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Thermal Cracking of Tars in a Continuously Fed Reactor with Steam

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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

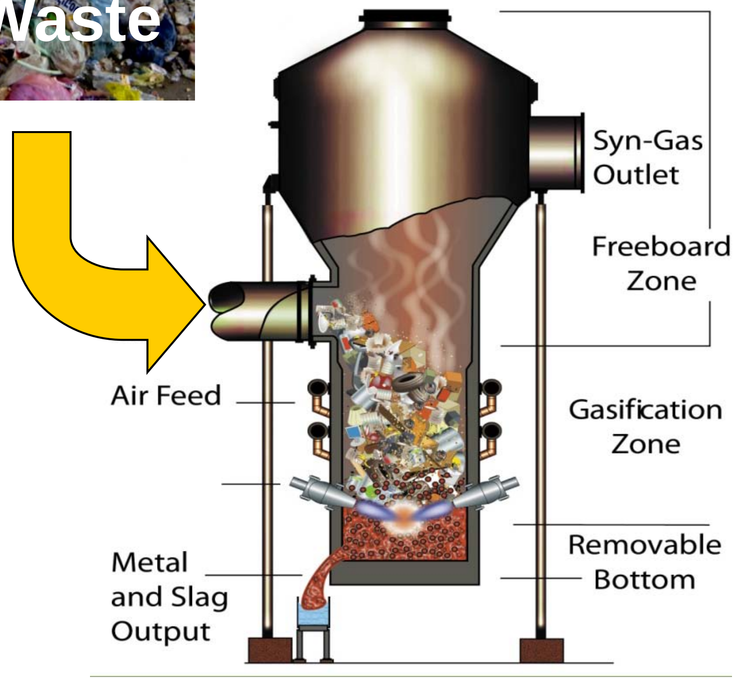
Water Pollution

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 $^{o}C < T < 1000$ ^{o}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

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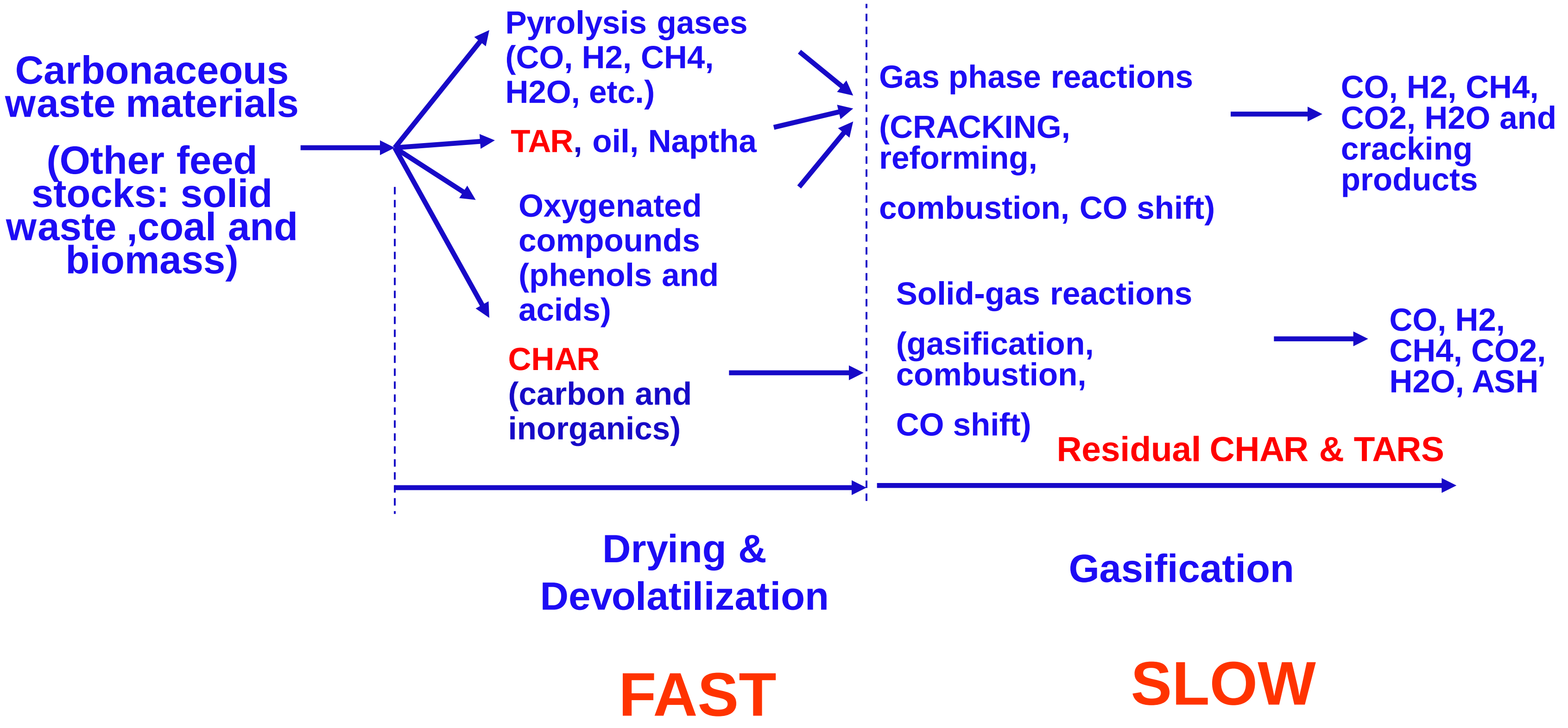
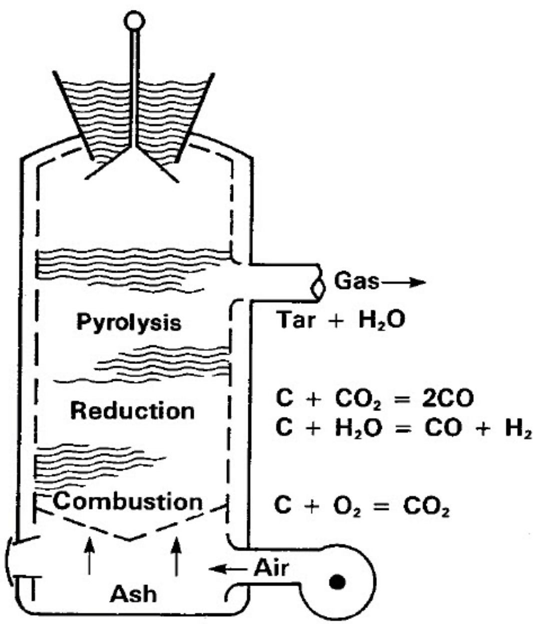
Background

