IRON ORE PELLET REDUCTION BEHAVIOR IN POTENTIAL LOW CO₂ BLAST FURNACE SCENARIOS

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Introduction

- According to 2050 roadmap, Europe has to decrease its greenhouse gas emissions by 80–95% by 2050 compared to the 1990 base level.
- As a part of the EU Emissions Trading System (EU ETS), steel industry also is forced to decrease CO₂ emissions.
- Since blast furnace-basic oxygen furnace (BF-BOF) route will be the dominating technology to produce steel for decades, the research should focus on BF technology or raw material development in order to further decrease CO₂ emissions.
- Two potential measures to decrease the emissions in BF ironmaking include the use of tuyere injected biomass-based reductants and use of top gas recycling blast furnace (TGR-BF) technology.
- Changes in the gas composition have impact on the reduction of iron burden, which affects the whole process.
- In this work the effect of using bio-based reductants and top-gas recycling BF on the iron ore burden reduction behavior is estimated.
Experimental procedure

- Low CO₂ emission reductant scenarios
- Blast furnace model
- Simulation results
- Blast furnace shaft gas compositions
- Thermogravimetric experiments on iron burden
- Effect of bio-based reductants on the reduction behavior of iron ore pellets
## Simulated BF scenarios

<table>
<thead>
<tr>
<th></th>
<th>Case 1 (PCI, Ref. case)</th>
<th>Case 2 (Charcoal)</th>
<th>Case 3 (Torrefied biomass)</th>
<th>Case 4 (TGR-BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke</td>
<td>304.6</td>
<td>304.6</td>
<td>304.6</td>
<td>234.2</td>
</tr>
<tr>
<td>PCI</td>
<td>155.5</td>
<td>0</td>
<td>81.3</td>
<td>155.5</td>
</tr>
<tr>
<td>Charcoal</td>
<td>0</td>
<td>165.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Torrefied biomass</td>
<td>0</td>
<td>0</td>
<td>125.6</td>
<td>0</td>
</tr>
<tr>
<td>Injected top gas</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>401.9</td>
</tr>
<tr>
<td>(Nm³/tHM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ultimate and proximate analysis of injected reductants and recycled top gas

<table>
<thead>
<tr>
<th>Unit</th>
<th>PCI</th>
<th>Charcoal</th>
<th>Torrefied biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>wt % db.</td>
<td>85</td>
<td>84.69</td>
</tr>
<tr>
<td>H</td>
<td>wt % db.</td>
<td>3.89</td>
<td>3.35</td>
</tr>
<tr>
<td>N</td>
<td>wt % db.</td>
<td>2.1</td>
<td>0.13</td>
</tr>
<tr>
<td>O</td>
<td>wt % db.</td>
<td>2.1</td>
<td>10.6</td>
</tr>
<tr>
<td>S</td>
<td>wt % db.</td>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>Ash</td>
<td>wt % db.</td>
<td>7.755</td>
<td>1.875</td>
</tr>
<tr>
<td>Moisture</td>
<td>wt % db.</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>LHV</td>
<td>MJ/kg</td>
<td>33.5</td>
<td>31.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit</th>
<th>Top gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>Vol %</td>
</tr>
<tr>
<td>CO</td>
<td>Vol %</td>
</tr>
<tr>
<td>CO₂</td>
<td>Vol %</td>
</tr>
<tr>
<td>N₂</td>
<td>Vol %</td>
</tr>
<tr>
<td>H₂O</td>
<td>Vol %</td>
</tr>
<tr>
<td>Density</td>
<td>kg/Nm³</td>
</tr>
<tr>
<td>LHV</td>
<td>MJ/Nm³</td>
</tr>
</tbody>
</table>
BF shaft gas compositions

- BF shaft gas compositions were obtained from the simulation results.
- Shaft gases consist of N$_2$, H$_2$, H$_2$O, CO and CO$_2$.
- Charcoal shaft gas composition was similar to PCI and therefore excluded from the reduction experiments.
- TGR-BF simulation has the highest reducibility and PCI has the lowest reducibility.
Laboratory equipment

**Furnace**
1. Reduction tube
2. Sample basket
3. Thermocouple
4. Electrically heated furnace
5. Gas inlet
6. Transparent lid with cooling gas inlet and reducing gas outlet

**Gas supply system**
7. Gas containers
8. Mass flow controllers
9. Potassium generator
10. Sulphur generator
11. Water vapour generator

**Camera recording system**
12. Light source
13. Mirror
14. Camera

** Auxiliary instruments**
15. Scale for TGA
16. Computer system

Blast Furnace gas phase Simulator (BFS)
Reduction behavior of 3 different iron ore pellet types were studied in the experiments.

