



Thermal Cracking of Tars in a Continuously Fed Reactor with Steam

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New Orleans, LA

May 9-12, 2011

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE MAY 2011		2. REPORT TYPE		3. DATES COVERED 00-00-2011 to 00-00-2011	
4. TITLE AND SUBTITLE Thermal Cracking of Tars in a Continuously Fed Reactor with Steam				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Maryland, Dept. of Mechanical Engineering, 1131 Glenn Martin Hall, College Park, MD, 20742				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Presented at the NDIA Environment, Energy Security & Sustainability (E2S2) Symposium & Exhibition held 9-12 May 2011 in New Orleans, LA. U.S. Government or Federal Rights License					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 21	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



Outline

- Motivation
- Objectives
- Background
- Experimental Setup
- Results
 - Effect of Residence Time on Syngas Production
 - Kinetics of Syngas Production in a Continuous Reactor
 - Effect of Reactor Temperature on Syngas Production
- Conclusions
- Acknowledgments

Motivation

- Solid waste disposal is a global social and environmental issue

Air Pollution



Water Pollution



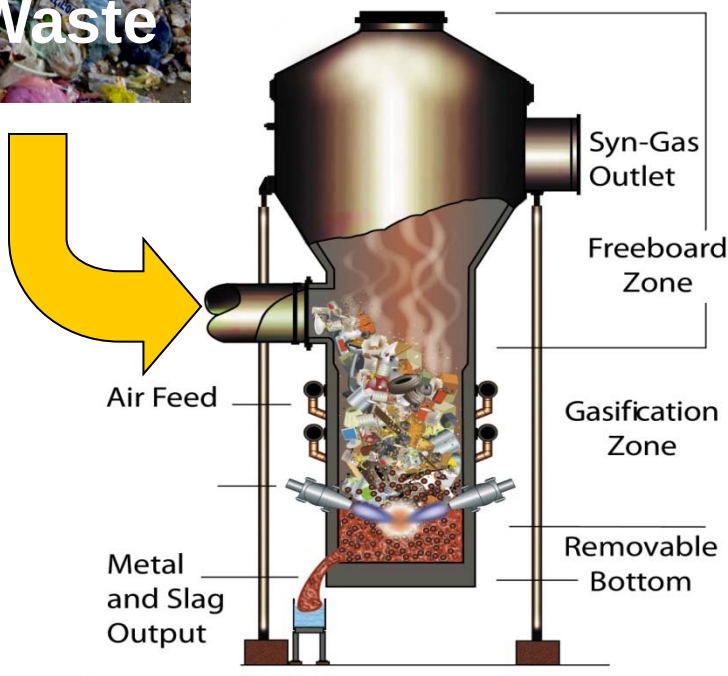
Soil Pollution



- Energy recovery from wastes is sustainable and carbon neutral or perhaps negative
- Eco-friendly energy recovery from wastes requires the development of new, efficient and novel technologies

Motivations (2)