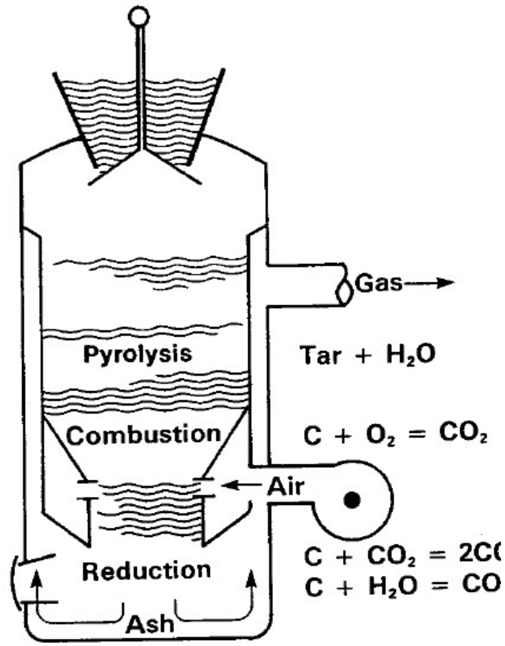


[Ref. 1: Reimert and Schaub, 1989]

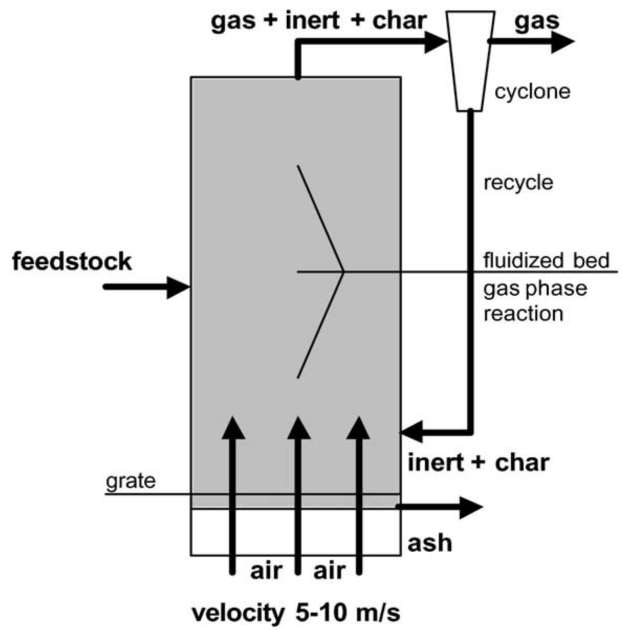
Background (2)



Updraft Gasifier (UG)



Downdraft Gasifier (DG)



Circulating Fluidized Bed Gasifier (CFBG)

- Clearly defined zones
- Good HEX gas/feed due to CC flow
- High tar (up to 100 g/Nm^3)

- Tar cracking in the CZ
- Low tar (< 1 g/Nm^3)

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

Nm^3 - Normal cubic meters 0 ^{o}C and 1 atm

Background (3)

