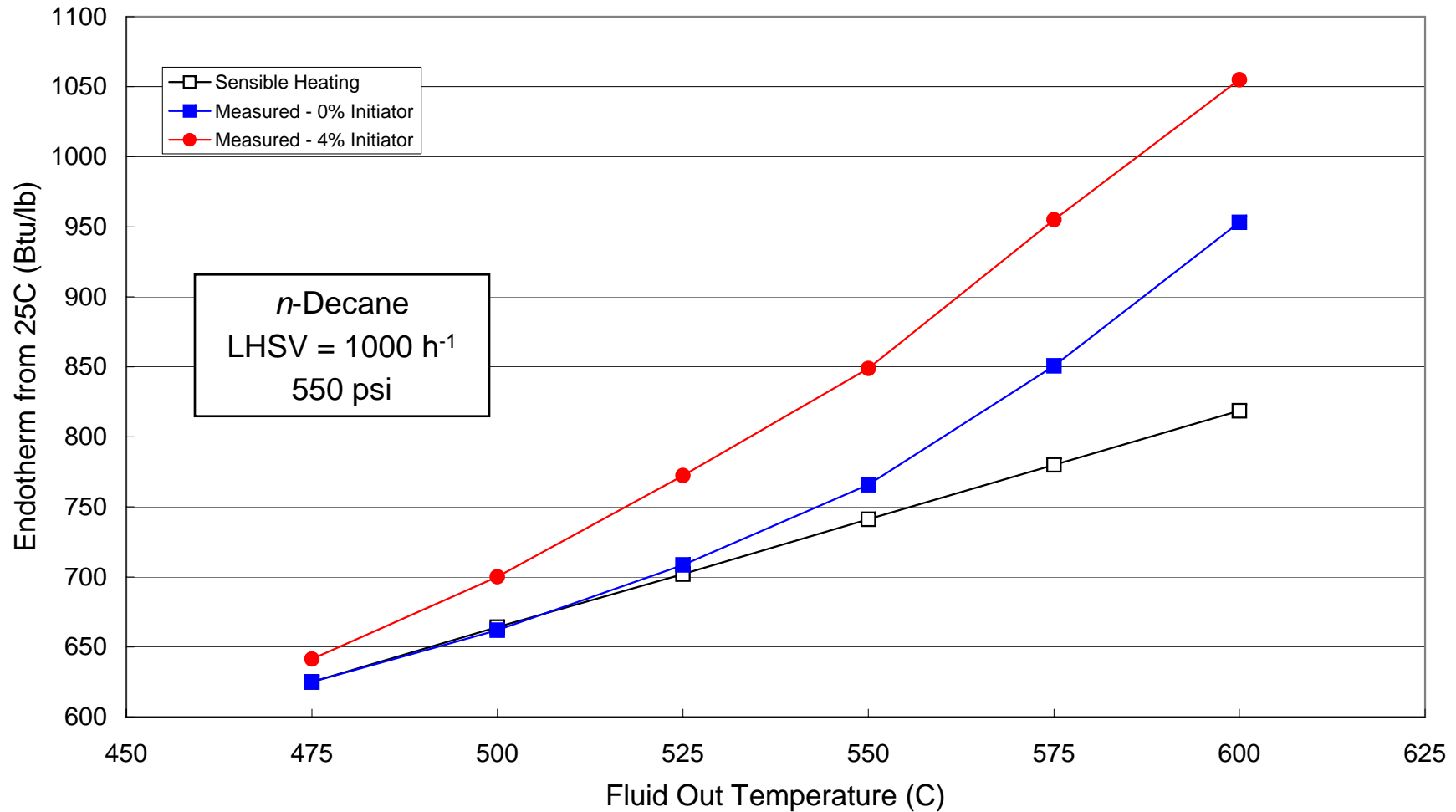
Significant Power Increase with Initiator Addition



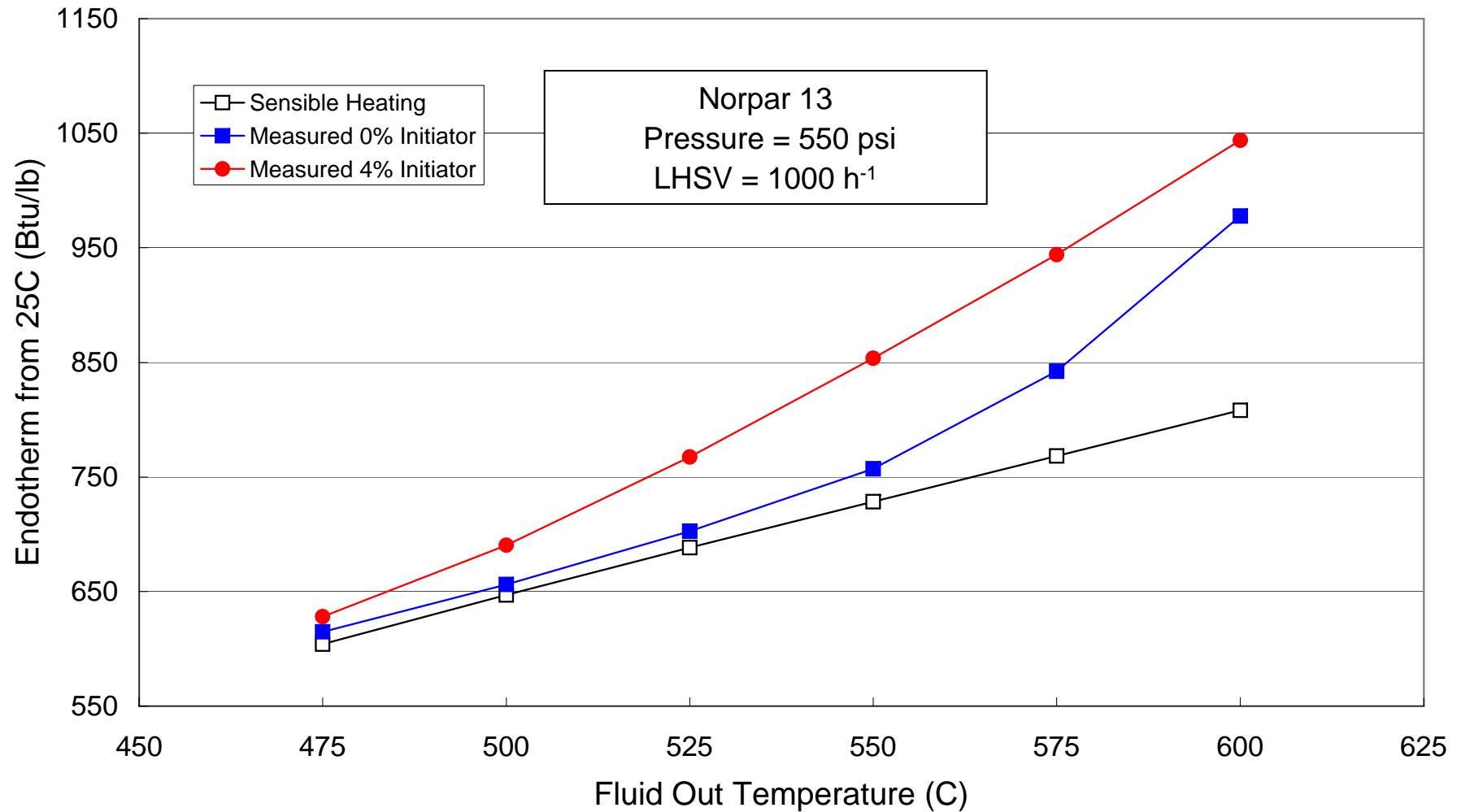
The Initiator Improves the Heat Sink Capacity of JP-7



