Effect of char recirculation in fixed bed gasifiers: experimental and modelling analysis

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Small-scale biomass gasification in EU

Size of the plants < 0.5 MW_{el}
Number of installed plants > 1000

Application: CHP (feed in tariff)
Technology: fixed bed gasifiers

Source: 2018 - IEA bioenergy Task 33
The South Tyrol (Südtirol) region

Area: 7400 km²
Population: 511750 ab.
42% forest

46 plants in operation
~ 1300 ton/year of char
150 €/ton for disposal
Possible utilization pathways

Many possible application are reported in the literature

- for co-firing in power plants
- as soil improver
- as adsorbent
- as catalytic support

**THE AIM OF THIS WORK** is to investigate the effect of recirculating char in fixed bed gasification systems
Open-top gasifier

Fixed bed reactor  -  Nominal size: 4 kg_{biom}/h
Open-top gasifier

- 1st air
- 2nd air
- unburned biomass
- control level
- gasification
- reactive char
- char combustion
- reactive char
- non reactive char

Components:
- Reactor
- Cyclone
- Scrubber
- Moisture trap
- Flare
- Bypass valve
- Fabric filter
- Char tank
- Water tank
- Blower
- Orifice plate
**Measured quantities and characterized properties**

- Mass IN
- Mass OUT
- Charge and discharge time
- Secondary air mass flow rate (mass flow controller)
- Producer gas flow rate (differential pressure over a calibrated orifice)
- Gas composition (microGC)

**Derived quantities and process parameters**

- Biomass and char mass flow rates
- Total air IN (nitrogen balance)
- Equivalence Ratio
- Energy fluxes
- Cold Gas Efficiency
Fuel characterization

Standard spruce pellet EN plus A1 – 6 mm diameter

- moisture content
- ash content
- elemental analysis C,H,N,S (Vario MACRO Cube, Elementar)
- HHV - LHV (C 200 - IKA)

<table>
<thead>
<tr>
<th>Moisture [%wt_{ar}]</th>
<th>Ash [%wt_{dry}]</th>
<th>C [%wt_{dry}]</th>
<th>H [%wt_{dry}]</th>
<th>N [%wt_{dry}]</th>
<th>S [%wt_{dry}]</th>
<th>O [%wt_{dry}]</th>
<th>LHV [MJ/kg_{dry}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>0.3</td>
<td>49.8</td>
<td>5.6</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
<td>43.8</td>
</tr>
</tbody>
</table>
### Study cases

<table>
<thead>
<tr>
<th></th>
<th>char yield / recirc. share [%]</th>
<th>2nd air injected [NLPM]</th>
<th>Blower SP [Hz]</th>
<th>ER [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case A</strong></td>
<td>~ 10</td>
<td>10</td>
<td>40</td>
<td>&lt; 0.25</td>
</tr>
<tr>
<td><strong>Case B</strong></td>
<td>~ 5</td>
<td>26</td>
<td>40</td>
<td>~ 0.25</td>
</tr>
</tbody>
</table>

### Sub-cases
- **0**: fuel IN = standard pellet (biomass)
- **R**: fuel IN = standard pellet (biomass) + char (produced in the corresponding sub-case 0)
Char characterization

Char composition - Carbon content

Char composition - Ash content

Case A0  Case AR  Case B0  Case BR
Char characterization

- higher ash content $\rightarrow$ higher conversion
Mass flow rates

• producer gas: almost constant
• char: increases
Gas composition

- CO
- CO2
- H2
Gas composition
**Overall effect of char recirculation**

- Overall char yield: decreases

Mathematical expressions:

\[
Y_{\text{char}} = \frac{\dot{m}_{\text{char \ OUT}}}{\dot{m}_{\text{biom \ IN}} + \dot{m}_{\text{char \ IN}}}
\]

\[
Y_{\text{char \ NoR}} = \frac{\dot{m}_{\text{char \ OUT}} - \dot{m}_{\text{char \ IN}}}{\dot{m}_{\text{biom \ IN}}}
\]
Overall effect of char recirculation

- Overall char yield: decreases
- Overall CGE: increases in case B (process conditions better tuned up)

\[
CGE = \frac{\dot{m}_{\text{gas}} \cdot LHV_{\text{gas}}}{\dot{m}_{\text{biom IN}} \cdot LHV_{\text{biom IN}} + \dot{m}_{\text{char IN}} \cdot LHV_{\text{char IN}}}
\]

\[
CGE_{\text{NoR}} = \frac{\dot{m}_{\text{gas}} \cdot LHV_{\text{gas}}}{\dot{m}_{\text{biom IN}} \cdot LHV_{\text{biom IN}}}
\]
2nd air modulation

- Can the process conditions be further tuned up to optimize the process for char recirculation?

<table>
<thead>
<tr>
<th>char yield / recirc. share</th>
<th>2nd air injected</th>
<th>Blower SP</th>
<th>ER (when the fuel is only biomass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[%]</td>
<td>[NLPM]</td>
<td>[Hz]</td>
<td>[-]</td>
</tr>
<tr>
<td>Case C</td>
<td>3 - 10</td>
<td>14 - 32</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.19 - 0.25</td>
</tr>
</tbody>
</table>
**2nd air modulation**

Main effects of increasing 2nd air flow rate
2nd air modulation

Char yield
2\textsuperscript{nd} air modulation

Gas composition

![Graphs showing the effect of 2\textsuperscript{nd} air modulation on gas composition.](image-url)
2nd air modulation

Cold gas efficiency
Modelling approach

- based on a **thermodynamic solid-gas equilibrium** approach (Gibbs energy minimization method)
- overcomes the issues of the classical equilibrium strategy (fixed temperature and pressure)
- introduction of an **adiabatic gasification temperature**, defined in analogy to the concept of **adiabatic flame temperature** for the combustion process.
Model calibration

\[
\text{correction} = \frac{\Delta H_{\text{OUT}}}{\Delta H_{\text{IN}}}
\]
Four different exp. campaigns
- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFI ED PELLETS (TP)
- BARK AND CHIPS (BC)

Model calibration

Adiabatic formulation

Enthalpy, H

Correction formula:
\[ \text{correction} = \frac{\Delta H_{\text{OUT}}}{\Delta H_{\text{IN}}} \]

Reactants

temperature

Gasification products

Comb. products

\( \Delta H_{\text{IN}} \)

\( \Delta H_{\text{OUT}} \)

Four different exp. campaigns

- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFIED PELLETS (TP)
- BARK AND CHIPS (BC)

Calibration to match the experimental CGE

\[
\text{correction} = \frac{\Delta H_{\text{OUT}}}{\Delta H_{\text{IN}}}
\]
Four different exp. campaigns
- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
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Calibration to match the experimental CGE

correction = \frac{\Delta H_{\text{OUT}}}{\Delta H_{\text{IN}}}

Adiabatic formulation

char yield [%]

Model calibration

CGE [%]

Correlation plots for different datasets (LM, CR, TP, BC):
Long term effect of char recirculation
Conclusions

Char recirculation:

• Allows a significant reduction of the overall char yield (in the order of 40 - 60 %)
• Do not significantly impact the process if this is well tuned up
  • Gas composition and LHV remain almost constant
  • CGE slightly decreases (as per the producer gas flow rate)
  • Considering the overall effect, CGE slightly increases
• Secondary air modulation can make even more feasible char recirculation
• An asymptotic condition is reached after a certain number of recirculation cycles, as confirmed by both modelling and experimental results

Open question

• What is the effect of granulometry?
  (this worked well, but the char particles were still maintaining the original pellet shape)
Acknowledgments

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Thank you very much for your kind attention!

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