Pellets of similar size distribution (d = 10-12,5 mm) were selected in the experiments to enhance comparison.

Pellets were magnetically separated to reduce the amount of FeO in the pellet core which might have an effect on the pellet cracking phenomenon.

<table>
<thead>
<tr>
<th>Component (wt-%)</th>
<th>Acid pellet</th>
<th>Olivine pellet</th>
<th>Magnesite pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe\textsubscript{tot}</td>
<td>65.4</td>
<td>67.1</td>
<td>63.67</td>
</tr>
<tr>
<td>FeO</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>MgO</td>
<td>0.16</td>
<td>1.25</td>
<td>1.53</td>
</tr>
<tr>
<td>Al\textsubscript{2}O\textsubscript{3}</td>
<td>0.29</td>
<td>0.3</td>
<td>0.38</td>
</tr>
<tr>
<td>SiO\textsubscript{2}</td>
<td>5.27</td>
<td>1.69</td>
<td>6.14</td>
</tr>
<tr>
<td>CaO</td>
<td>0.49</td>
<td>0.38</td>
<td>0.16</td>
</tr>
<tr>
<td>K\textsubscript{2}O</td>
<td>0.111</td>
<td>n.a.</td>
<td>0.115</td>
</tr>
<tr>
<td>Na\textsubscript{2}O</td>
<td>0.052</td>
<td>n.a.</td>
<td>0.057</td>
</tr>
<tr>
<td>S</td>
<td>0.01</td>
<td>0</td>
<td>0.006</td>
</tr>
<tr>
<td>Slag formers (wt-%)</td>
<td>6.37</td>
<td>3.62</td>
<td>8.22</td>
</tr>
<tr>
<td>CaO/SiO\textsubscript{2}</td>
<td>0.09</td>
<td>0.22</td>
<td>0.03</td>
</tr>
</tbody>
</table>
The results indicate highest iron burden reduction potential for the TGR-BF scenario.

This leads to highest reduction rate of iron ore pellets in the experiments and ends up to the highest reduction degree.

The torrefied biomass scenario has a slightly higher reduction potential than the pulverized coal injection.
The results show the highest reduction degree RD (~85–95%) for the TGR-BF scenario.

PCI ends up around 50–60 % RD.

Torrefied biomass scenario ends at about 60–75 % RD.

Comparison between pellet types shows slightly higher RD for acid pellet in the PCI and the torrefied biomass scenarios and highest RD for olivine fluxed pellet in the TGR-BF scenario.
The Reduction Swelling Index (RSI) show negative values in almost all reduction scenarios which indicates of pellet shrinking during the reduction.

The RSI values show highest pellet shrinkage in the TGR-BF scenario.

It can be concluded that slight pellet shrinking occurs in all cases and in the TGR-BF scenario the phenomenon is more pronounced.
Iron ore pellets after reduction by BFS

**PCI**

- Magnesite 1
- Magnesite 2
- Olivine 1
- Olivine 2
- Acid 1
- Acid 2

**Torrefied biomass**

- Magnesite 1
- Magnesite 2
- Olivine 1
- Olivine 2
- Acid 1
- Acid 2

**TGR-BF**

- Magnesite 1
- Magnesite 2
- Olivine 1
- Olivine 2
- Acid 1
- Acid 2
Pellet microstructure after reduction

PCI

Torrefied biomass

TGR-BF
Conclusions

- A BF model was used to simulate BF shaft conditions for a torrefied biomass injection, a top-gas recycling blast furnace (TGR-BF) scenario and a pulverized coal injection (PCI) as a reference scenario.
- The results indicate highest iron burden reduction potential for the TGR-BF scenario with highest reduction rate and reduction degree.
- The cracking phenomenon during the reduction was highest in the TGR-BF scenario which increases the reduction rate since cracks allow passage for the reducing gas into the inner parts of the pellets. However, this could lead in generation of fines which might be harmful in the BF process.
- Minor pellet crack formation was observed in the torrefied biomass and PCI scenarios.
- In all studied scenarios slight shrinking of the iron ore pellets was observed, indicating that the pellets have no tendency for swelling in the investigated conditions. The shrinking phenomenon was pronounced in the TGR-BF scenario.
- Further clarification is required from the effect of higher reduction potential of the reducing gas on the iron ore pellet reduction behavior. In addition, the impact of different gas component concentrations on the reduction process needs to be investigated.
Thank you!

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