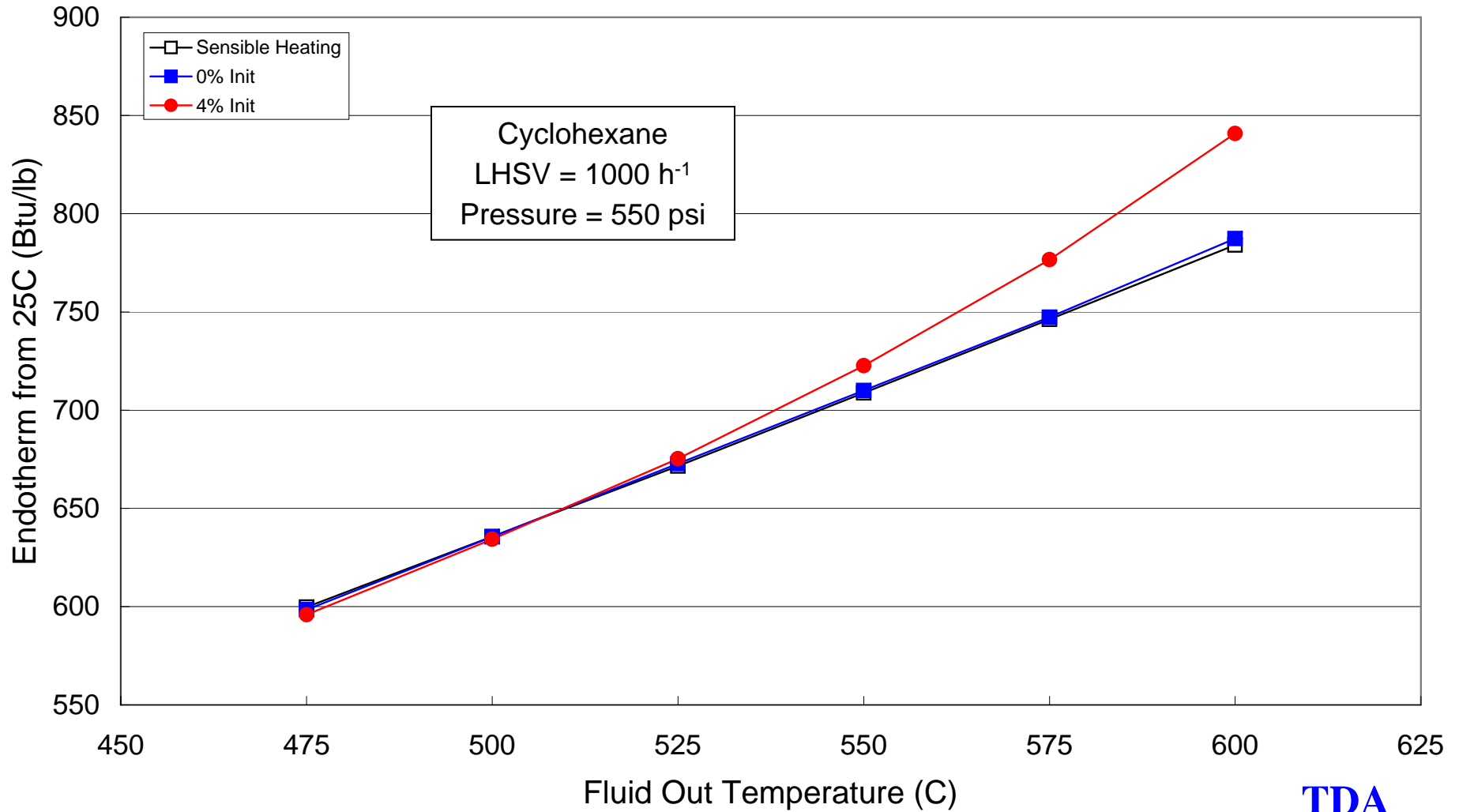
Substantial Increases in *n*-Decane Heat Sink Capacity



