Aspen Plus™ Process Model for Production of Gaseous Hydrogen via Steam Gasification of Bagasse

Mohamed Elbaccouch and Ali T-Raissi
Florida Solar Energy Center
University of Central Florida
Cocoa, FL, USA
Objectives

• Determine the potential of producing hydrogen gas from an air-fired biomass gasifier utilizing local resources for use in the NASA Shuttle program

• Use Aspen Plus™ chemical process simulator (CPS) platform to model the process
Simulation Criteria

- Thermo-neutral plant design for production of \( \text{H}_2 \) from bagasse
- Aspen Plus™ Chemical Process Simulator: no heat generation
- Flowsheet consisted of four sections:
  1) Dryer section to partially dry the bagasse
  2) Gasifier consisting of bagasse combustion zone and gasification zone
  3) Gas clean up section to purify the \( \text{H}_2 \) product
  4) Pressure swing adsorption unit to recover \( \text{H}_2 \) at desired purity levels
Methodology

- Part of the bagasse was used as fuel to supply heat to the plant
- Temperature of the combustor was set at 1550º C
- Heat generated was inputted to the plant’s reactors and flow streams
- All other process units operate adiabatically
- 900 kg/hr of bagasse was used to produce 17.4 kg/hr of ultra pure hydrogen gas
Rationale

• Biomass gasification is a well-developed & old technology (see examples below)
• Syngas (H₂+COₓ) so generated is a renewable energy source
Hydrogen via Biomass Gasification
Simple Capital Equipment Layout

Brazil

McNeil Station, VT

Maui, HI
Biomass Resources in Florida: Flexible, Available, and Inexpensive

- Fast Growing Grasses
- Orange Peels
- Bagasse
Why Aspen Plus™ CPS?

- Process design oriented language facilitates complex chemical process calculations
- Applies mass and energy balances and chemical equilibrium relationships to predict design performance
- Small sections of a complex integrated system can be generated and tested as separate modules before integration
- Contains large property data bank and thermodynamic models
Simulation Assumptions

• Linear plant capacity
• Ultimate analysis of bagasse used as the feedstock composition input to the plant
• Process yields no tar
• Residence time in the gasification zone is long enough to allow approach to chemical equilibrium (Gibbs reactor model)
Modeling Approach

Air in

Biomass feed

Producer gas out

Air

Dryer

Biomass Feed

Drying Zone

Fuel to Clean-up Section

Combustor-1

Biomass

Combustor-2

Biomass

Biomass

Gasifier

Comb. Zone

Grate

Biomass

Unreacted Biomass

Unreacted Biomass + Ash

Ash bin

Ash out

Unreacted Biomass + Ash

Heat

CO₂ + H₂O + NOx + Unreacted Biomass

Producer gas out
## Aspen Optimized Gasification Conditions (17 kg/hr $H_2$ gas)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass feed</td>
<td>900 kg.hr$^{-1}$</td>
</tr>
<tr>
<td>Combustor-1 temp</td>
<td>1550 °C</td>
</tr>
<tr>
<td>Combustor-2 temp</td>
<td>1550 °C</td>
</tr>
<tr>
<td>Gasifier output temp</td>
<td>1150 °C</td>
</tr>
<tr>
<td>Water removed from Dryer</td>
<td>159 kg.hr$^{-1}$</td>
</tr>
<tr>
<td>Split ratio: biomass to combustors 1&amp;2</td>
<td>0.47</td>
</tr>
</tbody>
</table>
## Simulation Results

### Ultimate Analysis of Bagasse (dry basis)

<table>
<thead>
<tr>
<th>Ultimate Analysis</th>
<th>Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>8.61</td>
</tr>
<tr>
<td>C</td>
<td>46.38</td>
</tr>
<tr>
<td>H</td>
<td>5.86</td>
</tr>
<tr>
<td>N</td>
<td>0.19</td>
</tr>
<tr>
<td>Cl</td>
<td>0.01</td>
</tr>
<tr>
<td>S</td>
<td>0.05</td>
</tr>
<tr>
<td>O</td>
<td>38.9</td>
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</tbody>
</table>

### Gasifier Output kg.hr⁻¹

<table>
<thead>
<tr>
<th>Gas</th>
<th>kg.hr⁻¹</th>
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<tbody>
<tr>
<td>H₂O</td>
<td>481</td>
</tr>
<tr>
<td>C</td>
<td>None</td>
</tr>
<tr>
<td>H₂</td>
<td>12</td>
</tr>
<tr>
<td>N₂</td>
<td>1919</td>
</tr>
<tr>
<td>Cl₂</td>
<td>0.06</td>
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<tr>
<td>CO</td>
<td>219</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.001</td>
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<tr>
<td>H₂S</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Hydrogen Flow Rate in Aspen Plus™ CPS Results

H2 (kg/hr)

- Gasifier
- Reformer
- Shift
- PSA
- Off-gas
Biomass Feedstock Requirements for Multiple Shuttle Launches
Summary

• Hydrogen production from bagasse gasification process for Shuttle program at the NASA-KSC was analyzed using Aspen Plus™ CPS

• Plant consisted of dryer, gasifier, clean-up, & PSA sections

• Gasifier operates with no carbon formation nor heat production

• Plant functions within the typical range of industrial processes
Acknowledgements

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