Update on the development of POSCO’s hydrogen-based ironmaking process, HyREX

Low-Carbon Iron and Steel Making R&D Center
PosLAB, POSCO
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POSCO established the target of CO₂ reduction 30% by 2035, 100% by 2050
POSCO Hydrogen Ironmaking - HyREX

FBR

Sinter Feed (T.Fe 58~62%)

Hydrogen

H₂ DRI

ESF

Electricity

Hot Metal

Conventional Steelmaking

BOF

Secondary Refining

Continuous Casting

Direct Use of Sinter Feed

Hot metal and Slag similar to BF

Use of existing steelmaking facilities

🌱 Low-cost raw materials
🌱 Abundant availability

👍 High Fe yield
👍 Slag recyclable (alternative to BF slag)

👍 No restrictions on high grade steel manufacturing
POSCO Hydrogen Ironmaking - HyREX

HyREX Process

* HyREX: Hydrogen Reduction

**Fe_2O_3 + 3H_2 → 2Fe + 3H_2O**

FINEX Fluidized Bed Technology
Operational technology in large-scale ESF (SNNC)

Fast development with own technologies
FBR Redesign for Hydrogen Use: Overall

- **Revision of reactor design criteria**
  - Adjustment on fluidizing condition
- **Re-design of multi-staged fluidized beds**
  - Target reduction degree
  - Specific gas consumption
  - Temperature profile
  - Residence time
- **Countermeasures for high reduction degree**
  - Raw material control
  - Anti-sticking & plating measure
- **Process and plant engineering**
  - Heating up of hydrogen
  - Material selection under hydrogen condition
  - Explosion-proof design
FBR Redesign for Hydrogen Use: Fluidization

### Characteristics of H₂ as fluidizing gas

- **Lower density and viscosity under hydrogen condition**

<table>
<thead>
<tr>
<th></th>
<th>FINEX gas</th>
<th>HyREX gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ [%]</td>
<td>15~20</td>
<td>70~80</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>1.55</td>
<td>0.62 (40%)</td>
</tr>
<tr>
<td>Viscosity [Pa-s]</td>
<td>4.22x10⁻⁵</td>
<td>3.51x10⁻⁵ (83%)</td>
</tr>
</tbody>
</table>

- Requires 40% higher velocity compared to that of FINEX
  - Good fluidization quality confirmed in Sim. & Exp.

### Reduction kinetics of H₂ in fluidized bed

- Using lab-scale fluidized bed, kinetics of hydrogen reduction analyzed
- Visualization of fluidized bed using CFD simulation
  - Enables to determine reactor size & residence time
  - Prediction of reduction behavior under various operation conditions
  - Demo plant CFD visualization under progress

- Lower density and viscosity under hydrogen condition

- Reducing reaction kinetics
FBR Redesign for Hydrogen Use: Reduction

Experimental Facilities

- Experimental fluidized bed in various scale

### Fluidized bed reduction test

- Investigation on H₂ reduction behavior under various fluidized bed conditions
  - Ore blend, gas temperature and Gas Oxidation Degree (GOD)

<table>
<thead>
<tr>
<th>Ore</th>
<th>Bed Temp. and GOD</th>
<th>Effect of bed Temp. and GOD</th>
<th>Effect of ore blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore_A</td>
<td>~ 750°C</td>
<td>-Fe (30%)</td>
<td>-FeO (11%)</td>
</tr>
<tr>
<td>Ore_B</td>
<td>~ 760°C</td>
<td>-FeO (60%)</td>
<td>-Fe (90%)</td>
</tr>
<tr>
<td>Ore_C</td>
<td>~ 770°C</td>
<td>-FeO (90%)</td>
<td>-Fe (90%)</td>
</tr>
<tr>
<td>Ore_D</td>
<td>~ 780°C</td>
<td>-FeO (90%)</td>
<td>-Fe (90%)</td>
</tr>
<tr>
<td>Ore_E</td>
<td>~ 800°C</td>
<td>-FeO (90%)</td>
<td>-Fe (90%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bed dia. [mm]</th>
<th>Solid charge [kg]</th>
<th>Gas species</th>
<th>Temperature [°C]</th>
<th>Pressure [bar.g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab-scale</td>
<td>Bench scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>300</td>
<td>H₂, H₂O, CO, CO₂, N₂</td>
<td>&lt; 1,000</td>
<td>~ 4</td>
</tr>
<tr>
<td>1 (PSD 1~2mm)</td>
<td>50 (PSD &lt;8mm)</td>
<td>H₂, CO, CO₂, N₂</td>
<td>&lt; 950</td>
<td>1.8</td>
</tr>
</tbody>
</table>
FBR Redesign for Hydrogen Use: Sticking

