“Analysis of Low Carbon Blast Furnace by Mathematical Model“

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Carbon flow in the integrated steel works

Ca. 20GJ/t

Ironmaking process

- Low coke rate
- Energy saving
- Biomass

Energy supply

Down stream

- Energy saving
- Clean energy use

Heat of formation $\Delta H_f^0$ (kJ/mol)

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H_f^0$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>-74</td>
</tr>
<tr>
<td>CO</td>
<td>-110</td>
</tr>
<tr>
<td>CH$_3$OH</td>
<td>-239</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>-285</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>-393</td>
</tr>
</tbody>
</table>

Decrease in Input-carbon

CCUS
CO$_2$ emissions from the integrated steel works

- Coke oven: 12%
- Calcination: 4%
- Power plant: 1.2%
- Blast furnace: 19%
- Hot stove: 15%
- Sintering: 18%
- Downstream: 31%

Total CO$_2$ emissions: 2031 kg/t
CO$_2$ emissions from the integrated steel works

**CO$_2$ emissions**

- **Coke oven**: 3.2%
- **Calcination**: 3.5%
- **Power plant**: 15.2%
- **Oxygen BF + TGR**: 19.1%
- **Down stream**: 4%

**Energy supply**

**Blast furnace**: 1.9%

**Sintering**: 14.4%

**Total CO$_2$ emissions**: 1848 kg/t (-9%)
Effect of top gas recycling on CO2 emissions

![Graph showing the impact of top gas recycling on CO2 emissions and energy supply in ironmaking processes.](image-url)
Effect of top gas recycling on coke rate

- Conventional BF: PCR: 150-200 kg/t
- Oxygen BF: PCR: 140-300 kg/t

Excess energy to downstream [Gcal/t]

Carbon input [kg-C/t]

Coke rate [kg/t]
Low carbon BF by top gas recycling and its subjects

Conventional BF

Oxygen BF + Top gas recycling

Top gas

CO₂ capture

Gas penetration of injected gas

Gas permeability at low coke rate

Indirect reduction

Direct reduction (endothermic)

Preheat

CO reduction

60% 80%

Hydrogen reduction

10% 10%

30% 10%

CO, H₂, N₂

CO, H₂

CO₂

Oxygen BF, Biomass

Hot blast PC
Combination model of DEM and CFD

General conservation equation

\[
\frac{\partial (\varepsilon_i \rho_i \phi_i)}{\partial t} + \text{div} (\varepsilon_i \rho_i \bar{U}_i \phi_i) = \text{div} (\varepsilon_i \Gamma_{\phi_i} \text{grad} \phi_i) + S_{\phi_i}
\]

Newton’s 2nd law

\[
m \frac{dv}{dt} = \sum F_n \quad I \frac{d\omega}{dt} = \sum F_s
\]
Calculated results by CEM+CFD model

Solid movement

[DEM]
Layer shape
Gray : Coke
Red : Ore

Representation of burden layer

Gas vector

Liq : 0.20
Velocity

Three-dimensional analysis on gas flow
Estimation of gas penetration at shaft gas injection

Base condition

Shaft gas injection at upper part

Shaft gas injection at lower part
Horizontal gas velocity and isobar planes in blast furnace
Influence of shaft gas injection velocity on gas penetration in various levels

Gas velocity

- $u_s = 9.0 \text{ m/s}$ (10%)
- $u_s = 27 \text{ m/s}$ (30%)
- $u_s = 45 \text{ m/s}$ (50%)

+2m above injection level

+1m above injection level

Injection level
Effect of inner volume of BF on shaft gas penetration

- a) 5775m³
- b) 3250m³
- c) 1444m³

Gas velocity:
- 5.0 [m/s]
- 2.5 [m/s]
- 0.0 [m/s]

Center:
- Upwards gas
- Horizontal gas velocity

Diagram showing gas velocity distribution for different inner volumes.
Simulation of softening test under load by DEM
Simulation of softening behavior of ore by DEM

Young’s modulus

- 3.5 GPa
- 0.35 GPa
- 0.035 GPa
- 0.0035 MPa

Shrinkage

Normal stress

Young’s modulus
Gas flow in cohesive zone calculated by DEM-CFD
Gas velocity vectors at various coke rate conditions

Coke rate  350 kg/t

Coke rate  240 kg/t
Isobars planes at various coke rate conditions

Coke rate 350 kg/t

Coke rate 240 kg/t
Effect of charging mode on gas flow

Coke rate  240 kg/t

Layered charging  50% mixing  100% mixing
Effect of charging mode on isobars planes

Coke rate 240 kg/t

Layered charging

50% mixing

100% mixing
Effect of coke mixed charge in low coke rate

Layered charge

Decrease in coke rate

Increase in pressure drop due to narrow coke slit
Conclusions

- The gas flow and solid motion with shaft gas injection and low coke rate conditions were three-dimensionally analyzed by a hybrid model of DEM and CFD.
- The influence of shaft gas injection is restricted to the peripheral zone.
- In smaller blast furnace, the injected gas can easily reach the central part.
- At low coke rate conditions, charging mode must be improved to keep permeability in the cohesive zone. Coke mixed charge has a favorable effect.
Thank you for your attention