Solid Waste Gasification as an Enabling Technology



Sustainable Energy



**Minimal
Environmental
Impact**



**Reliability,
Affordability, &
Maintainability
(RAM)**





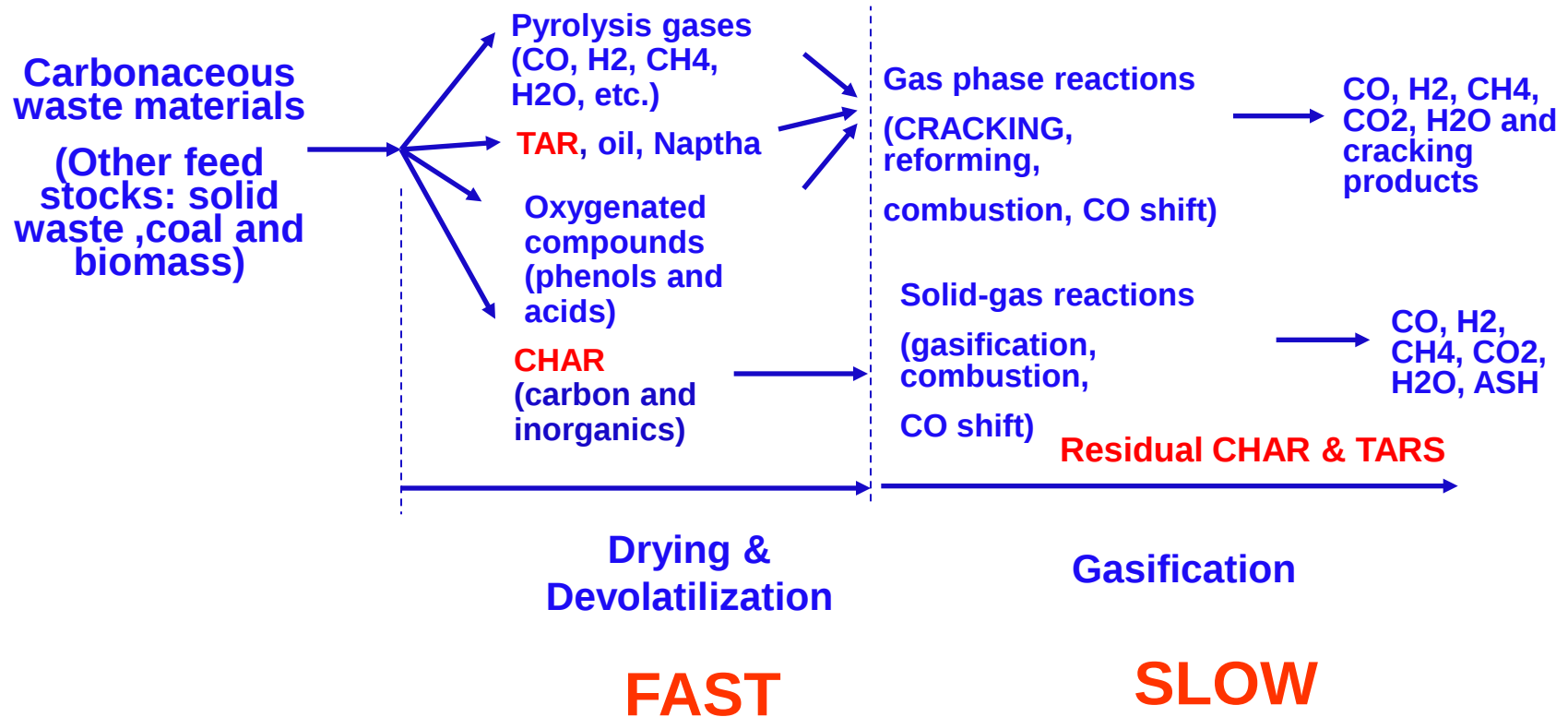
Objectives

- Investigate means to reduce high tar production in a continuously fed non-isothermal reactor operated at $800\text{ }^{\circ}\text{C} < T < 1000\text{ }^{\circ}\text{C}$ and 1 atm
- Develop efficient and effective methods to eliminate high tar production in a non-isothermal reactor
- Characterize tar reduction from the effects of:
 - Residence time of reaction
 - Kinetics of Syngas Production
 - Reactor temperature on syngas production



Background

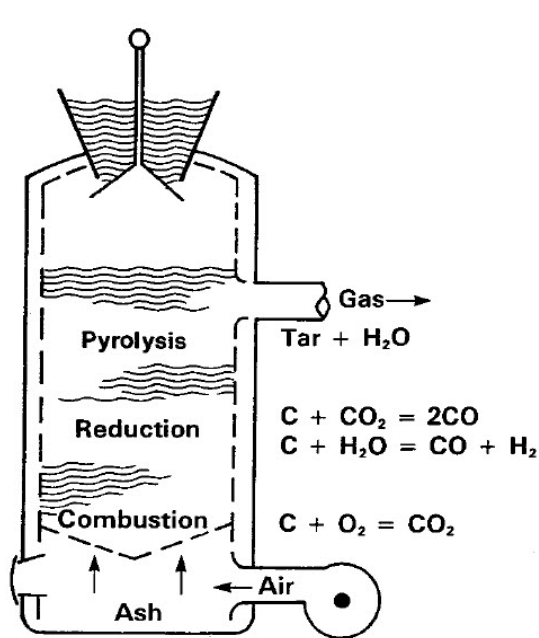
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[Ref. 1: Reimert and Schaub, 1989]

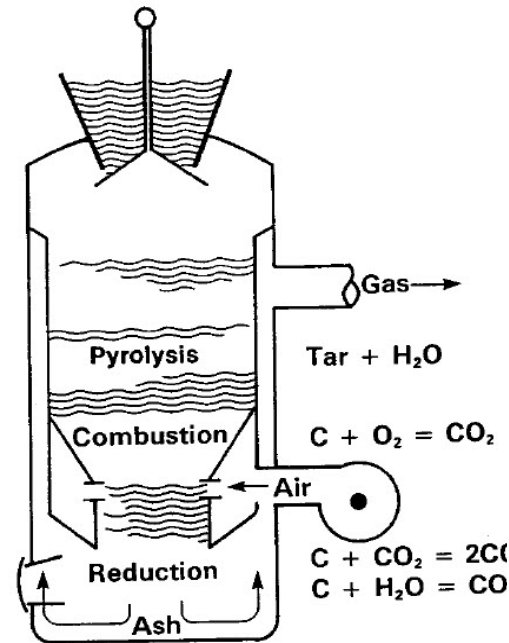
Background (2)

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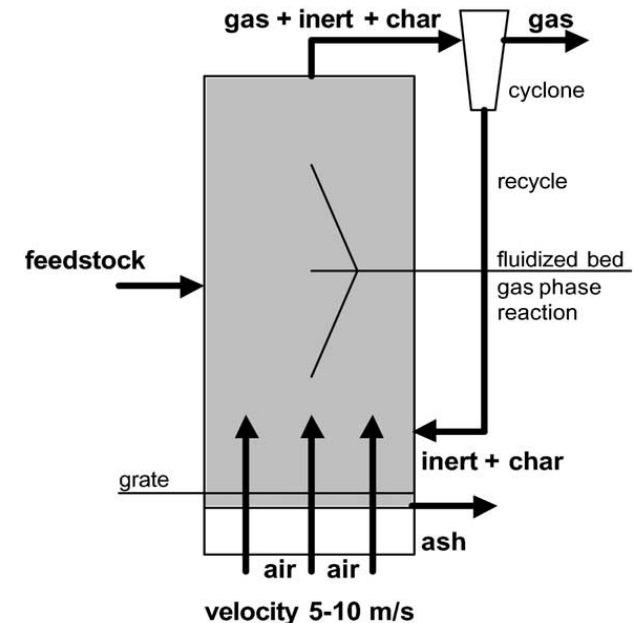
**Updraft Gasifier
(UG)**

