Development of PSA System for the Recovery of CO$_2$ from Blast Furnace Gas

Nov. 05 2013

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Blast Furnace

Iron ore \( (\text{Fe}_2\text{O}_3) \)

Coke \( (\text{C}) \)

Hot Air \( (1,000 \sim 1,100 \, ^\circ\text{C}) \)

Molten Iron \( (\text{Fe}) \)

Blast Furnace

\[ \text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \]

\[ 2\text{C} + \text{O}_2 \rightarrow 2\text{CO} \]

Blast Furnace Gas

\[ \text{CO} : 23\% \quad \text{CO}_2 : 22\% \]
\[ \text{N}_2 : 52\% \quad \text{H}_2 : 3\% \]

Ambient Pressure \( \sim 130\text{kPa} \)

Important Fuel Gas

Main Origin of \( \text{CO}_2 \)
CO₂ Emission in Japan

CO₂ emission in Japan lies around 1.0-1.3 billion tons per year. CO₂ emission from Steel Works is around 15%. Reduction of CO₂ is an important subject for Steel Makers.

JISF* starts COURSE 50** Project
(STEP 1 2008-2012)
(STEP 2 2013-2017)

*JISF : Japan Iron and Steel Federation

COURSE 50: CO₂ Ultimate Reduction of Steel-making Process by Innovative Technology for Cool Earth 50
Subjects in COURSE 50

Use of $H_2$ at Blast Furnace for Iron Ore Reduction
Separation of $CO_2$ from BFG with amine or PSA
Recovery of Wasted Heat to supply separation energy

COG ($H_2$:50-60%)
BFG ($CO_2$:21-23%)

Coke Oven  Blast Furnace  Heat Recovery

Our subject

Separation
Amine
PSA

$CO_2$  CCS?
Outline of PSA Project

Target

• CO₂ Recovery ≥ 80% or CO₂ Purity ≥ 90%
• Flammable Gas Recovery ≥ 90%
• Reduction of CO₂ Recovery Cost > 50% (≤ 2,000 yen/t)
Laboratory PSA Apparatus

PSA Tower: ID.40mm x 500mmH x 4 Towers system (Usually use 3 towers)

Feed Gas: CO₂, CO, N₂, H₂

Each flow rate is controlled independently and mixed.
3 Steps 3 Towers PSA System

- **Adsorption**: BFG, N₂, CO, CO₂
- **Rinse**: CO₂
- **Desorption**: Vacuum Pump

**Cycle Time**: Press. & Adsorption → Rinse → Desorption
Zeolum F-9H shows high performance in PSA system. Technical target of the project is achieved. (blue area)

Adsortion 200kPa*
Desorption 7kPa*
Cycle Time 630sec

*absolute pressure

CO₂ Recovery (%) vs CO₂ Purity (%)

Zeolum F-9H
Active Carbon

80 85 90 95 100
No change in performance when cycle time larger than 450 sec. Performance at 300 sec is slightly lower but still acceptable.
Effects of CO₂ Concentration in Feed Gas

**Higher CO₂ concentration leads higher recovery rate.**

![Graph showing the relationship between CO₂ concentration in raw gas and CO₂ flow rate recovery. The graph indicates that higher CO₂ concentration results in a higher recovery rate. Gas feed rate is constant.](Image)

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Total cost is reduced at shorter cycle time because of lower capital cost and higher CO₂ concentration leads more advantage.
ASCOA-3* (JFE Steel Fukuyama Area)

*Advanced Separation System by Carbon Oxides Adsorption

Capacity : 3tons-CO$_2$/day
Plant Area : 21m x 25m

Start : March 2011
CO₂ Adsorption Towers ID: 750mm, Height: 1,200mm
General Test Operation

All technical targets were cleared during test operation period.

Graph showing CO₂ Recovery and Purity over time from 3/8 to 3/24.