The Initiator is Very Effective with a Mixture of Normal Paraffins

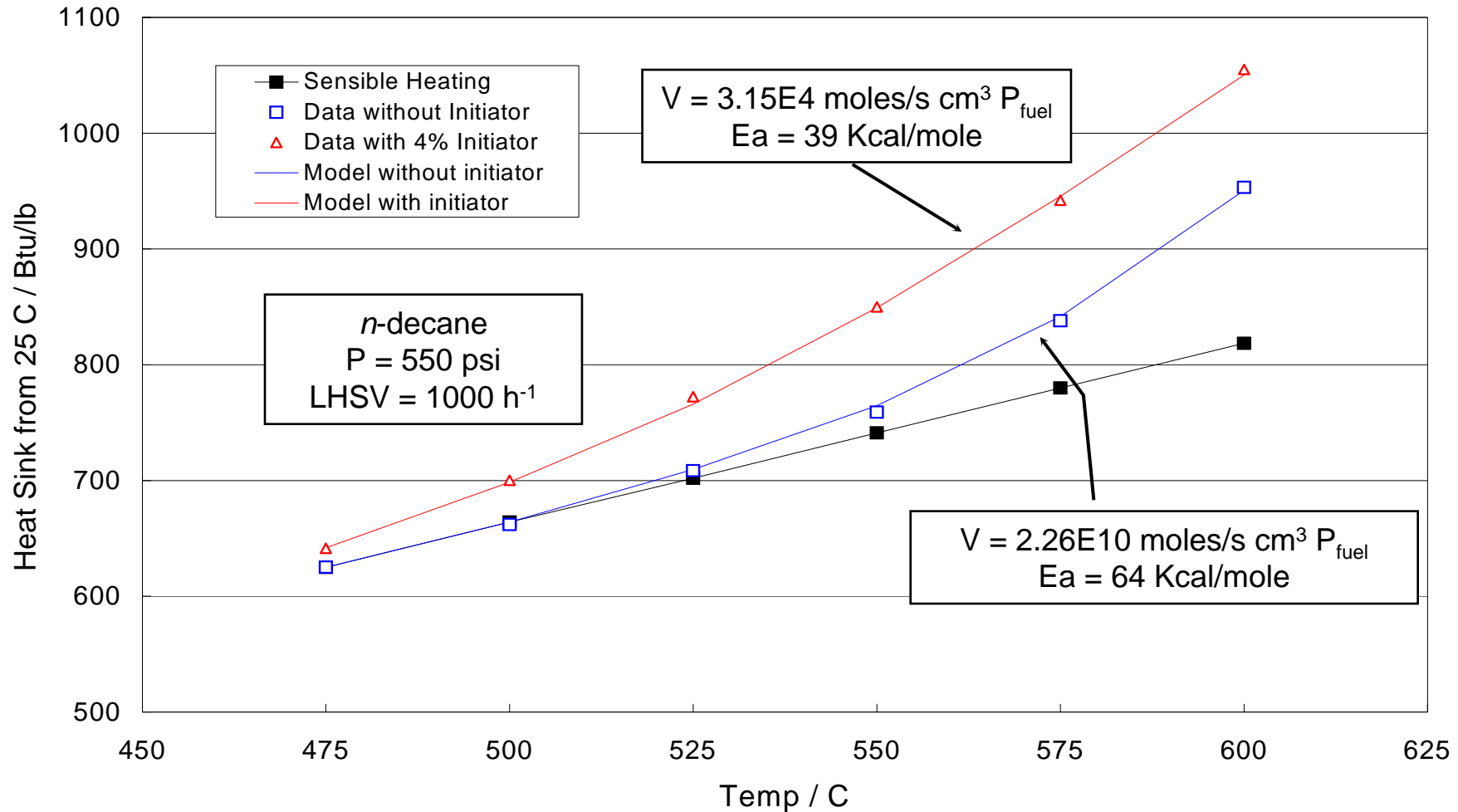


Cyclohexane is Thermally Stable without Initiator

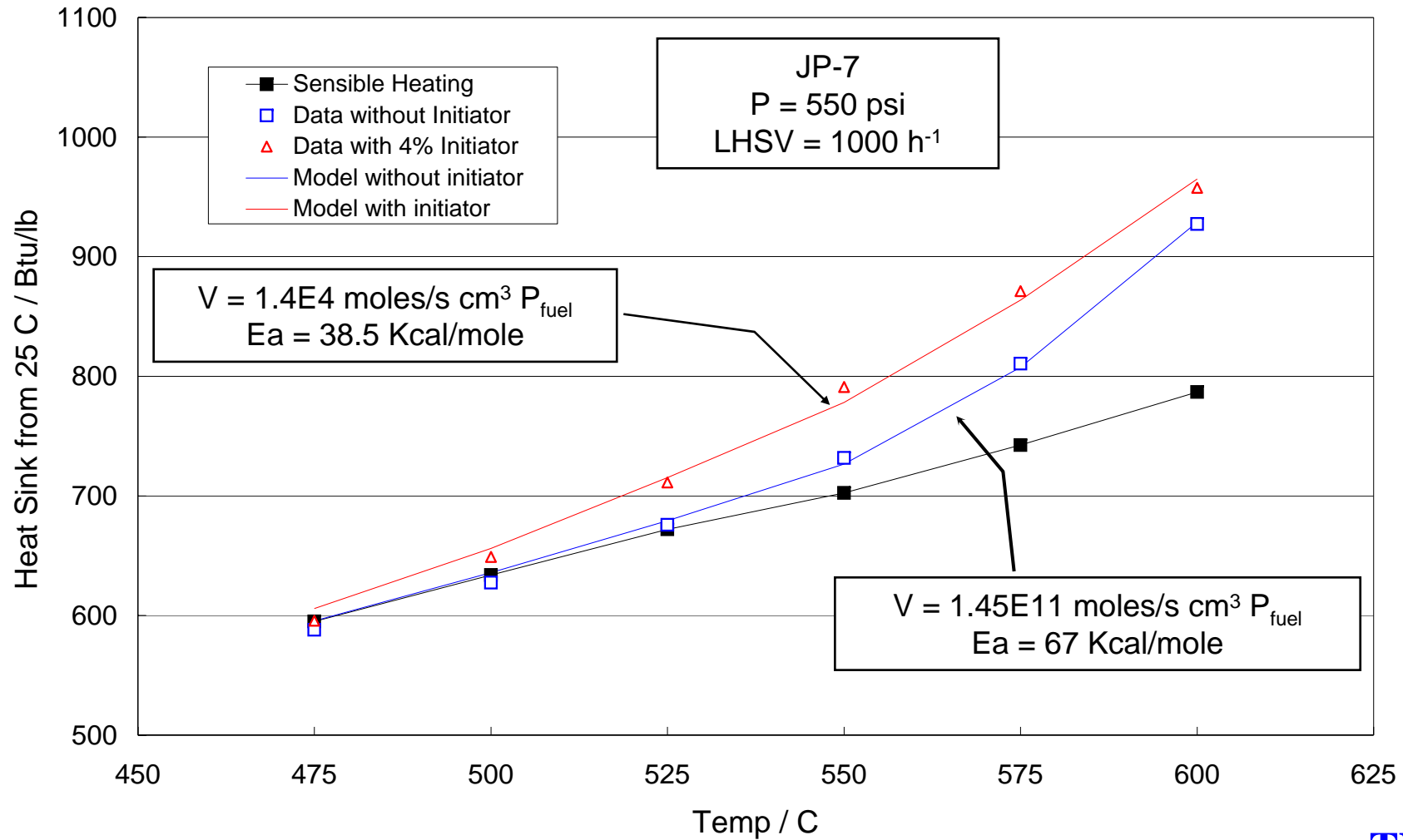


endotherm_plots_2

The Initiator Reduces the Activation Energy of the Cracking Reaction



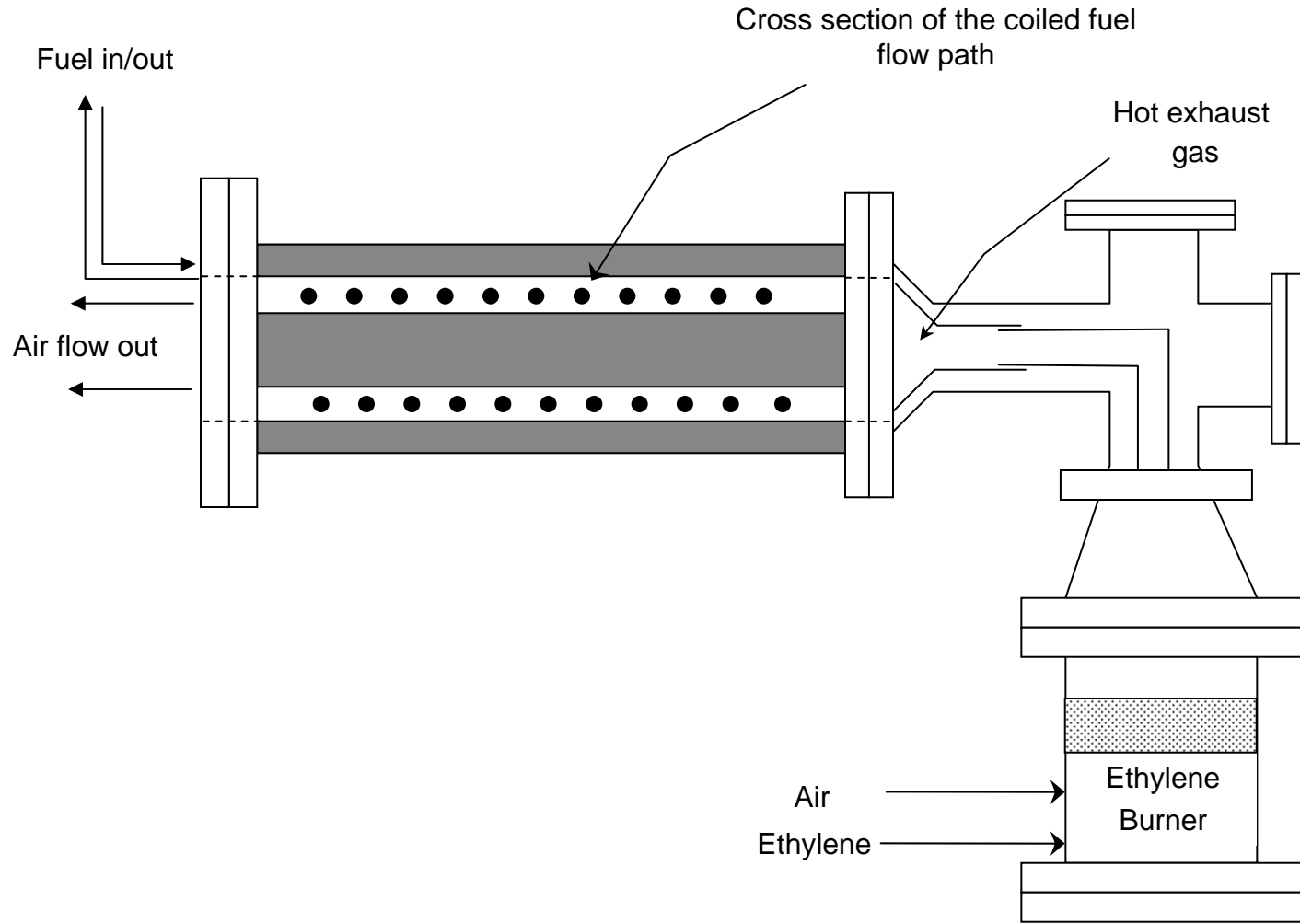
Kinetic Data for JP-7



Design and Construct Pilot Scale Air/Fuel Heat Exchanger

- Demonstrate heat sink capacity under realistic conditions.
- Heat flux of approximately 100,000 Btu/ft² h.
- $T_{\text{air in}} = 780^{\circ}\text{C}$, $T_{\text{air out}} = 350^{\circ}\text{C}$
- $T_{\text{fuel in}} = 65^{\circ}\text{C}$, $T_{\text{fuel out}} = 450^{\circ}\text{C}$