- Clearly defined zones
- Good HEX gas/feed due to CC flow
- High tar (up to 100 g/Nm³)



**Downdraft Gasifier
(DG)**

- Tar cracking in the CZ
- Low tar (< 1 g/Nm³)



**Circulating
Fluidized Bed
Gasifier (CFBG)**

- Oxidizing agent is forced through the distributor up
- Fluid forces on the solids ~ = weight of feedstock
- Good mixing
- Ideal for continuous

Nm³ - Normal cubic meters 0 °C and 1 atm



Background (3)

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Tars from Updraft, Downdraft and Circulating Fluidized Bed using biomass

Product Gas Analysis from Biomass

Updraft, Downdraft, and Fluidized Bed Gasifiers

Gasifier Type	Updraft ^a	Circulating Fluid Bed ^b	Downdraft ^c
Gas Analysis (vol-%)			
Hydrogen	6.9	11.2	15.2
Carbon Monoxide	29.5	20.2	22.1
Hydrocarbons	2.2	5.8	1.7
Carbon Dioxide	6.1	12	9.7
Nitrogen	55.3	44.6	50.8
Tars, (mg/Nm³)	100,000	10,000	1,000
Heating value, (MJ/Nm ³) (gross, dry basis)	5.53	5.86	5.8

^aMcLellan, 1996; ^bAlbrecht, 1996; ^cReed, 1988

[Ref. 2: Frederick, J., "Thermal Processing", Georgia Institute of Technology, May18, 2006]

Background (4)

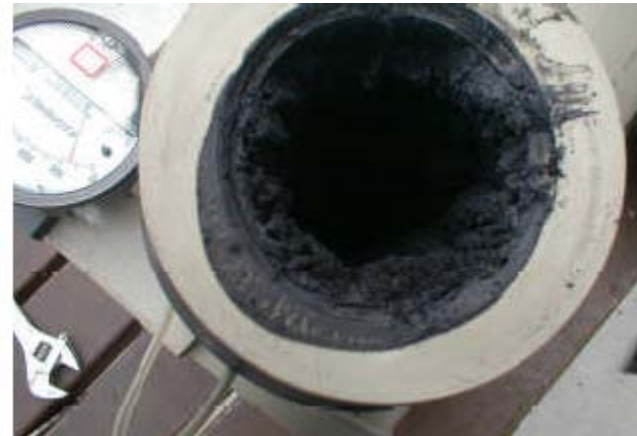
Tars

- Mixture of organic components present in gasification product gas with high molecular weight hydrocarbons [MW higher than ~ C6 (6)]
 - Harmful
 - Corrode gas turbine blades, foul heat recovery boilers, and other gas downstream components
 - Plug reforming catalysts
 - Disable sulfur removal systems

Plugging



Fouling



[Ref. 3: Biomass Gasification – Tar and Particles in Product Gases Sampling and Analysis”, European Standard CEN TC BT/TF 143, TC 143 WI CSC 03002, July 2005]



Background – Syngas Quality Requirements

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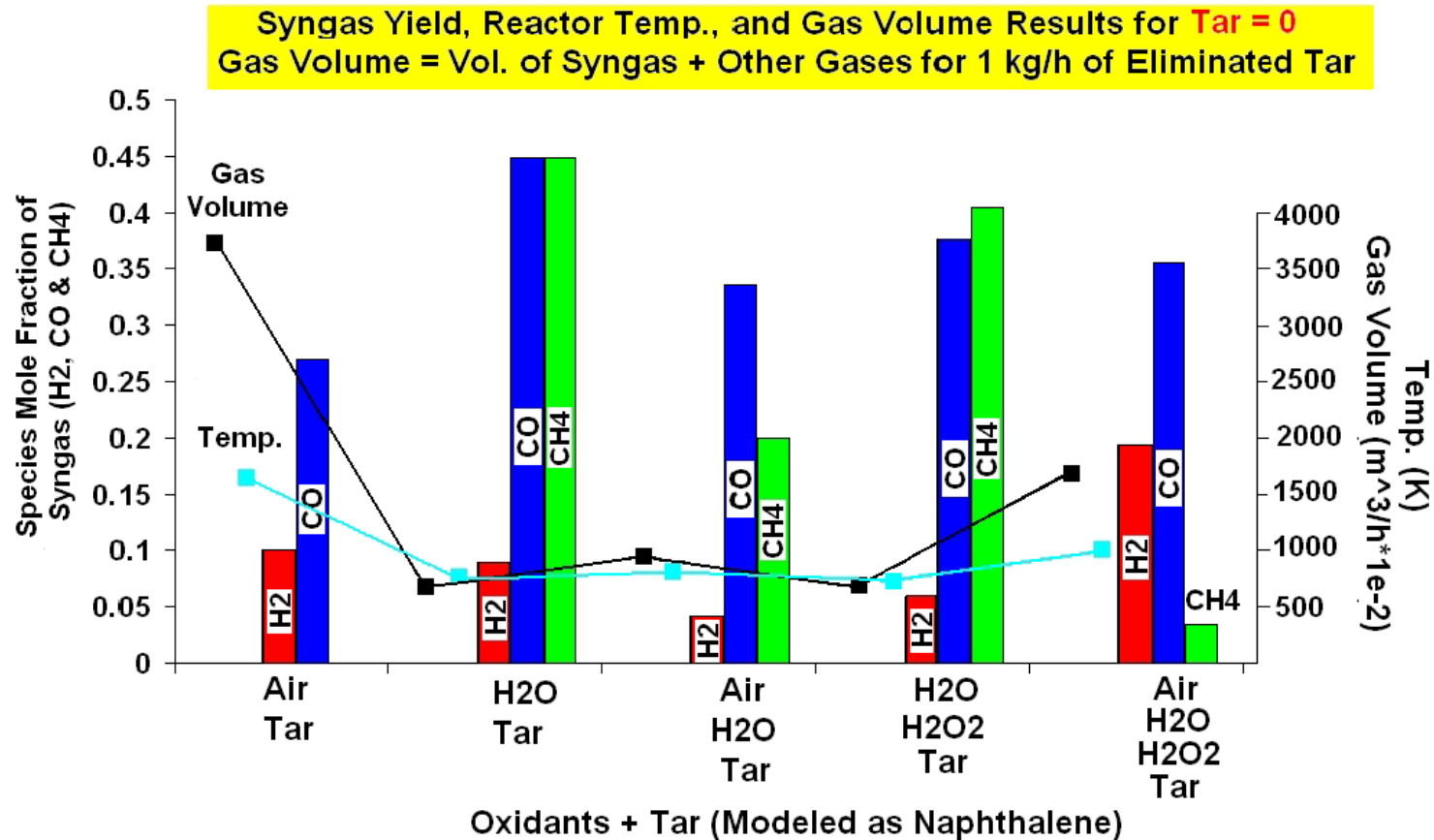
Contaminants	Units	IC Engine	Gas Turbine
Particles	mg/Nm ³	< 50	< 30
Particle Size	μm	< 10	< 5
Tar	mg/Nm ³	< 100	n.d.*
Alkali Metals	mg/Nm ³	n.d.*	< 0.24