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/Nm^3)	**100,000**	**10,000**	**1,000**
Heating value, (MJ/Nm^3) (gross, dry basis)	5.53	5.86	5.8

[a]McLellan, 1996; [b]Albrecht, 1996; [c]Reed, 1988

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

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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]

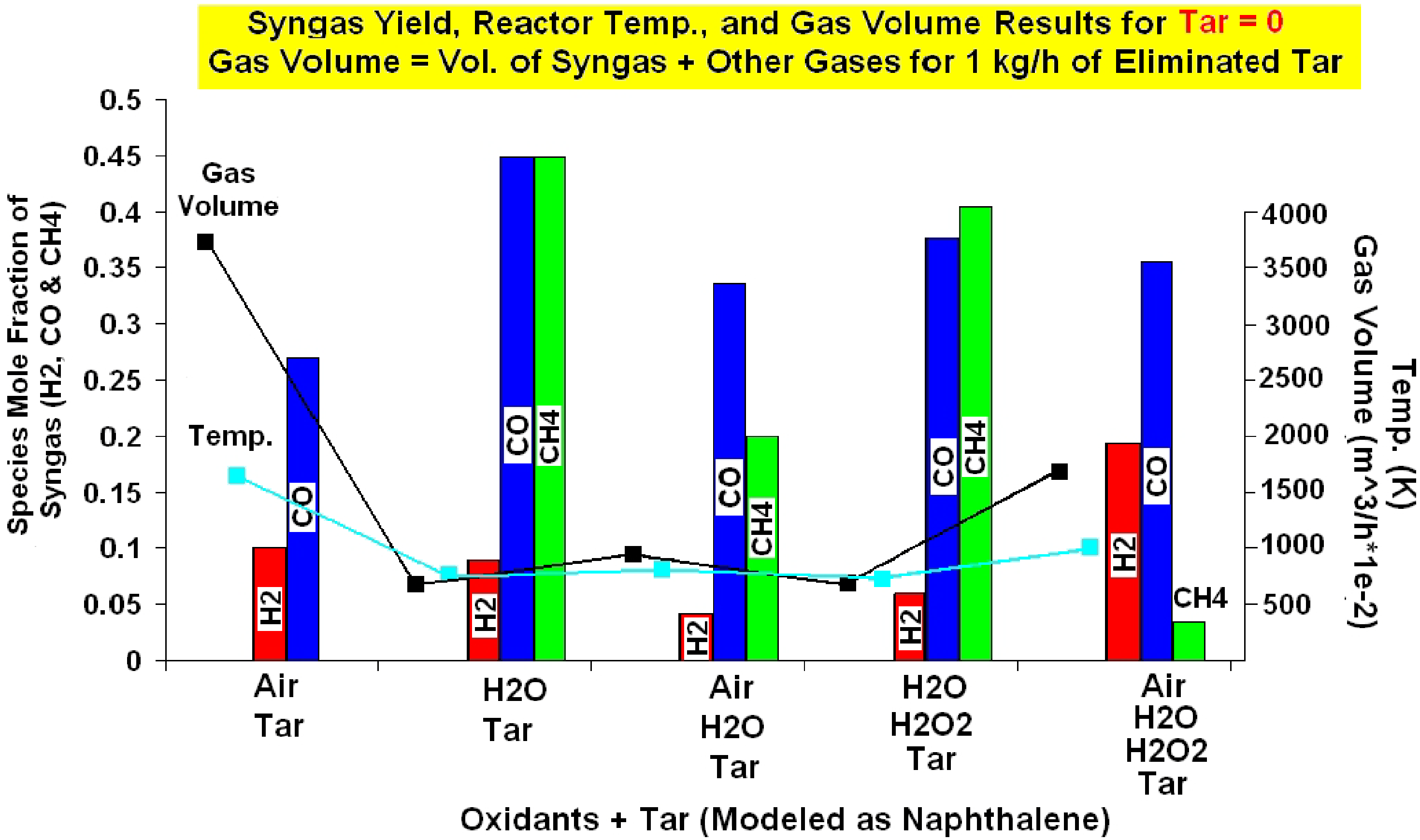
Background – Syngas Quality Requirements