Schematic of Ethylene Burner and the Heat Exchanger

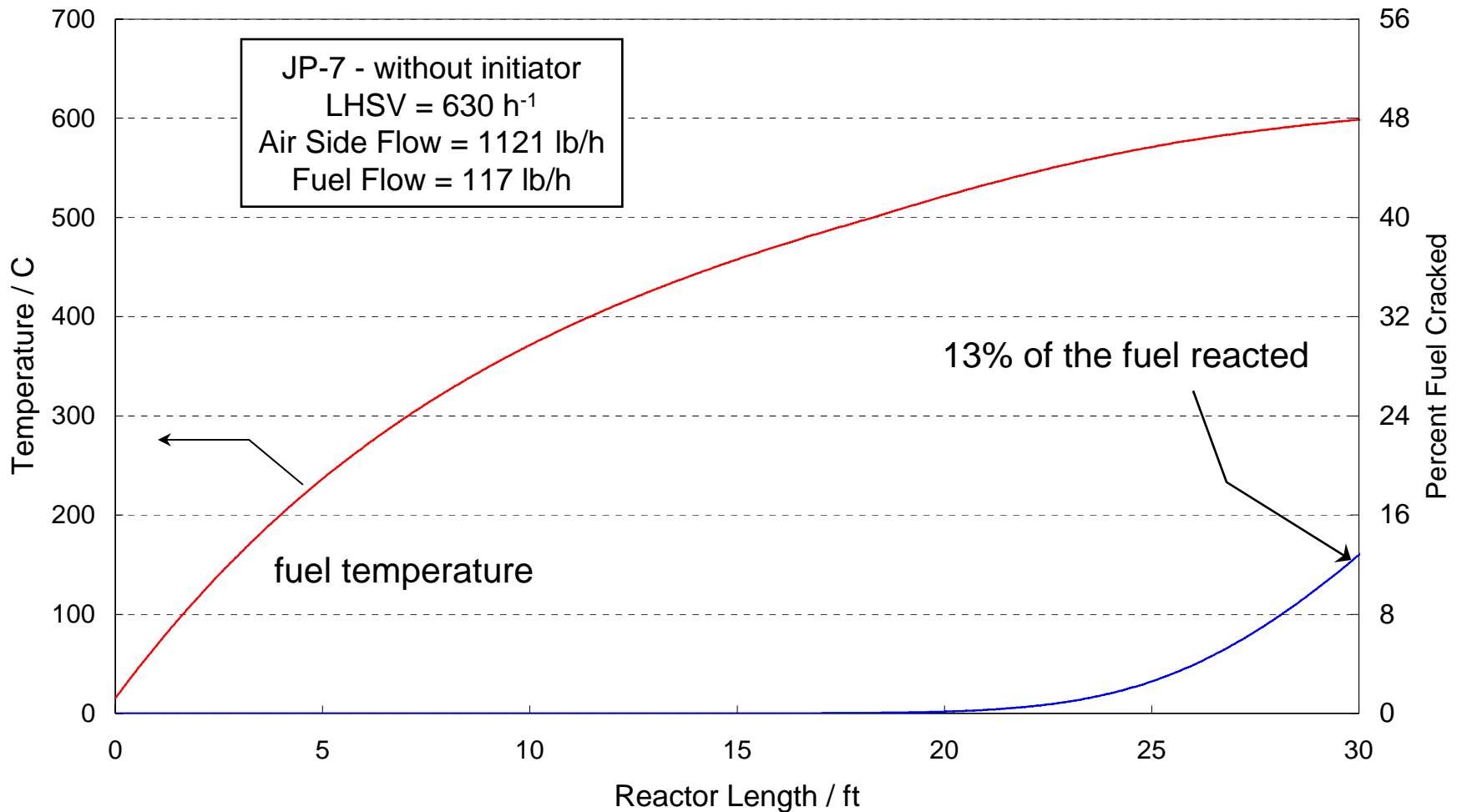


Finned Inconel Tubing for Fuel

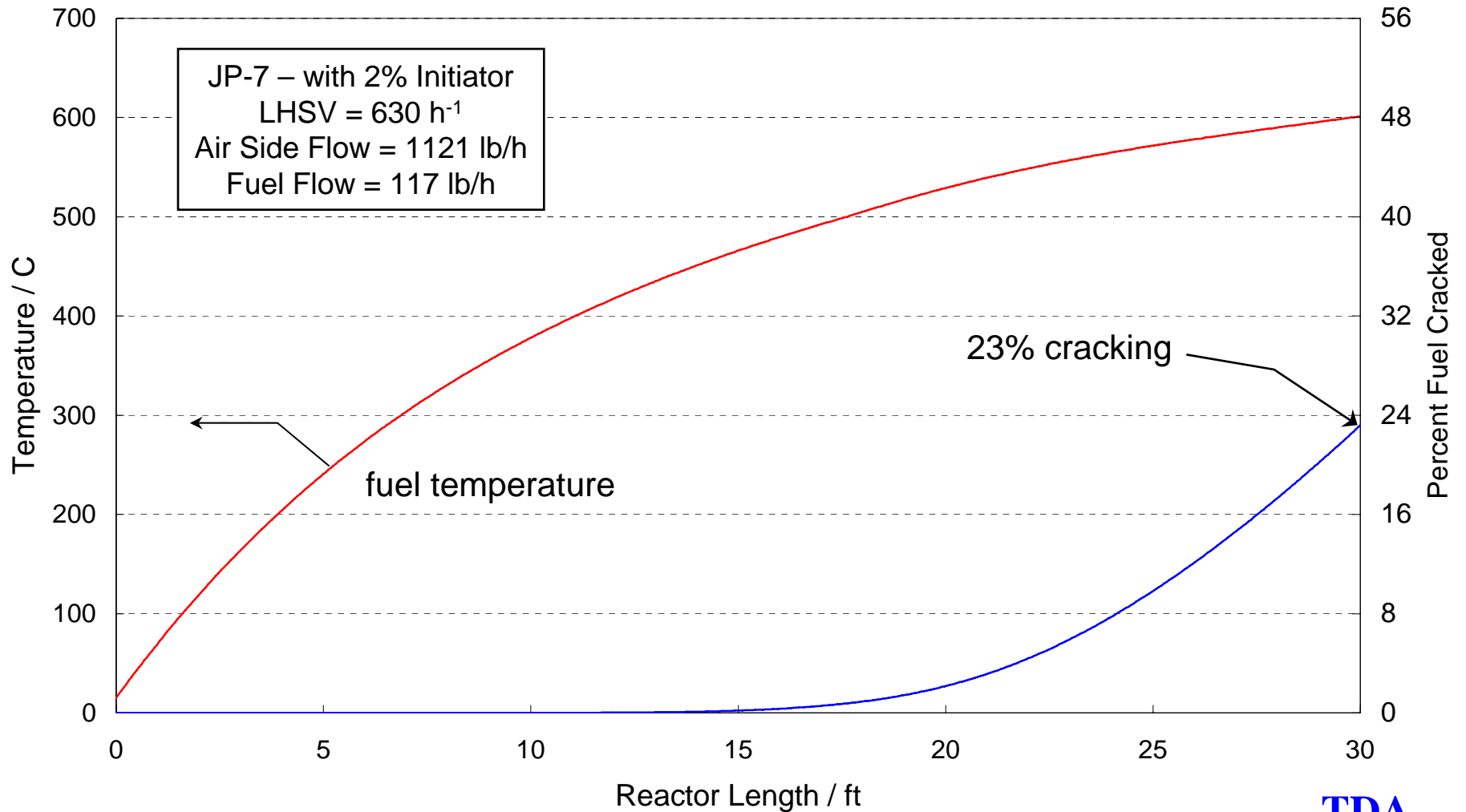


32 feet total finned tubing length
25.5 in overall unit length
3 in coil diameter
41 total wraps
~9.4 in length per wrap