[Ref. 4: Hasler P., and Nussbaumer T., “Gas Cleaning Requirements for Internal Combustion Engine Applications of Fixed Bed Biomass Gasification”, Biomass and Bioenergy, Vol. 16, 1999, pp. 385-395]

n.d.* - Not detectable



Background – Tar Reforming/Elimination Process



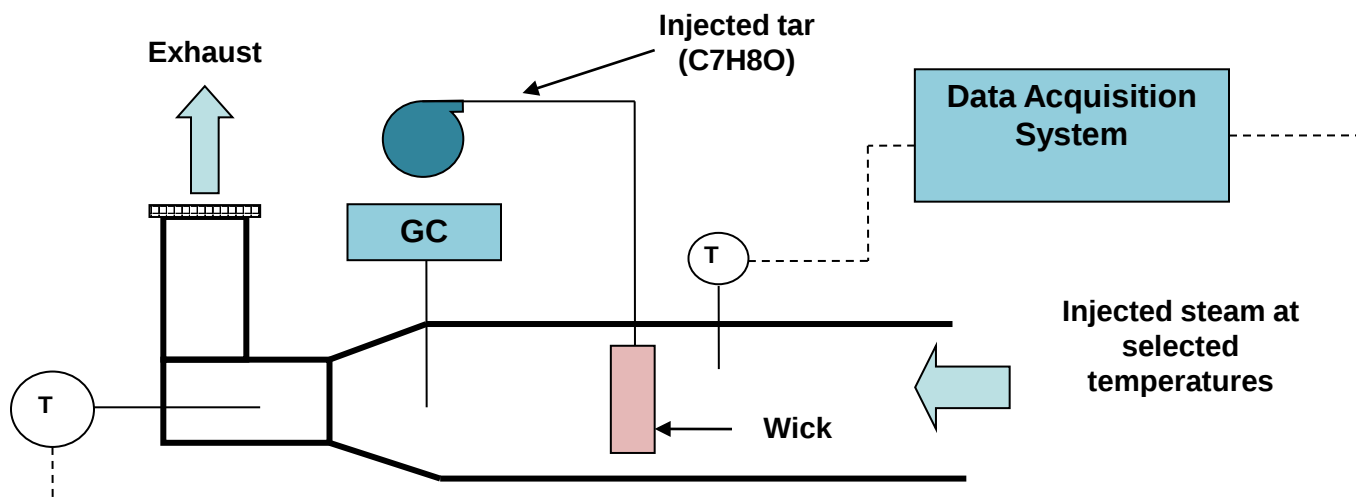
Syngas production results (in mole fractions) on tar elimination using thermodynamic equilibrium calculation

- Predicted highest production of fuel gases (CO, CH₄ and H₂) were obtained with pure steam
- The lowest synthesis gas (CH₄, CO and H₂) yield was obtained with air.