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

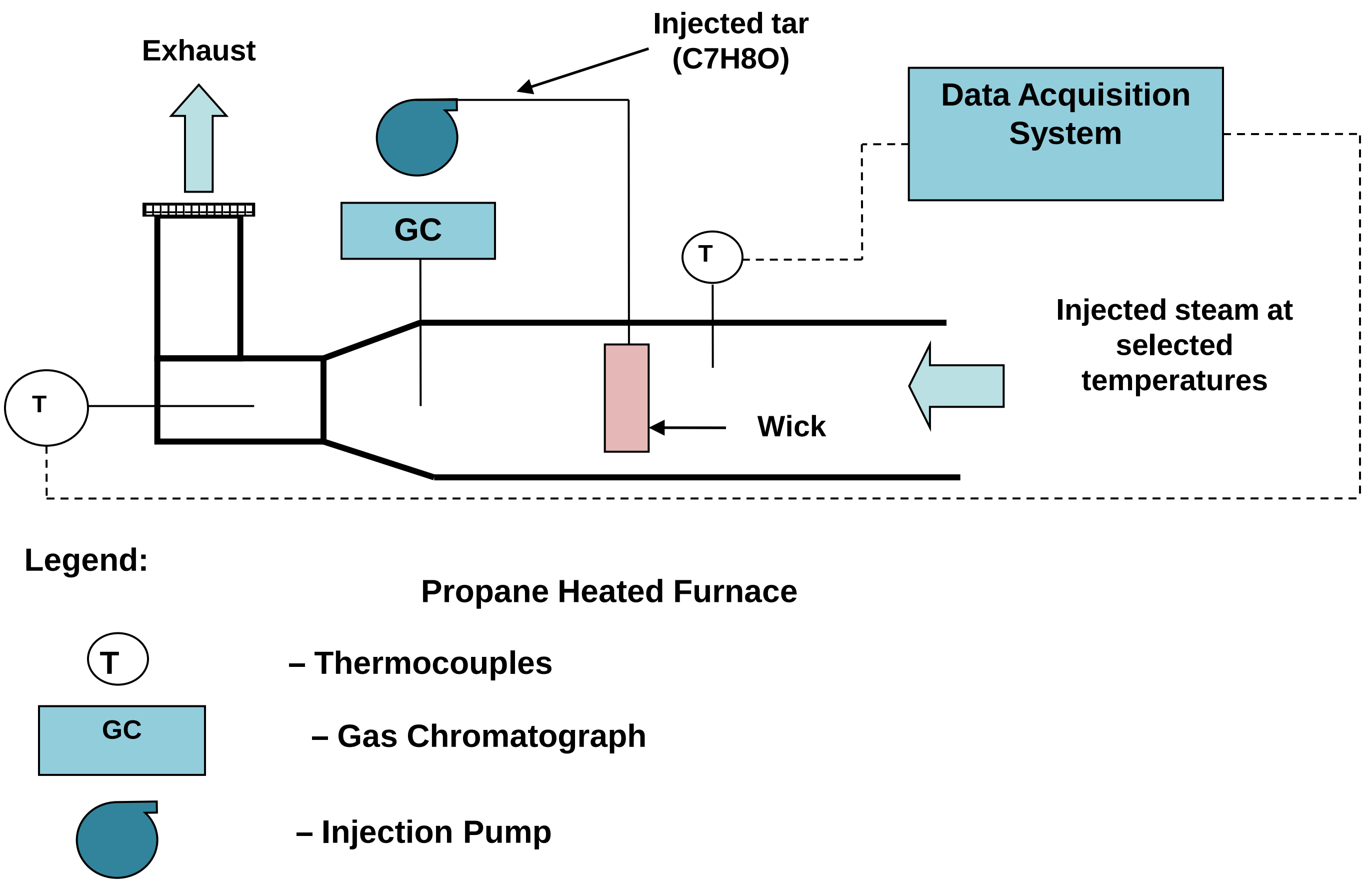
Background – Tar Reforming/Elimination Process