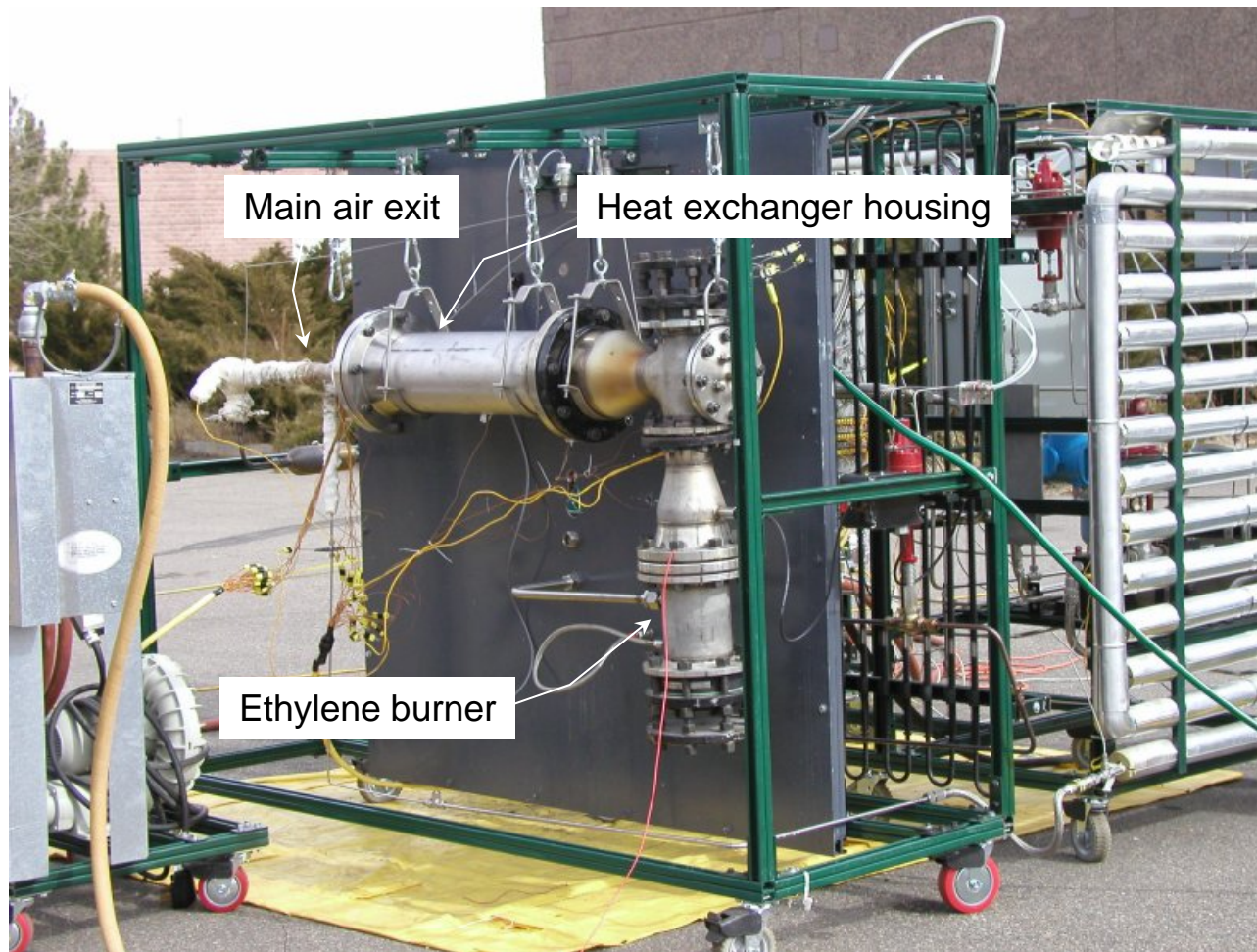
Kinetic Model Used to Predict Cracking Level



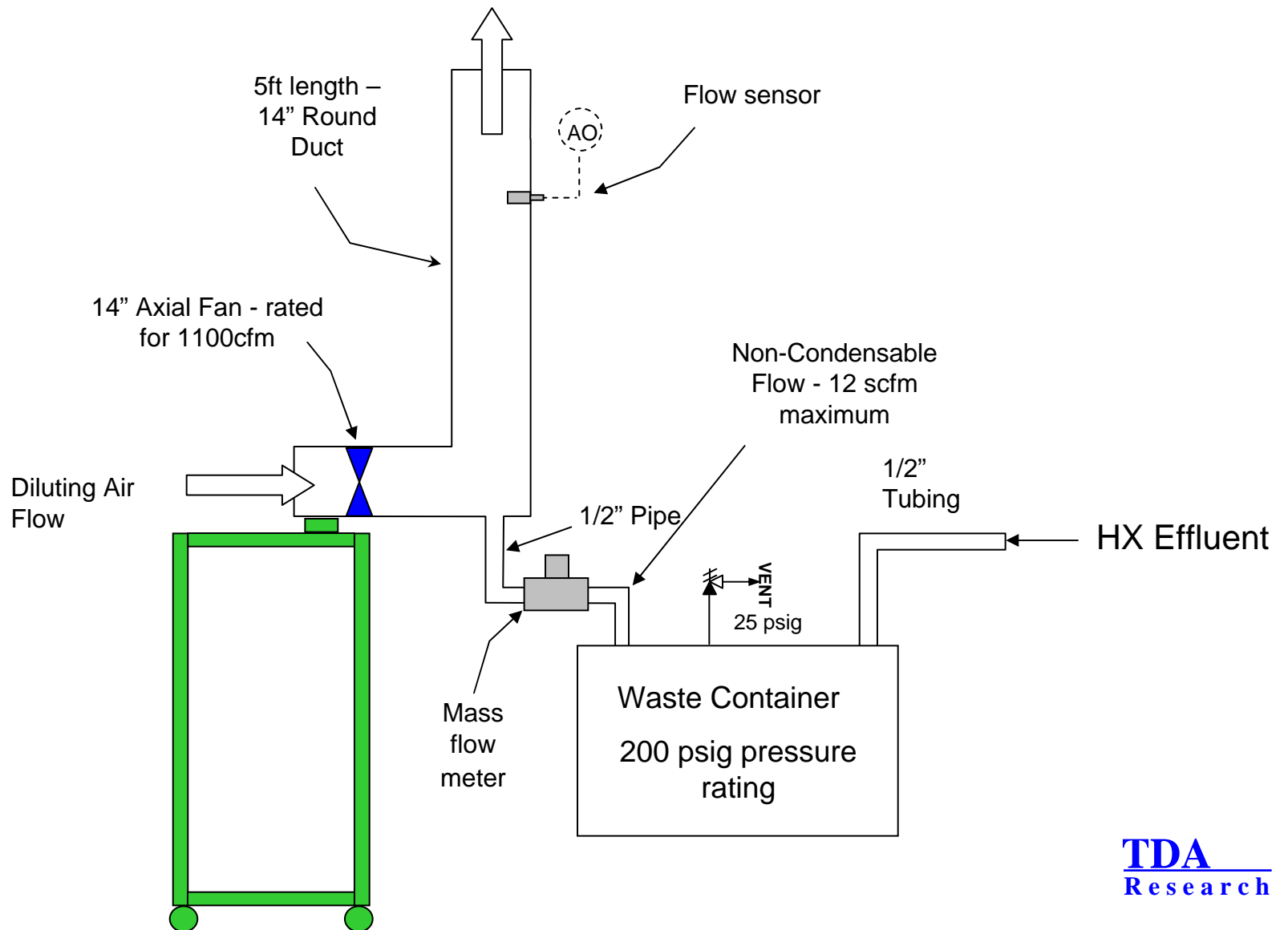
Addition of Initiator Increases the Fuel Cracking Reaction