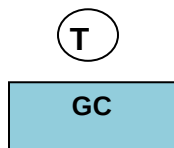
Experimental Setup

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Legend:

Propane Heated Furnace



– Thermocouples

– Gas Chromatograph

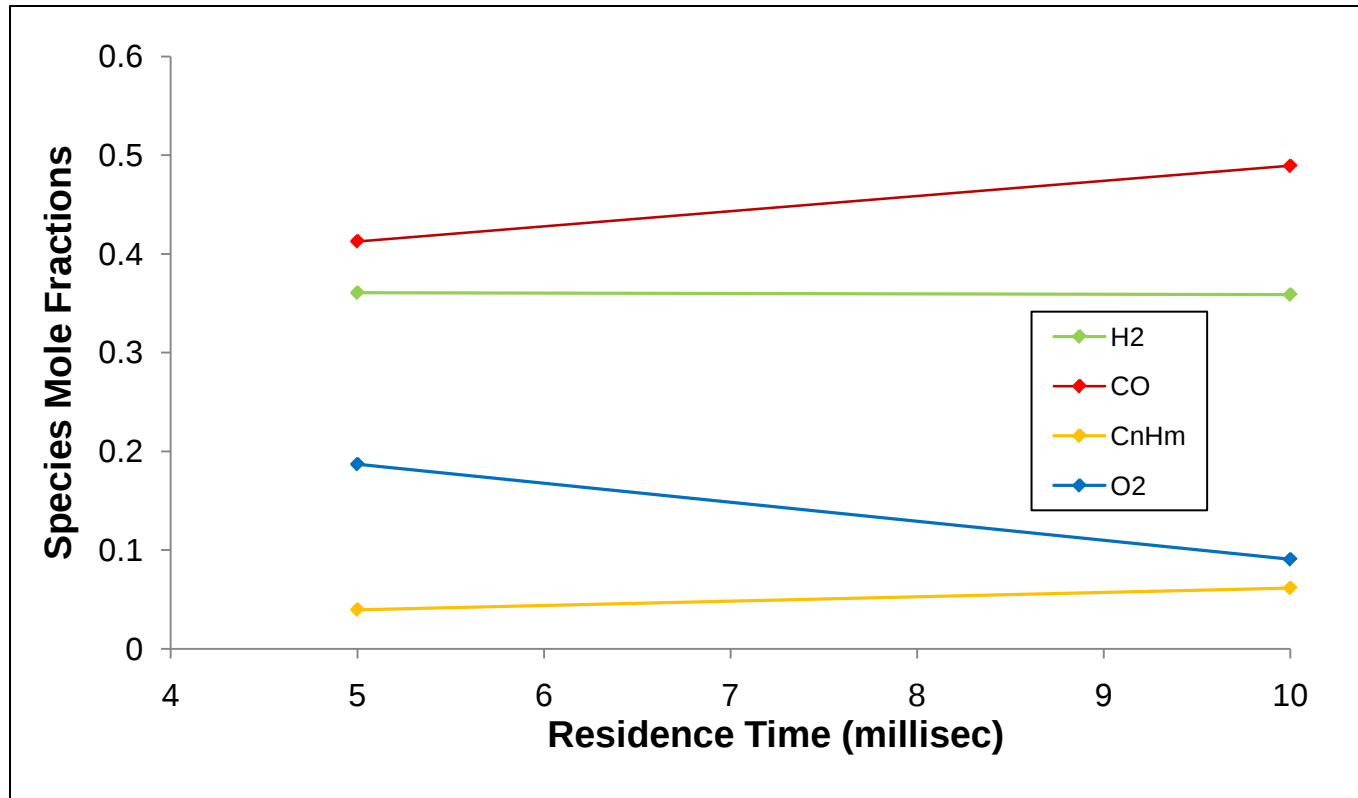


– Injection Pump

- The hot gas stream produced from the stoichiometric combustion of propane (C_3H_8) and air was used to preheat the test section of the reactor to the desired temperatures.