- CO₂ Recovery target: 3t/day
- Purity target: 90%
- Recovery ratio target: 80%

Key points:
- Max. Recovery: 4.3t/day
- Max. Purity: 99.5%
- Achieve 3 targets during test operation period.
Cost Reduction

-Power Consumption of Vacuum Pump-

Higher CO₂ recovery leads lower power consumption

![Graph showing the relationship between CO₂ recovery and power consumption. The graph indicates that higher CO₂ recovery leads to lower power consumption.](image)
Further Cost Reduction (Higher Dew Point)

Operation is stable even at a higher dew point.
(Dew point of raw gas: -60°C → -30°C)

- Gas Pressure: 50kPa
- CO₂ Conc.: 33-34%
- 5tons/day Condition (Cycle Time: 300sec.)
- 6tons/day Condition (Cycle Time: 225sec.)
CO₂ Adsorption Towers
11 Resistance Thermometers
Temperature Distribution (Horizontal Direction)

Temperatures at center and half radius move simultaneously.
Temperature Distribution

☆ Temperature change indicates adsorption-desorption behavior of CO$_2$

☆ Adsorption-Desorption behaviors at center and half radius are the same.

→ It is easy to scale-up the adsorption tower to the horizontal direction.

☆ Homogeneity of gas flow in enormous adsorption tower?
Pressure difference of lower side of adsorbent layer is only 0.02 kPa in a commercial scale adsorption tower.

There are no problems in pressure distribution.
Design of Adsorption Tower

Adsorption Tower
- Size: 4,000mmΦ × 17,000mm
- Thickness: 12mm
- Weight: 50tons
- Material: SM490B
- Designed Pressure: 190kPa/FV

Adsorbent Layer

Adsorbent: Zeolum F-9H
- Apparent Density: 0.65kg/L
- Weight: 65tons
Commercial Plant Image
(Capacity: 1Mt-CO₂/y)

Before Development

Tower 6.5m φ × 23m

Vacuum Pump

200kt/y × 5 units
Investment: 15B¥

Compressor

After Development

1.26Mt/y

Blower (Common)

Tower 4m φ × 17m

Vacuum Pump

500kt/y × 2 units
Investment: 7B¥
Recovery cost was achieved the target! ($\leq 2,000\text{yen/t}$)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Capital</td>
<td>7,000 Million ¥</td>
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<tr>
<td>Unit Cost</td>
<td>840 ¥/t-\text{CO}_2</td>
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<tr>
<td>Power</td>
<td>145 kWh/t-\text{CO}_2</td>
</tr>
<tr>
<td>Steam</td>
<td>0.05 t/t-\text{CO}_2</td>
</tr>
<tr>
<td>Utility Cost</td>
<td>1,060 ¥/t-\text{CO}_2</td>
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<tr>
<td>Adsorbent</td>
<td>390 tons</td>
</tr>
<tr>
<td>Unit Cost</td>
<td>40 ¥/t-\text{CO}_2</td>
</tr>
<tr>
<td>Total Unit Cost</td>
<td>1,940 ¥/t-\text{CO}_2</td>
</tr>
</tbody>
</table>
Cost Estimation from ASCOA-3 Operation Results

Recovery Cost (Yen/t-CO₂)

- Initial: 4,040 ($41/t)
- ASCOA-3: 1,940 ($20/t)
- Target: 2,000 ($21/t)

Cost Estimation from ASCOA-3 Operation Results

- Utility
- Capital
- Adsorbent

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Summery

1. Zeolite type adsorbent has a good performance in Laboratory PSA and ASCOA-3
2. Shorter cycle time and higher CO$_2$ concentration in BFG reduce the cost for CO$_2$ separation
3. The size of commercial adsorption tower was reduced to 1/3～1/4 as the fruit of development
4. CO$_2$ recovery cost achieved the target through the operation result with ASCOA-3 and imaging the design of commercial plant

Acknowledgement

We appreciate to NEDO for their financial support.
Thank you for your attention!