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

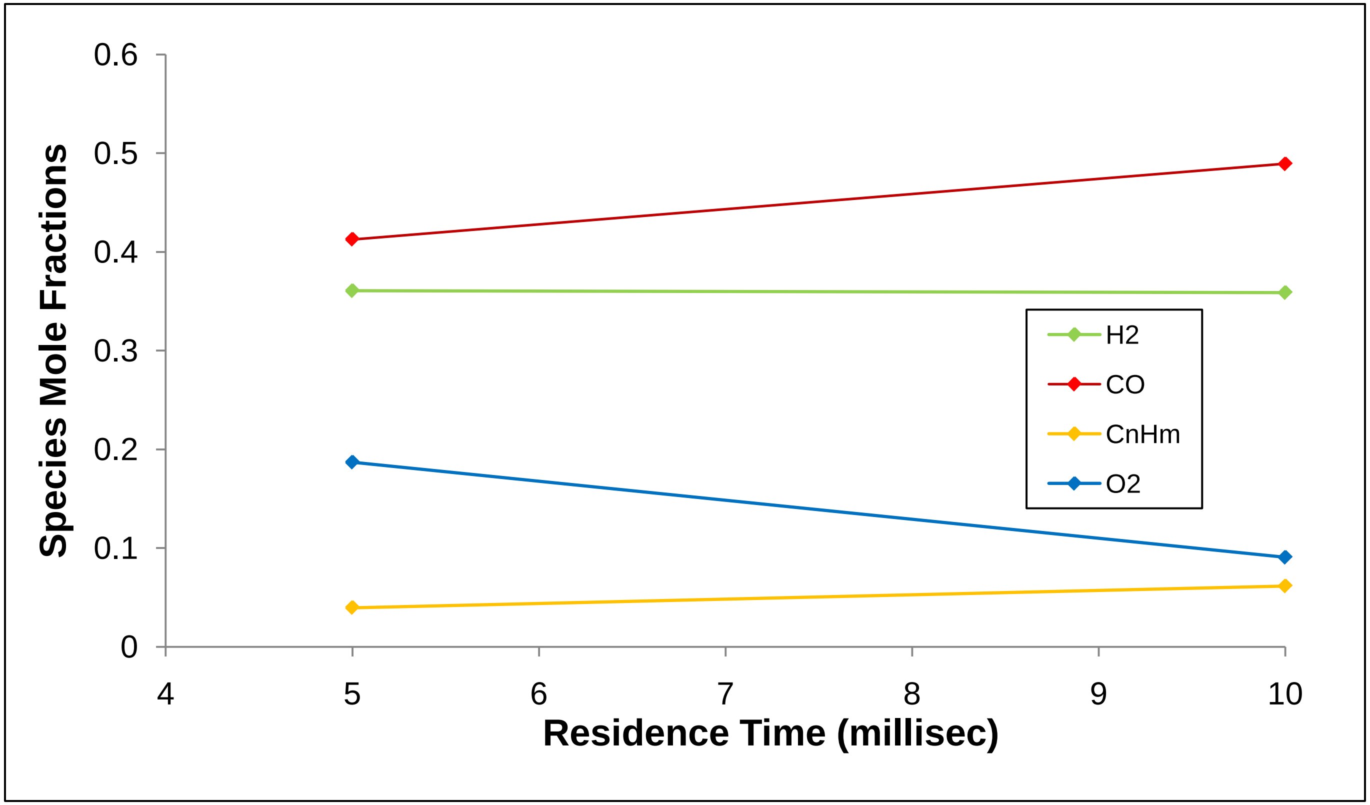
- Predicted highest production of fuel gases (CO, CH4 and H2) were obtained with pure steam
- The lowest synthesis gas (CH4, CO and H2) yield was obtained with air.

Experimental Setup



- 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/Nm^3 for T_{ave} = 850 ^oC, 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