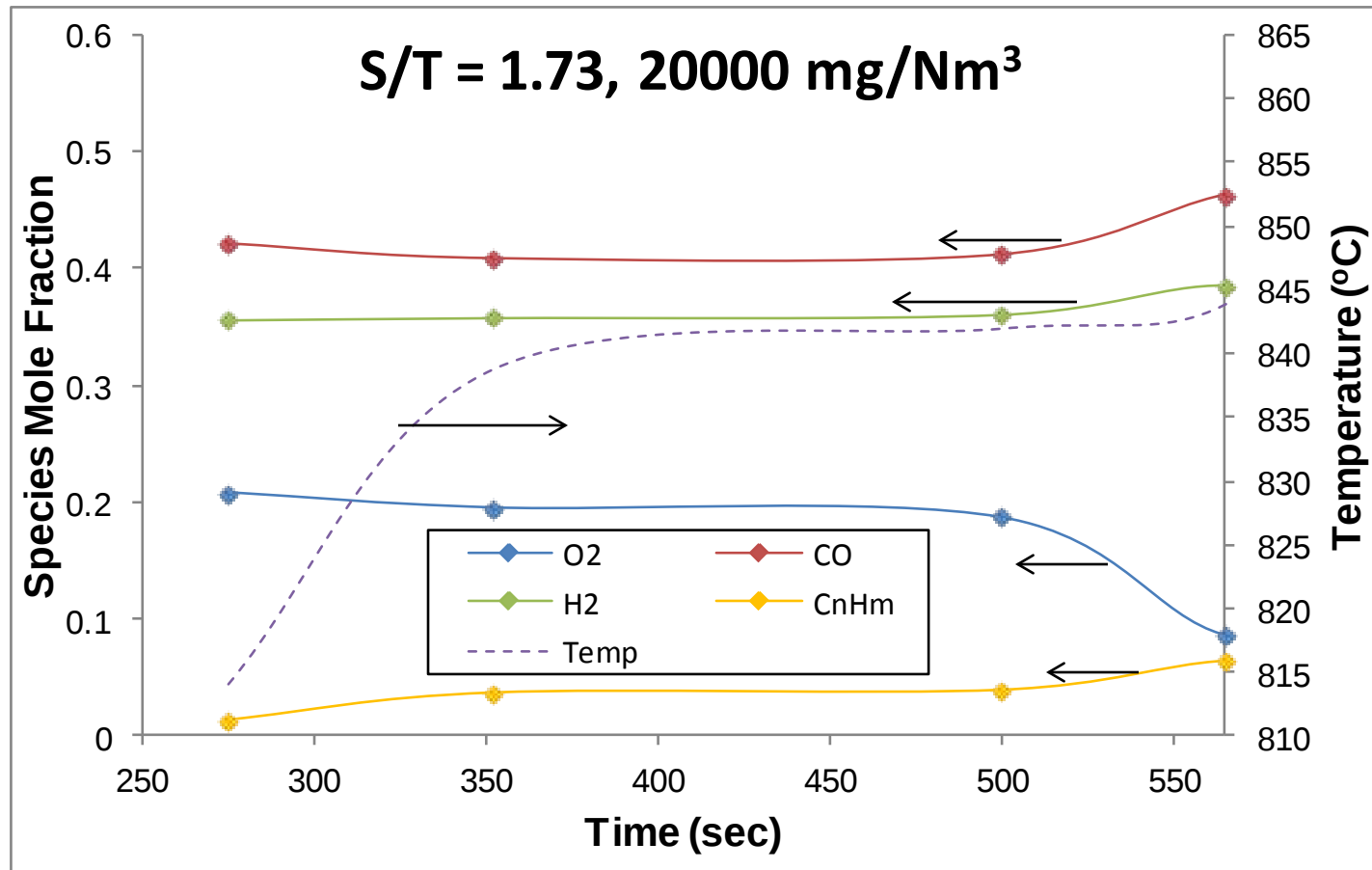


Experimental Results – Effect of Residence Time on Syngas Produced During Tar Reduction Process



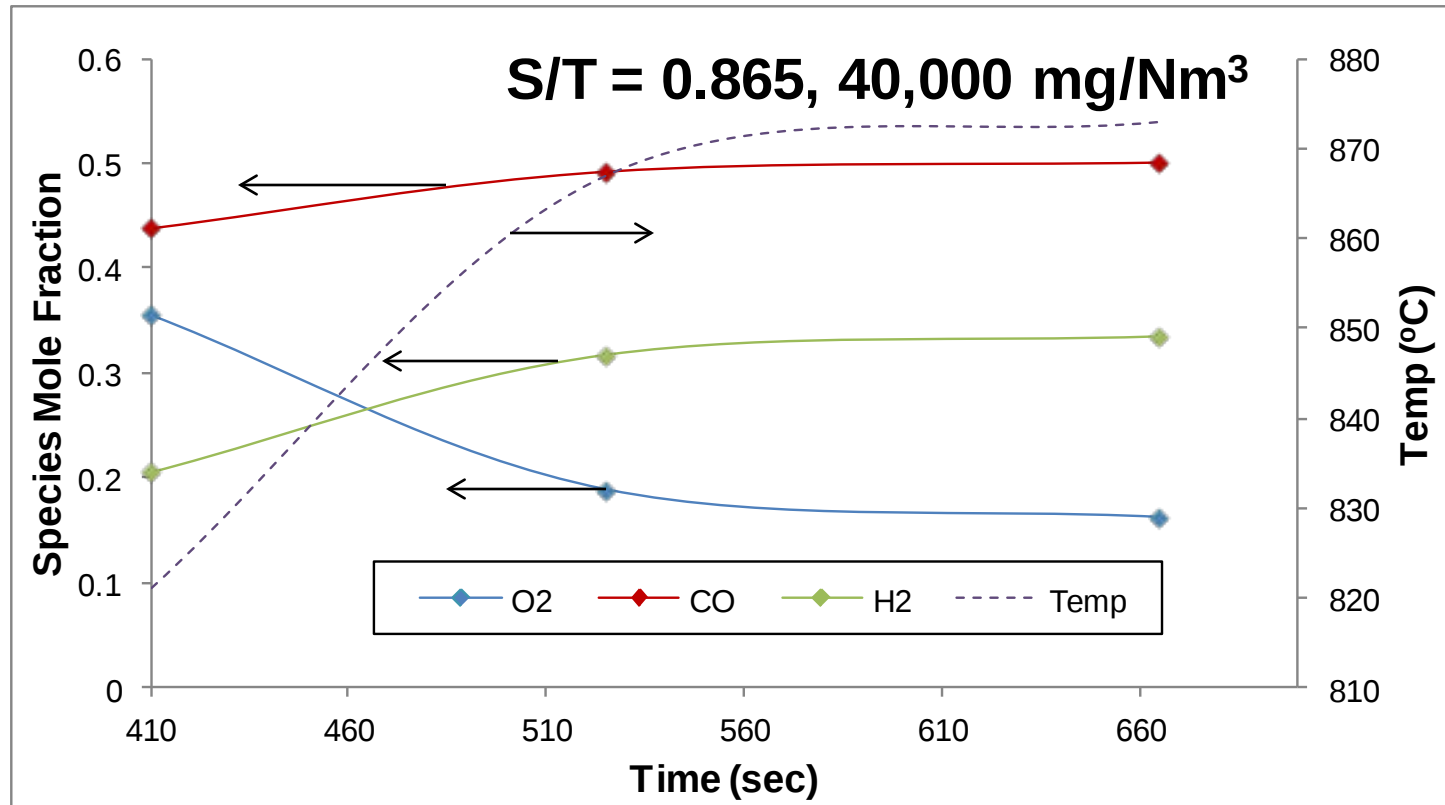
- Doubling the residence time (tar concentration = 20,000 mg/Nm³ for $T_{ave} = 850$ °C, S/T = 1.73) resulted in an increase both for CO and CnHm (except H₂ gas).
- This indicates increased tar conversion at greater residence times