Sticking behavior and de-fluidization

- No whisker formation and less sticking

  - RD 90%
    - [DRI CO reduction]
  - RD 90%
    - [H₂ reduced DRI]

- Effect of ore type on the sticking & fluidization behavior

  - RD: 92%
    - Fluidized Bed \(\Delta P\)
      - Time (Sec)
        - [Stable fluidization Case]
  - RD: 57%
    - Bed Collapse
      - Time (Sec)
        - [De-fluidization Case]

Evaluation of flowability of H₂-DRI

- Investigation on flowability of DRI with high RD
  - Evaluation of flowability using standard apparatus
    - Small scale rheometer that can measure flowability in high temp.
      - DRI: < 50g
      - Temp.: ~ 600°C (DRI storage temp.)
  - DRI reduced by H₂ is found to have better flowability compared to that of DRI reduced by CO
FBR Redesign for Hydrogen Use: Hydrogen Heating

- International R&D collaboration project funded by Korean government
- Construction completed for direct & electrical heating facility (50~100 Nm³/h, 50~100 kW), Experiments underway
- Hybrid heating method may be applied considering investment cost and thermal efficiency

Indirect Gas Heating
- Industrial-scale readily available
- Good for low T application
- Complicated structure

Direct Gas Heating
- High efficiency
- Simple structure
- Good for high T application
- H₂O in the heated gas

Electrical Heating
- Easy temperature control by adjusting power consumption
- No available industrial-scale
Gas utilization is limited by temperature, moreover H₂ reduction is endothermic reaction.

In order to maximize H₂ gas utilization, off-gas recycling is mandatory with gas cleaning system.
FBR Redesign for Hydrogen Use: Process Design

PIPOP*

*Python-based Ironmaking Process design & Optimization Program

- Python and Pyomo based ironmaking process modeling and optimization program developed by POSCO for HyREX & FINEX process
- Convenient for iterative calculations for complex processes
- Can solve large-scale nonlinear optimization problem within a few seconds
- Various application available!

- Heat & mass balance for every reactor units and streams
- Gas heating condition for target gas temperature and quality
- Gas mixing and cleaning condition for target purity
- Flux and carbon usage for target product quality

Optimization of H₂ & Energy consumption
Simulation of various raw material usage
Evaluation of different process configurations
ESF for H$_2$ DRI Melting: Major Features

- **Design concept for H$_2$ DRI melting in ESF**
  - Based on SNNC ESF*, Similar but different design for H$_2$ DRI smelting
    
  _* SNNC: Fe-Ni plant @ Gwangyang Works_

- **ESF structural design**
  - Robust structure for long-term operation
  - Feeding equipment for briquette or powder of H$_2$ DRI
  - Cooling panels and erosion resistant refractories
  - Optimal electrode control system
  - Off-gas system for gas recycle

- **ESF operational design**
  - Brush arc operation for rapid melting
  - Stable control of temperature and composition
  - Monitoring systems for automatic operation
  - Slag chemistry control for recycling
ESF for H₂ DRI Melting: Large Lab-scale Test

- Batch Type Operation
- 280 kVA (70V, 4000A)
- Electrode: 150mmΦ

- 1st Trial: Low Reduced DRI (RD: 65%) + Cokes + Additive
  - (Raw Materials)
  - (After Melting)

- 2nd Trial: HBI (Crushed, RD 90%) + Carbonizing Material + Additive
  - (Raw Materials)
  - (After Melting)

- 3rd Trial: H₂-DRI (RD 90%) + Carbonizing Material + Additive
  - (Raw Materials)
  - (After Melting)

Fe-4.2%C-0.02%P-0.015%S
**Phase 1: Fe-Ni Process (Completed)**

- **The actual operation data of SNNC**
  - Inputs/Outputs material and energy balance etc.

