Utilization of char from biomass gasification for onsite energy production

Introduction and modelling of a secondary reactor

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Main objectives of this presentation

- Introduction to small scale gasification and gasification by-products
- Proposing a solution
- Modelling and analysis
Fundamentals of small scale gasification

Basic reactions

Boudouard
C + CO₂ → 2CO

Water gas reaction
C + H₂O → CO + H₂

Methanation reaction
C + 2H₂ → CH₄

Shift gas conversion
CO + H₂O ↔ CO₂ + H₂
Gasification and by-products
Introduction

Methods

Results

Discussion/Conclusions

Process scheme

Wood chips

Gas & by-products

H / E

FILTER

ICE

Char

Flue gases

Producer gas

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Issues concerning char and flue gases

Char in small gasification typically has a yield from 2 up to 10 % of the initial mass of the feedstock.

Due to the scale restrictions of small scale units, organized strategies have not yet been developed.

ICE emissions are the output stream with the highest mass yield.

In principle, flue gases are discarded to the environment without any additional treatment.
Examining a case study

Joos gasifier (45 kWe and 120 kWth)
San Leonardo, Passaria (South Tyrol – Italy)

References
S. Vakalis et al. (2015), Monitoring und Analyse von repräsentativen kleintechnischen Biomassevergasern in Südtirol

S. Vakalis et al. (2014) Measuring the performance of biomass small scale gasification plants by implementing mass and energy balances.
Joos gasifier
Char/ash composition: 35 % of the final yield consists from ash. (also: 64 % carbon, 1% Hydrogen)
Further optimization “incentives”

• Energy efficiency of 71.25 %
• Nonetheless, auxiliaries demand 17% of the energy to operate
  • (i.e 3.45 % of initial)
• Economic gains of 28 cents/ kWe over 70 % of efficiency *
• High temperature heat exchangers have high heat losses
• High exergy dissipation in autothermal gasifiers

Process scheme
Introduction and modelling of a secondary reactor

GASIFIER → H/E → FILTER → ICE

Secondary reactor
Fluidized Bed
Char
Flue gases
H/E
ICE (B)
Secondary producer gas
Application of a Thermodynamic Model

- Matlab - Cantera environment
- Villars–Cruise–Smith (VCS) algorithm
- Zero dimensional, adiabatic
- 2-phase equilibrium model
- Multiple gasifying agents
- Fluidized bed gasifiers
- Model validated in 12 gasifiers

Reference: Baratieri, M., Baggio, P., Fiori, L., Grigiante, M., Biomass as an energy source- Thermodynamic constraints on the performance of the conversion process, Bioresource Technology 99 (2008), pag. 7063–7073
Composition of secondary producer gas (db%)
Total Energy Content (LHV) of secondary gas

- 700 kWh
- 800 kWh
- 900 kWh
- 1000 kWh
- 1100 kWh
- 1200 kWh
- 1300 kWh

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Energy gain after ICE

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### Balancing the operation of auxiliaries (8.3 kWe)*

<table>
<thead>
<tr>
<th></th>
<th>900 K</th>
<th>1000 K</th>
<th>1100 K</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>40%</td>
</tr>
<tr>
<td>4</td>
<td></td>
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<tr>
<td>5</td>
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</tbody>
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*With two added pumps (2 x 0.25 kW), blower (0.25 kW) and ICE (B) compressor (1.2 kW)*
## Comparison of efficiencies

<table>
<thead>
<tr>
<th></th>
<th>Standard operation</th>
<th></th>
<th>With reactor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gross</td>
<td>Net</td>
<td>Gross</td>
<td>Net</td>
</tr>
<tr>
<td>(for 35% at 1000K)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input (kWh)</td>
<td>198</td>
<td>198</td>
<td>221</td>
<td>221</td>
</tr>
<tr>
<td>Electricity</td>
<td>42</td>
<td>34.86</td>
<td>52.79</td>
<td>44.48</td>
</tr>
<tr>
<td>Thermal Power</td>
<td>98.05</td>
<td>94.34</td>
<td>98.05</td>
<td>90.34</td>
</tr>
<tr>
<td>Total Energy (kWh)</td>
<td>140.05</td>
<td>129.2</td>
<td>150.84</td>
<td>134.82</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>71 %</td>
<td>65 %</td>
<td>76 %</td>
<td>68 %</td>
</tr>
<tr>
<td>Exergy efficiency</td>
<td>28.5 %</td>
<td>25.7 %</td>
<td>32.3 %</td>
<td>30.5 %</td>
</tr>
</tbody>
</table>
Conclusions

- Char and emissions from ICE are by-products that are underutilized and no satisfactory management strategies have been developed.
- An apparatus is introduced that utilizes char residue from gasification and emissions from ICE for the production of a gaseous fuel.
- Only a marginal change in the heating value is observed at the range between 900 K and 1100 K.
- The additional would on average increase 12% the energy production of the facility.
- Interesting applications at “dual-fuel engine“ gasifiers.
THANK YOU FOR YOUR ATTENTION!

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