Experimental Results – Effect of Time and Temperature on the Evolution of Syngas



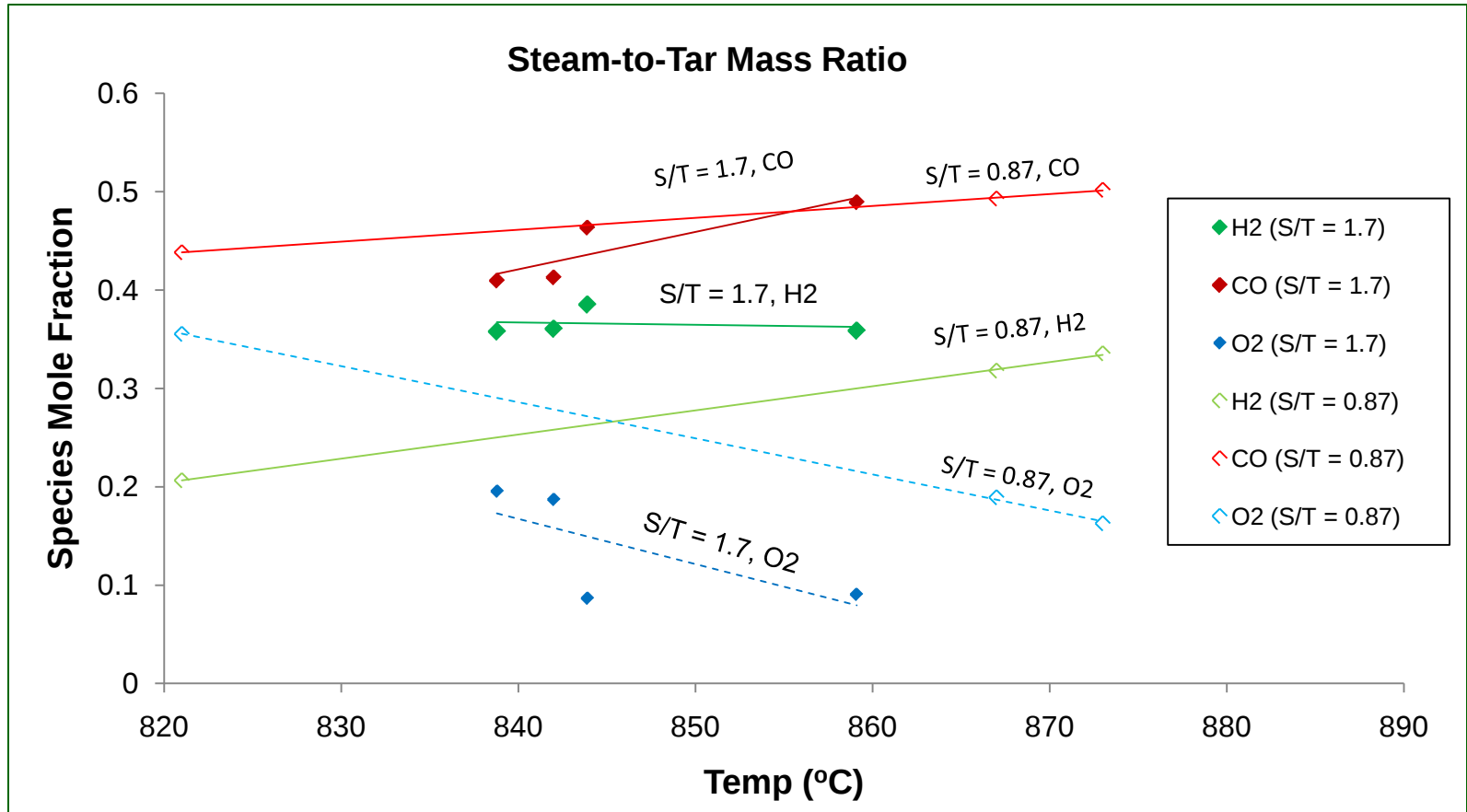
- Evolution of syngas production is nearly constant at $814 \text{ }^{\circ}\text{C} < T < 840 \text{ }^{\circ}\text{C}$ (tar conversions at these conditions).
- For $T > 840 \text{ }^{\circ}\text{C}$, there is an increase in syngas production, especially for CO. This is also accompanied with a sharp decrease in O₂ which may also accompany an increase in tar conversion.

Experimental Results – Effect of Time and Temperature on the Evolution of Syngas (2)



- For Tar Conc. = 40,000 mg/Nm³, the evolution of syngas production moderately increases at 820 °C < T < 867 °C, implying that tar conversions at these conditions also increase moderately.
- For near isothermal condition (867 to 873 °C), the production of syngas has reached a steady-state condition.
- As temperature rises to 867 °C, the O₂ concentration abruptly decreases, indicating that good syngas quality could be achieved at these conditions.