Installed in Test Rig



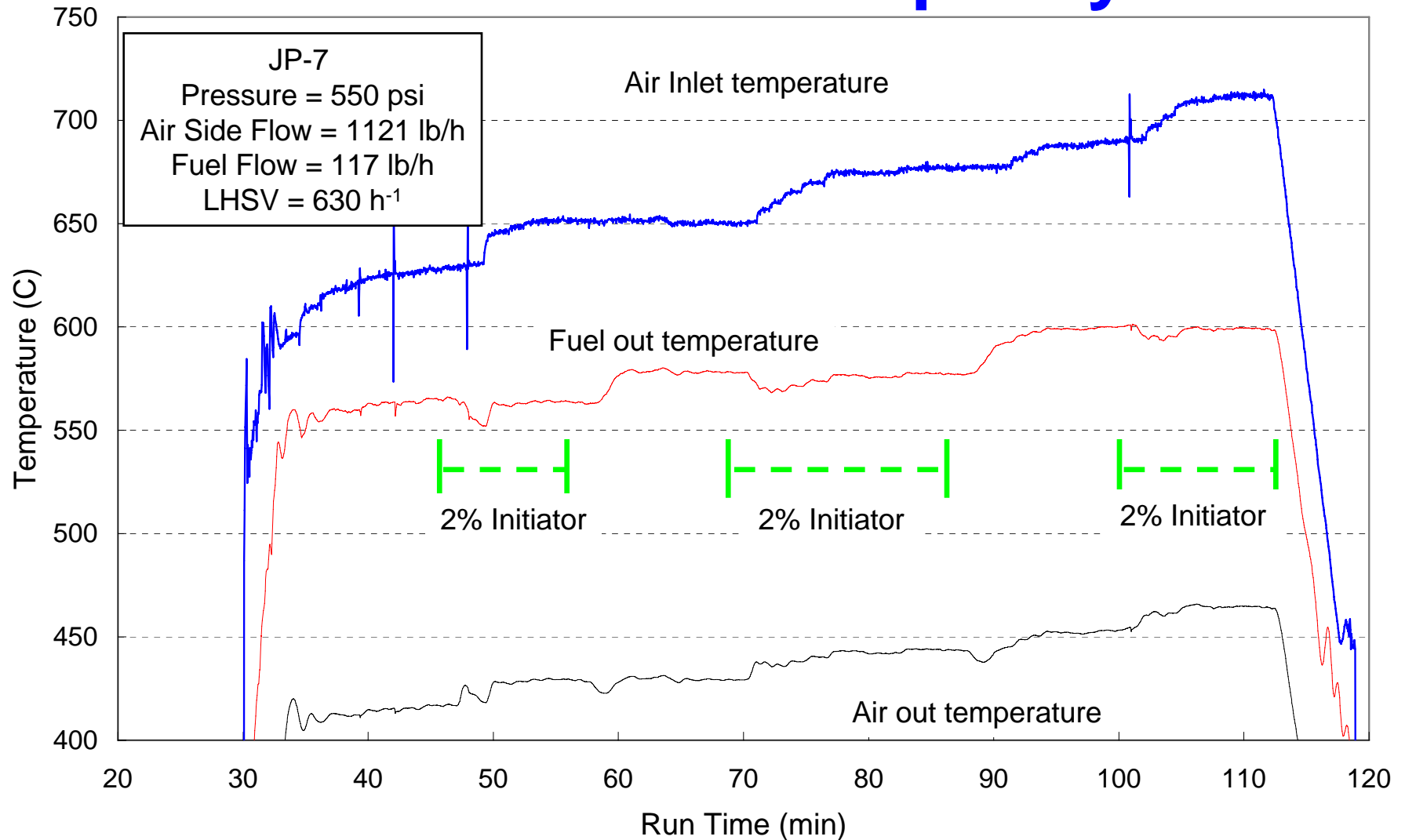
We Measured Non Condensable Flow



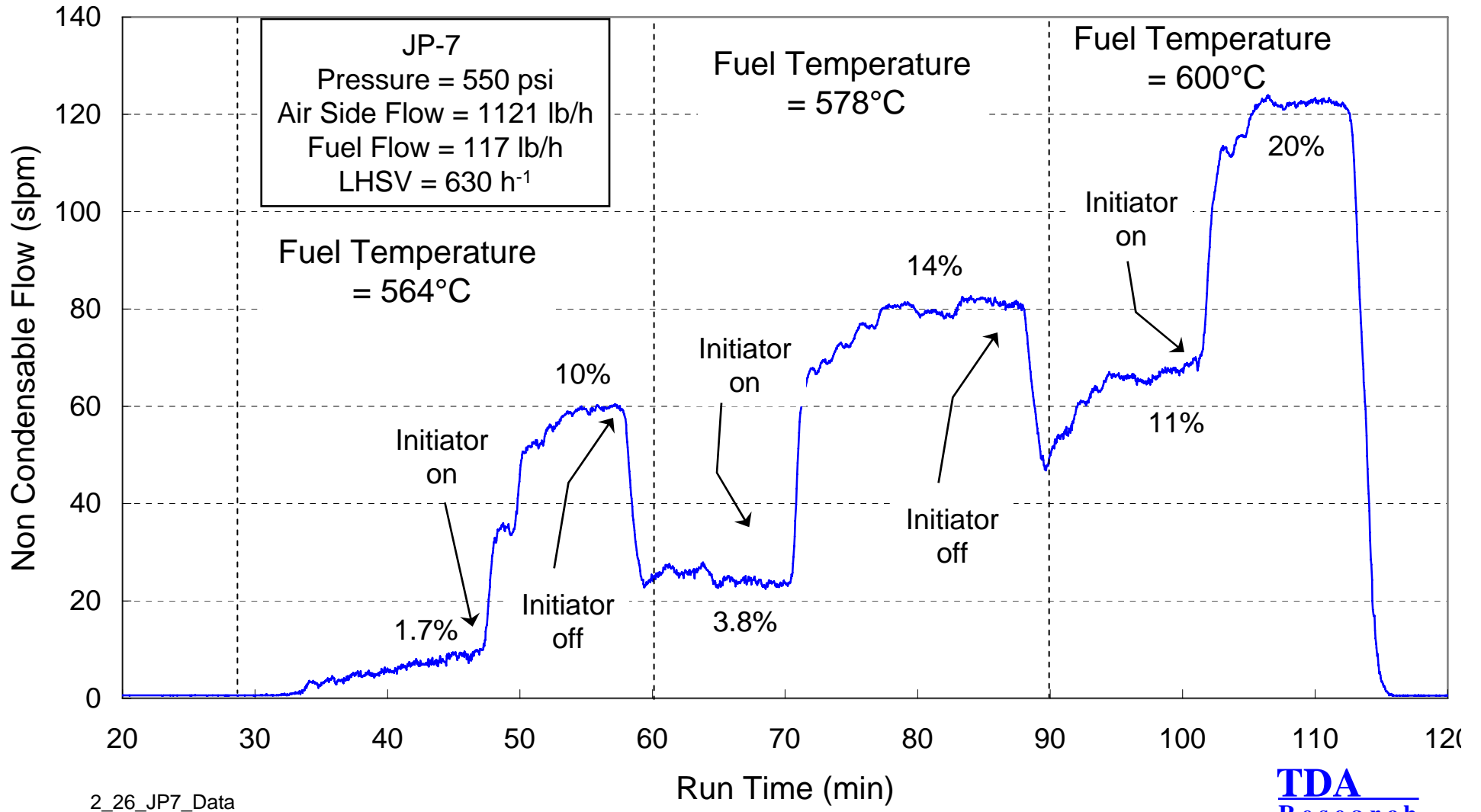
Pilot Scale Rig in Operation