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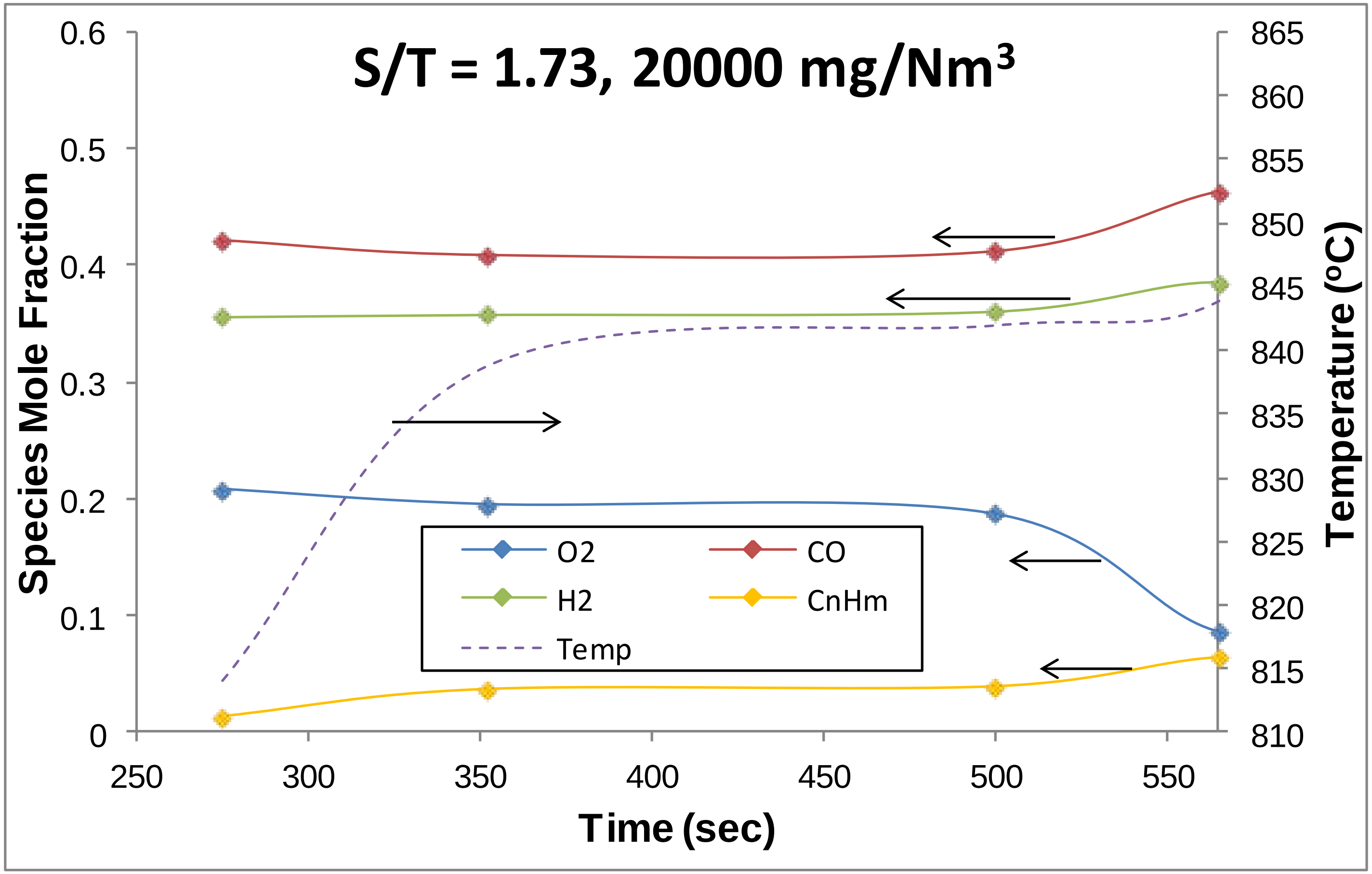
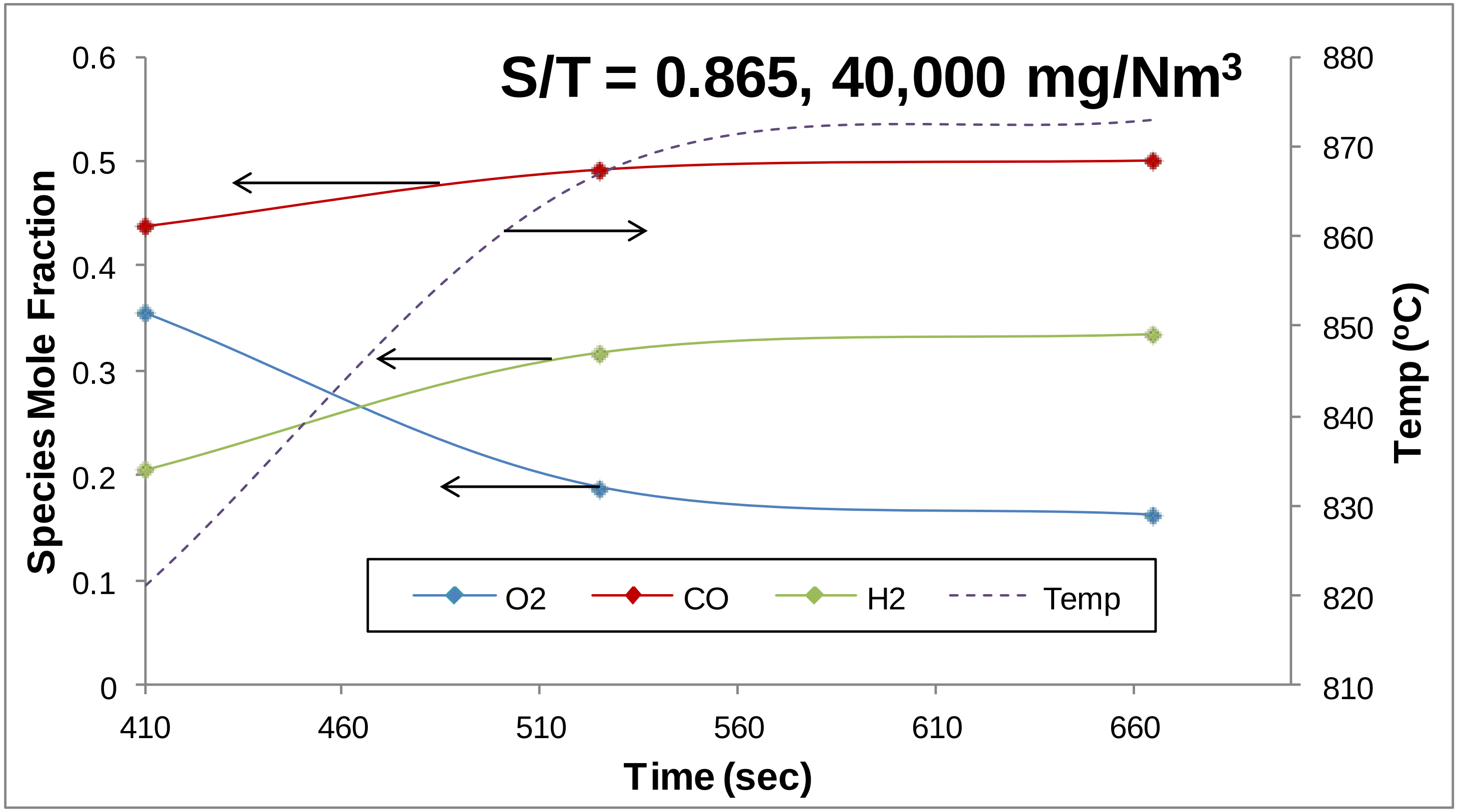
Experimental Results – Effect of Time and Temperature on the Evolution of Syngas



