Simulation and exergy analysis of a novel small-scale biomass gasifier: A "Multi-Box" application

Stergios Vakalis, Francesco Patuzzi, Dario Prando, Konstantinos Moustakas and Marco Baratieri
Gasification is a thermal process which under sub-stoichiometric conditions “packs” energy into chemical bonds.

Fuel (C-rich) \( \lambda < 1 \) 
Gasifying medium (air, \( O_2, CO_2 \) )

\[ \begin{align*}
\text{Gasifier} & \quad \text{Tar, Dust, Ash, Soot} \\
\text{Char} & \quad \text{Syngas or Producer gas}
\end{align*} \]
Small- scale biomass gasifiers

• Biomass Gasifiers during WW2
• > 1 m. small scale gasifiers
• Simple to use – but poor quality!
• No latter commercial applications due to petrol abundance
Modern small scale biomass gasifiers

• Novel designs have been able to produce gas of higher quality and heating value.
• The increased electrical efficiency along with the high subsidies have triggered a resurgence of small scale biomass gasifiers during the last years.

Friday 23rd (13.30) - SESSION XVII
The “NEXT GENERATION” project: valorization alternatives for char from small scale gasification
By Prof. Baratieri
How to model a downdraft gasifier?

- Evaporation of moisture
- Decomposition
- Combustible gases
- Gasification reactions

DRYING
PYROLYSIS
COMBUSTION
REDUCTION
Fundamentals of downdraft gasification

**Basic reactions**

- Boudouard
  \[ C + CO_2 \rightarrow 2CO \]

- Water gas reaction
  \[ C + H_2O \rightarrow CO + H_2 \]

- Methanation reaction
  \[ C + 2H_2 \rightarrow CH_4 \]

- Shift gas conversion
  \[ CO + H_2O \leftrightarrow CO_2 + H_2 \]
Status-quo of thermodynamic modelling

- Most models are single stage/ black box
- A few models follow the zone separation stages
- The products are not representative of reality
- None of these models is able to return methane and char yields of any measureable significance
- Realistic modelling values are usually a result of extensive “calibration”
Introducing the “Multi-box”

Thermodynamic Model

- Matlab - Cantera environment
- Villars–Cruise–Smith (VCS) algorithm
- 2-phase equilibrium model
- GRI-Mech 3.0
  - Also Curran mechanism
Developing the “Multi – Box”

The diagram illustrates the process of developing the "Multi – Box" with the following steps:

1. **Input**
   - $\text{C}_1\text{H}_{1.4}\text{O}_{0.6}$

2. **Drying**
   - **Combustion**
   - **Pyrolysis**

3. **Steam**
   - **Water-gas**
   - **Char – gas (T, P) equilibrations**

4. **Output**
   - **Methanation**
   - **Boudouard**
   - **Combined equilibration**
Results and validation

Producer gas

Char yield
Novel small scale gasifiers

Characteristics of modelled reactor

- 180-190 kW_{el} / 220-240 kW_{th}
- Rising Co – current
- Bottom fed (Pellets)
- Vortex above oxidation zone
- Char is slightly ‘fluidized’
- Dual-fuel engine
Adjusting the “Multi – Box”

input

$C_1H_{1.4}O_{0.6}$

drying

steam

H, P equilibrations

combustion

pyrolysis

gaseous equilibration

boudouard

methanation

combined equilibration

water-gas

Char – gas (T, P) equilibrations

output
Results - (Gas composition for ER: 0.22)

<table>
<thead>
<tr>
<th></th>
<th>Multi-Box Model</th>
<th>Case Study</th>
<th>Black Box model</th>
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<tbody>
<tr>
<td>H2</td>
<td>20.5</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>CO</td>
<td>26</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>CO2</td>
<td>10</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>CH4</td>
<td>1.5</td>
<td>2</td>
<td>0</td>
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</table>
Results - (Char Yield for ER: 0.22)

<table>
<thead>
<tr>
<th></th>
<th>Mass Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black box</td>
<td>0</td>
</tr>
<tr>
<td>Case Study</td>
<td>1.5</td>
</tr>
<tr>
<td>Multi - Box</td>
<td>1.8</td>
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</tbody>
</table>
Conclusions

• Creation of a multi-stage & process based model

• Results much closer to case study than black-box models

• Adjustment of combustion & pyrolysis boxes modelling

• “Multi-Box” addresses successfully the issues of methane concentration and char yield
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THANK YOU FOR YOUR ATTENTION
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