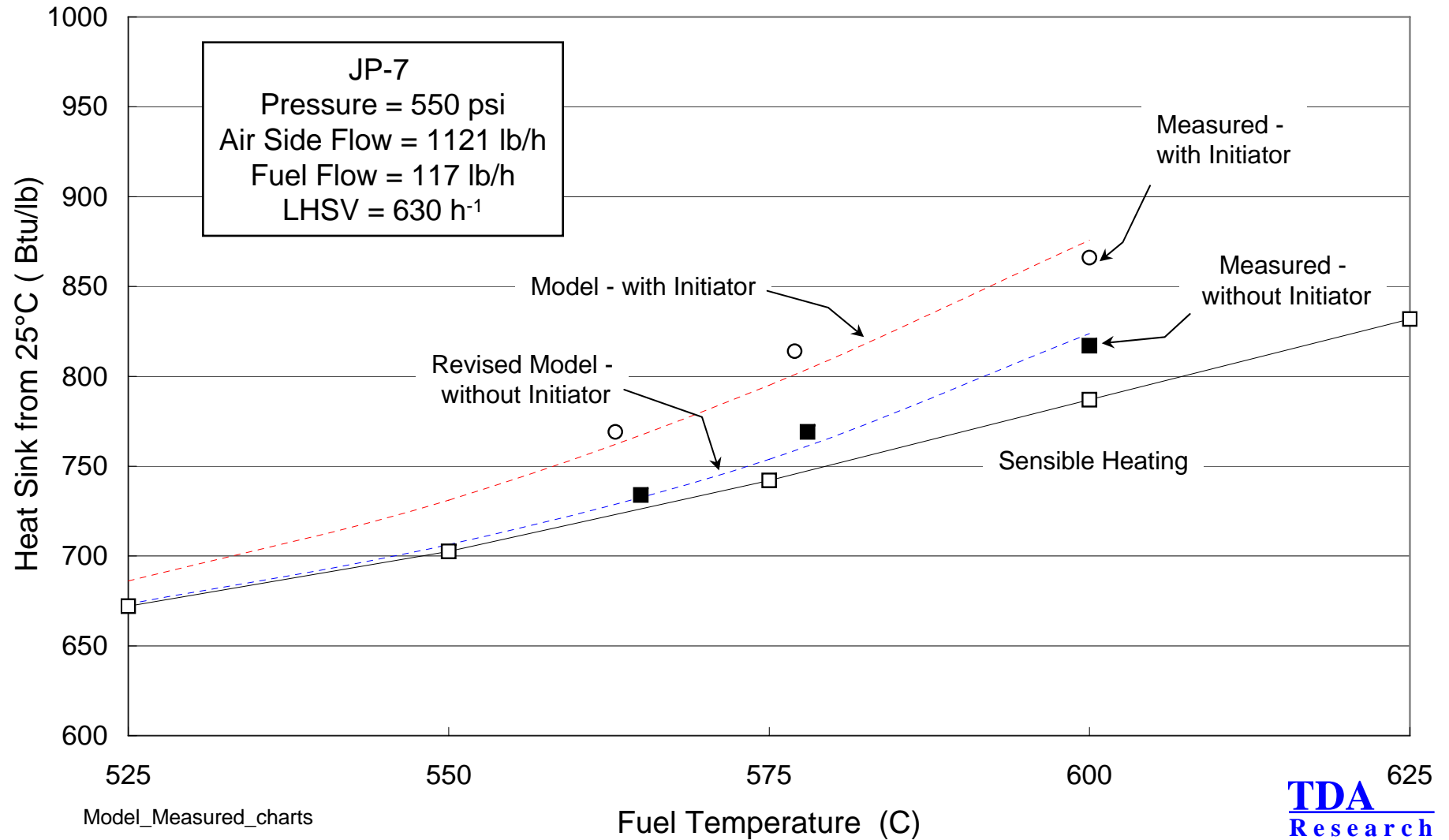
Initiator Causes an Increase in the Fuel Heat Sink Capacity



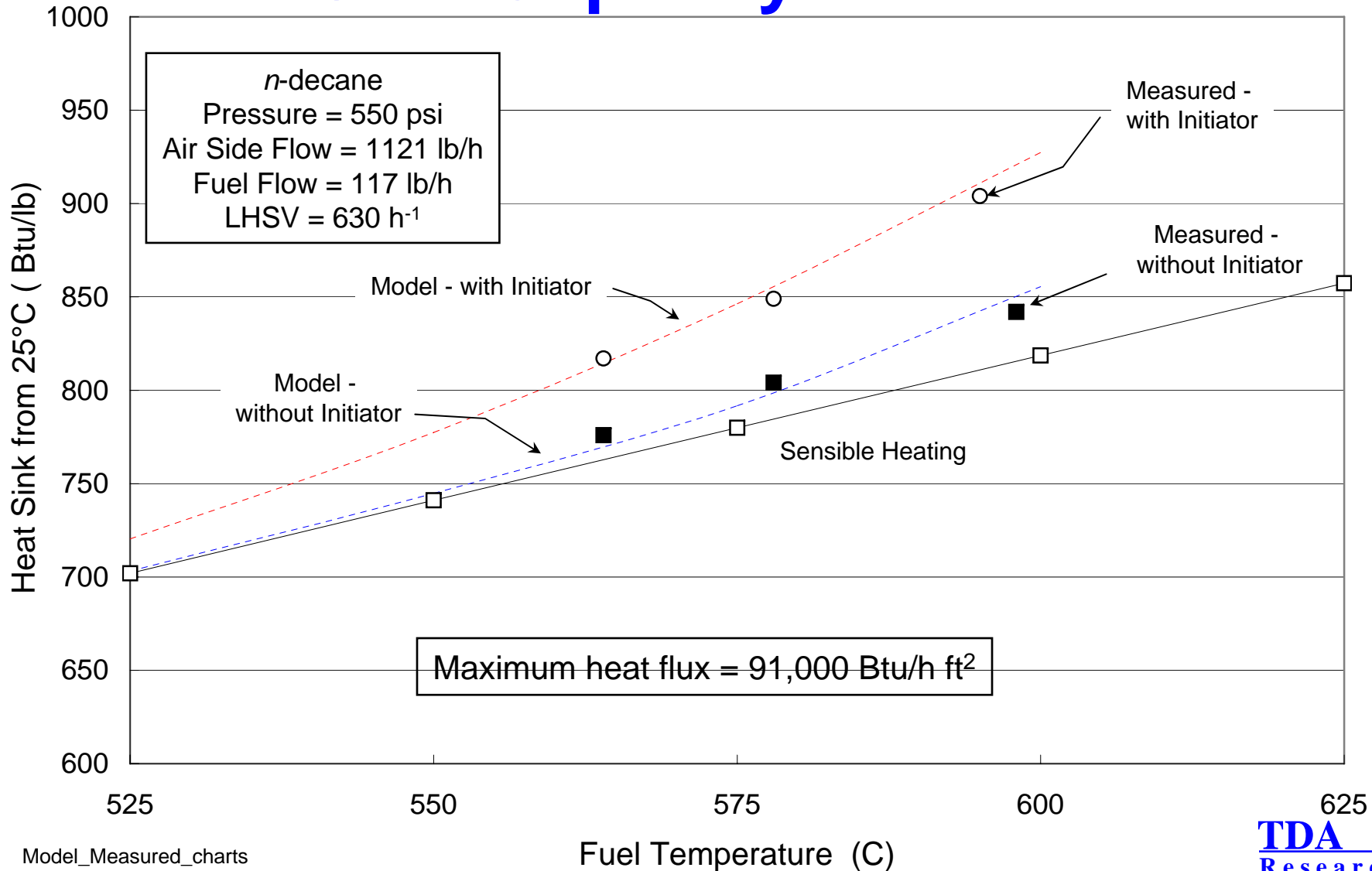
Initiator Produces Significant Increase In Non Condensable Flow