- Evolution of syngas production is nearly constant at 814 ºC < T < 840 ºC (tar conversions at these conditions).
- For T > 840 ºC, 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/Nm^3, the evolution of syngas production moderately increases at 820 $^oC < T <$ 867 ^oC, implying that tar conversions at these conditions also increase moderately.
- For near isothermal condition (867 to 873 ^oC), the production of syngas has reached a steady-state condition.
- As temperature rises to 867 ^oC, the O_2 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

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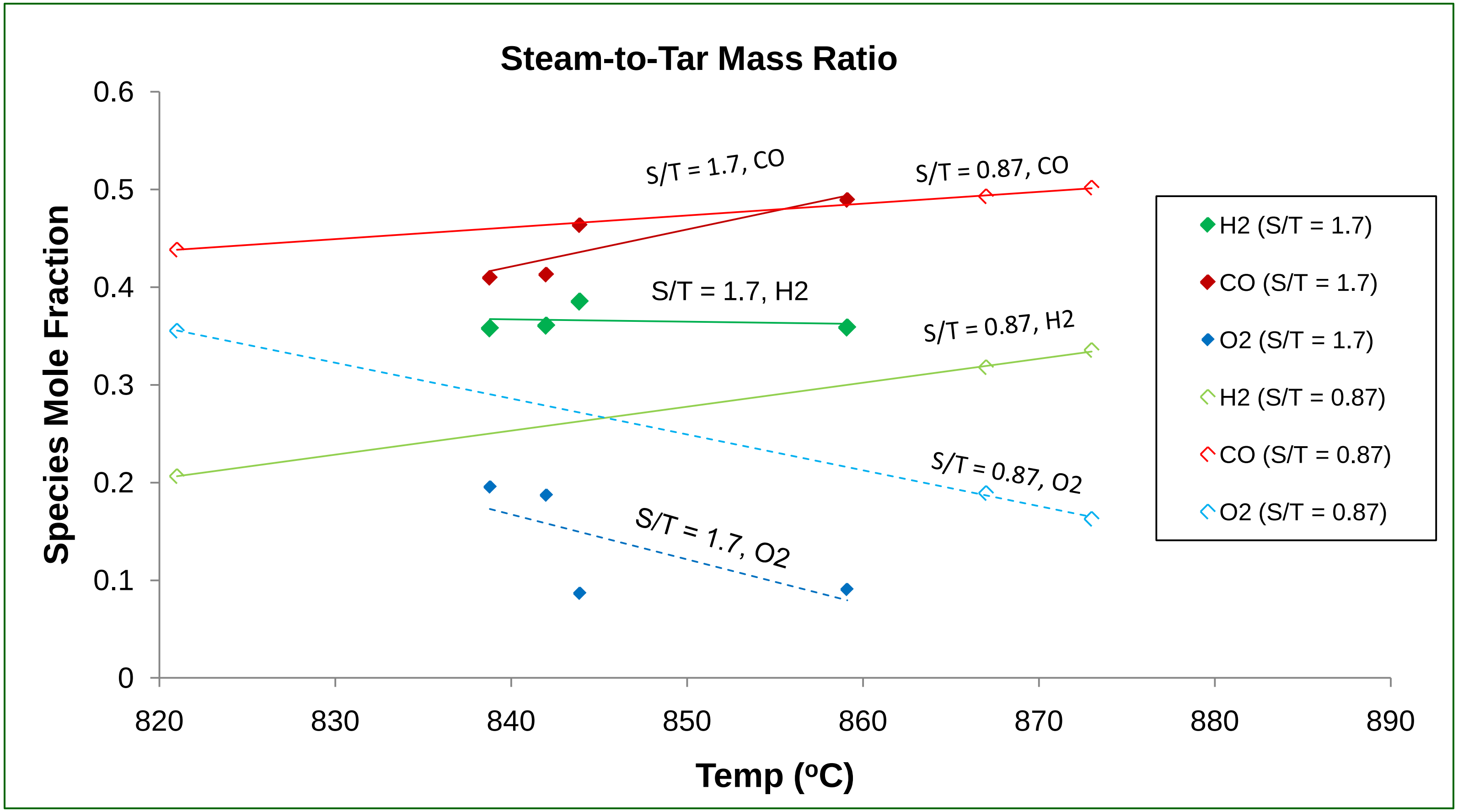