Experimental Results – Effect of Temperature and S/T on Syngas Production



- For both $S/T = 0.87$ and 1.7 , the syngas quality and conversion increase with an increase in temperature. Also, increase in production CO is accompanied with a decrease in O_2
- At $S/T = 1.7$, an increase in temperature did not result in an increase in H_2 . However, at these conditions the CO production increase, implying that tar conversion is improved with increase in temperature
- The rate of change in the production of CO for $S/T = 1.7$ is greater as compared to $S/T = 0.87$



Conclusions

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Continuously fed non-isothermal reactor using steam and O₂ enrichment provided the following:

- Carbon conversion could be increased with greater residence times
- The H₂ production decreased with increase in residence time due to the more favorable production of light hydrocarbons (C_nH_m).
- For updraft gasifiers or pyrolysis systems (usually high tar concentrations), it is possible to treat, reduce or convert these tars to more favorable gases, such as, CO, H₂ and C_nH_m (typically C₂ and C₃) using steam with O₂ enrichment as oxidizing agents.
- At higher tar concentrations or low steam/tar ratio of 0.865, the evolution of syngas production moderately increases between 820 to 870 °C
- The rate of change in the production of CO for S/T = 1.7 is greater as compared to S/T = 0.87



Acknowledgments

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This research was supported by ONR and NSWC Carderock Division. This support is gratefully acknowledged.



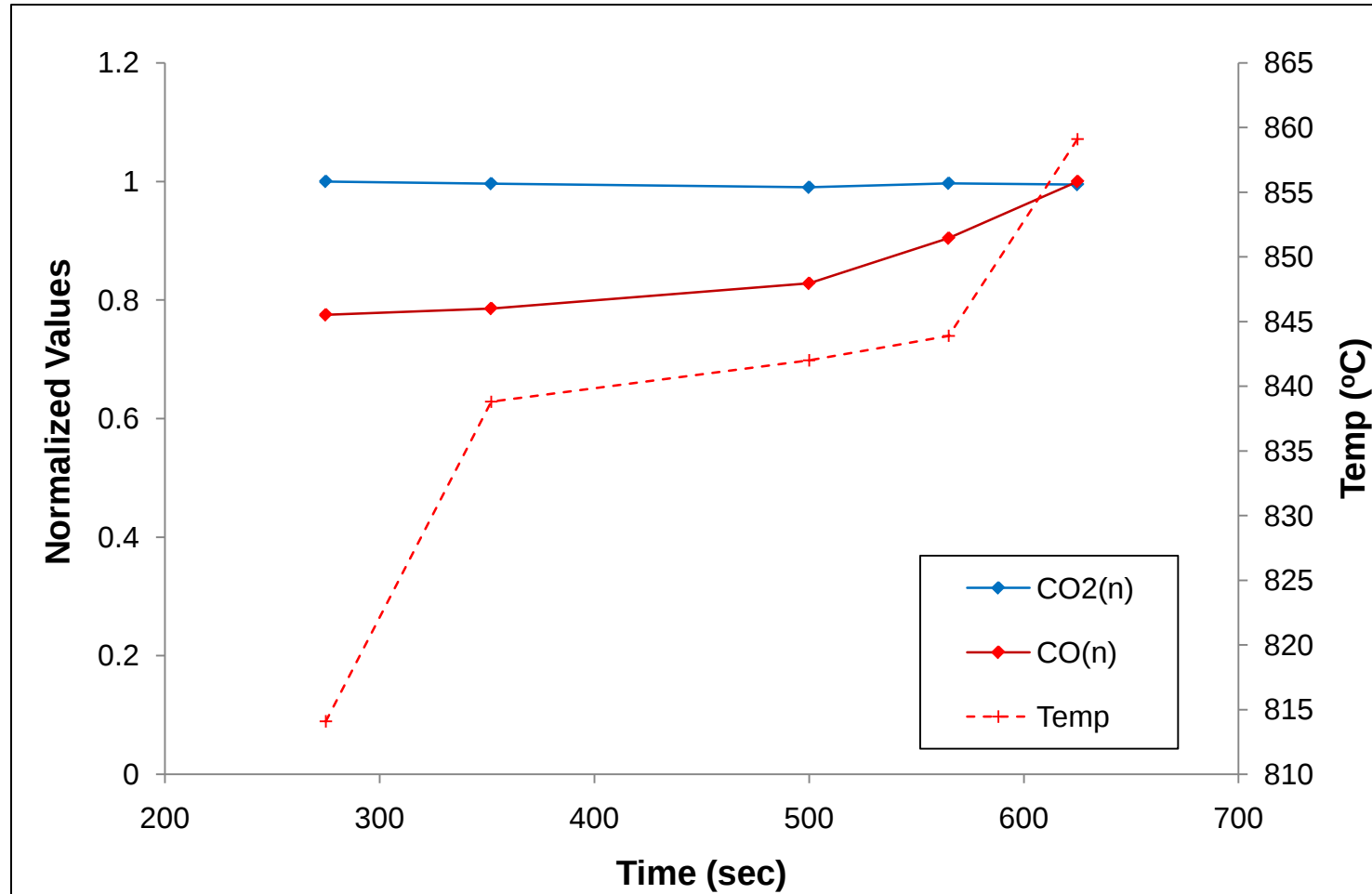
Thank You

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QUESTIONS?



Backup Slide – Evolution of CO₂ and CO



- Most of the conversion could be tracked with the changes in the mole fractions of CO



Bonus Slide – Pyrolysis of Paper

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