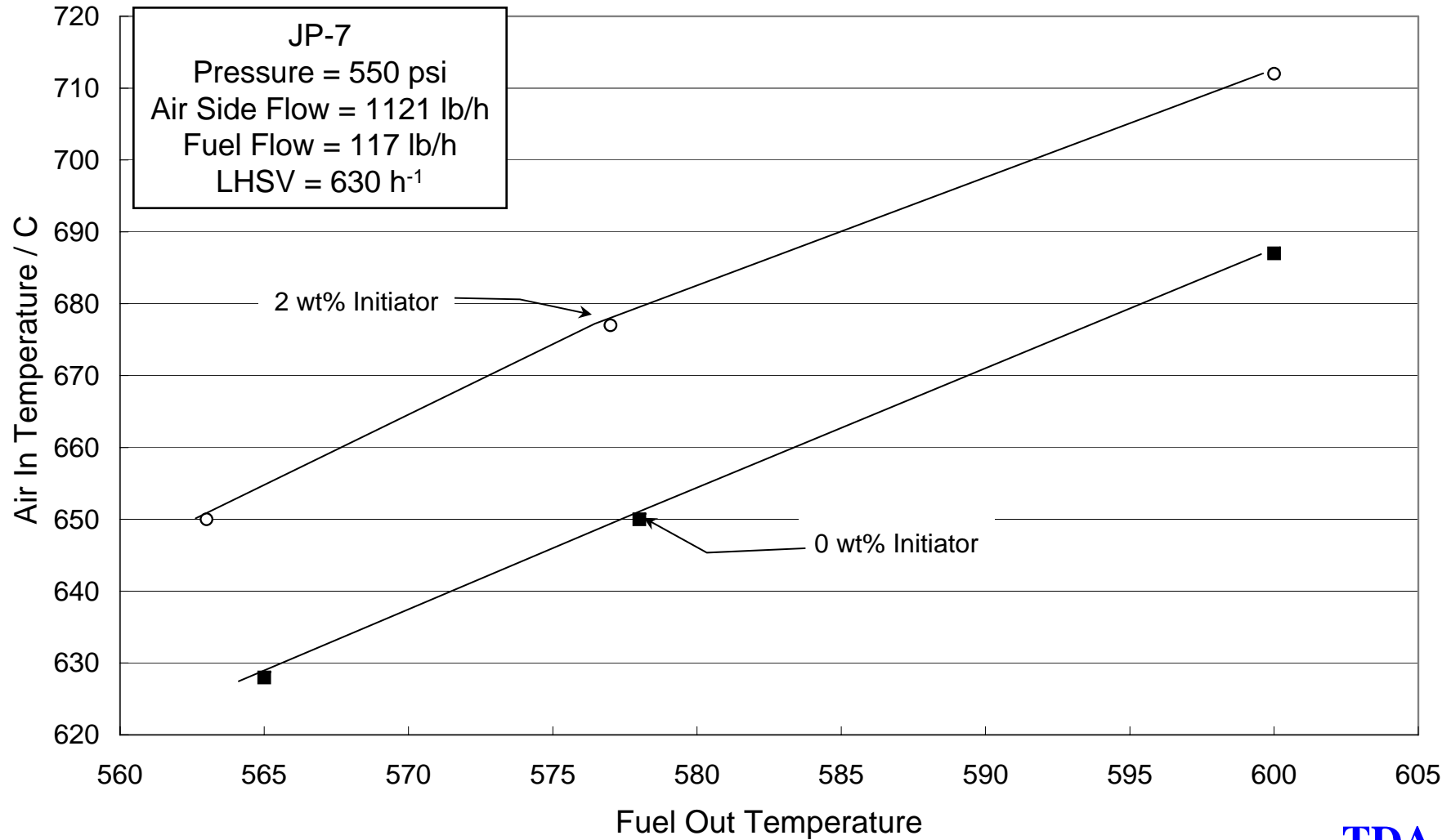
Model for JP-7 Fits the Data Well



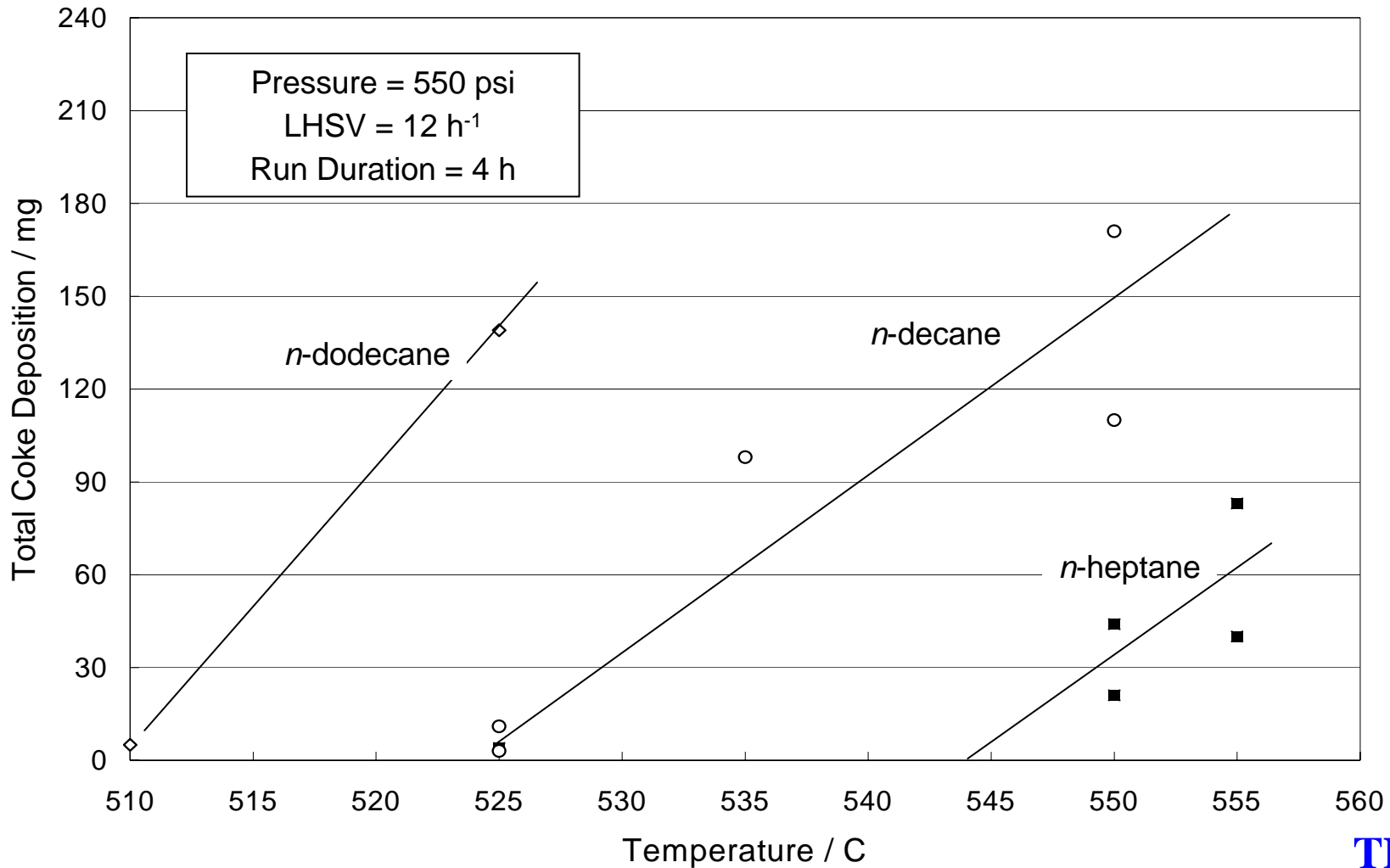
Initiated Cracking Adds Substantial Heat Sink Capacity for *n*-Decane



The Initiator Can Reduce the HX Temperature



Coke Deposition Rates are a Strong Function of Temperature



Summary

- The TDA initiator produces significant increases in the fuel heat sink capacities of JP-7 and model fuel compounds.
- The initiator reduces the activation energy for the thermal cracking reaction.
- We demonstrated the effectiveness of the initiator in a fuel/air heat exchanger that operated at realistic heat flux.
- The initiator reduces the HX temperature, which could substantially reduce coke deposition.

Acknowledgements

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