- For both S/T = 0.87 and 1.7, the syngas quality and conversion increase with an increase in temperature. Also, increase in production CO is accompanied with a decrease in O2
- At S/T = 1.7, an increase in temperature did not result in an increase in H2. However, at these conditions the CO production 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

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Conclusions

Continuously fed non-isothermal reactor using steam and O_2 enrichment provided the following:

- Carbon conversion could be increased with greater residence times
- The H_2 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, H_2 and C_nH_m (typically C_2 and C_3) using steam with O_2 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 ^oC
- The rate of change in the production of CO for S/T = 1.7 is greater as compared to S/T = 0.87

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Acknowledgments

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Thank You

QUESTIONS?

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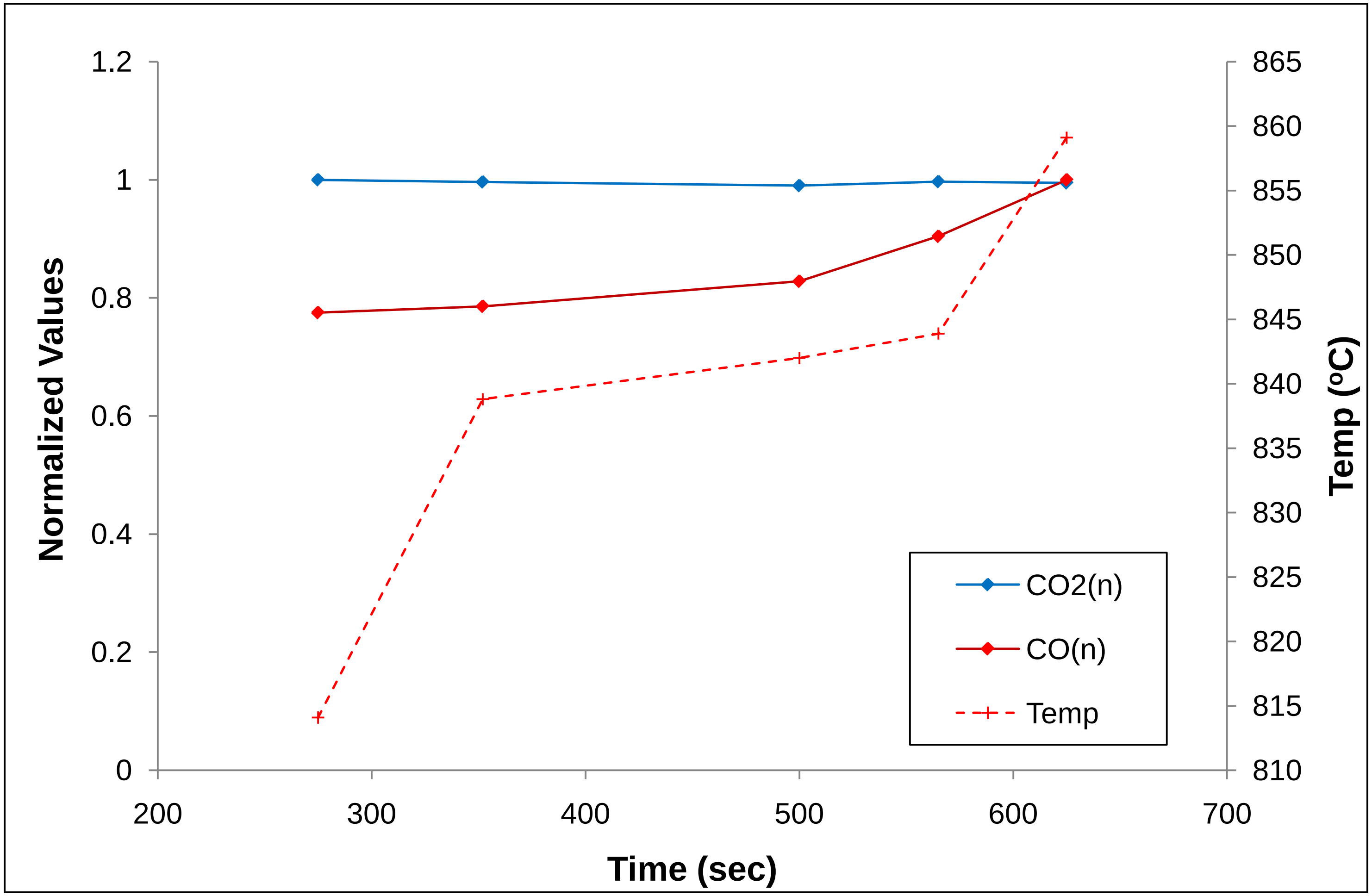
Backup Slide – Evolution of CO2 and CO



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

Bonus Slide – Pyrolysis of Paper