- **Thermodynamics Analysis**
  - Chemical reaction, mass and energy balance etc.

- **Computational Fluid Dynamics Analysis**
  - Temperature, Flowage etc.

**Phase 2: HyREX Process (Ongoing)**

- **ESF Simulator predicts the temperature, mass and composition of hot metal, slag, and gas**

- **ESF for H₂ DRI Melting: ESF Simulator**

  ![Diagram of ESF Simulator](image)
ESF for H₂ DRI Melting: Bench-scale Facility

■ Specification
  ○ Capacity: 1 ton/hr
  ○ Furnace: Round Type, 2.8m ID, Air tight, Moving furnace car
  ○ Transformer: 2.5 MVA, 3Phase AC Type, Brush & Immersed arc mode
  ○ Electrode: 12 inch (305mm), PCD 1.2 m
  ○ Tapping machine & mud gun, 1 hot metal & 1 Slag holes, 4~6 Taps/day

■ Schedule
  ○ Conceptual and basic design (~’23.1)
  ○ Detailed design: Mechanical and electrical parts (~’23.7)
  ○ Civil works and concrete foundation (’23.7~’23.8)
  ○ Manufacturing and installation (’23.9~12)
  ○ Hot test (~’24.1)
HyREX Demo Plant Engineering

Bench Scale Test
- FBR 50 kg/batch
- ESF 1.0 ton/hr

Know-How
- No.2 FINEX® (1.5 MTPA)
- No.3 FINEX® (2.0 MTPA)

Demonstration Plant
- SNNC No.1 ESF (Circle, 120MVA)
- SNNC No.2 ESF (Rectangle, 135MVA)
HyREX Demo Plant Engineering

**Process Engineering**
- Impurity Removal
- Gas Recycling
- H₂ by SMR
- H₂ Heating
- Ore+flux
- Hot Compaction
- Carbon Addition
- ESF Smelting
- 4 Stage Fluidized Bed

**Plant Engineering**
- Reactor
- ESF
HyREX Demo Plant Engineering

Layout

0.3MTPA HyREX Demo Plant

Reactor
ESF
Water-Treatment Facilities

Towers

Reactor Tower
ESF Tower
Four stage Reactor
Demonstration by 2030, hereafter Stepwise Replacement of BF with HyREX
HyREX R&D Partnership

Global Cooperation Hub for the HyREX development and commercialization

- University, R&D: 3
- Steel Maker: 5
- Mining: 4
- Hydrogen: 4
- ETC: 1

Total: 17

[ Partnership Status ]

[ First Newsletter (‘23.7) ]

[ Website (https://www.hyrex.co.kr) ]

POSOCO is developing hydrogen reduction ironmaking technology that does not emit carbon dioxide by leveraging years of experience with commercial-scale FINEX and SNBC’s ESF technology.
The R&D of HyREX is under progress with the physical experiments and numerical modeling combined with the actual operational experience from FINEX and SNNC Fe-Ni smelting plant. Several achievements are acquired in the respects of how to optimize the HyREX process parameters and integrate into the process engineering.

The pre-engineering of HyREX demonstration plant has been performed, and the basic data for EPC have been secured. The engineering work was initiated in earnest for plant building.

POSCO intends to develop the HyREX process as a reliable, universal, and globally available decarbonization solution for the steel industry. In this respect, POSCO is operating “HyREX R&D Partnership” as the technology exchange channels, information sharing of HyREX development status, and future cooperation.