Technology Development for Environmentally Harmonized Steelmaking Process

Workshop on Delivering Green Growth

Seoul Korea
March 4, 2010
**Basic idea**

1) Decrease of reduction amount (increased use of scrap): Outside the scope
2) Iron ore reduction (adopted)

**Alternative reducing agents**

| Steps for radical reduction | (1) Utilization of hydrogen
| 1) Further improvement of COG reforming efficiency by the use of waste heat
| 2) Verification of best solution for reformed COG utilization
| (2) Direct use of electricity
| 1) Hydrometallurgy
| (3) Use of C−Neutral agents
| 1) Biomass
  - Charcoal reduction, waste use

**Reduction by carbon**

| (1) CO₂ capture
| 1) CO₂ capture from BFG
  - Chemical absorption
  - Physical adsorption
| Scenario 2
| 1) Maximum use of waste heat
| 2) Expanded use of waste heat through CO₂ absorbent development
| 3) Utilization of external energy sources

| ② CO₂ capture from other reduction processes
| - Coal−based Smelting Reduction
| - Coal−based Direct reduction

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Drastic CO₂ emissions reduction in steel industry
Coal is used to reduce iron ore in steelmaking process.

Even with enhanced energy-saving, emission of CO₂ is unavoidable.

COURSE 50 aims at developing technologies to decrease CO₂ emissions by approximately 30% through reduction of iron ore by hydrogen as well as capture – separation and recovery – of CO₂ from blast furnace gas.

The initiative targets establishing the technologies by ca. 2030 with the final goal of industrializing and transferring them by 2050, taking advantage of renewing blast furnaces and relevant facilities.

Outline of COURSE 50
1. Total budget: approximately 10 billion yen (planned)
2. Term for R&D: Step 1 of Phase 1 for 5 years (Fy 2008 – Fy 2012)
3. R&D targets:
   (1) Development of technologies to reduce CO₂ emissions from blast furnace
   (2) Development of technologies to capture - separate and recover - CO₂ from blast furnace gas (BFG)
(1) Development of technologies to reduce CO₂ emissions from blast furnace

- Develop technologies to control reactions for reducing iron ore with reducing agents such as hydrogen with a view to decreasing coke consumption in blast furnaces.
- Develop technologies to reform coke oven gas aiming at amplifying its hydrogen content by utilizing unused waste heat with the temperature of 800°C generated at coke ovens.
- Develop technologies to produce high-strength & high reactivity coke for reduction with hydrogen.

(2) Development of technologies to capture - separate and recover - CO₂ from blast furnace gas (BFG)

- Develop techniques for chemical absorption and physical adsorption to capture - separate and recover - CO₂ from blast furnace gas (BFG).
- Develop technologies contributing to reduction in energy for capture - separation and recovery - of CO₂ through enhanced utilization of unused waste heat from steel plants.

Time Table of Technology Development

<table>
<thead>
<tr>
<th>Phase 1 Step 1 (2008~12)</th>
<th>Phase 1 Step 2 (2013-17)</th>
<th>Phase 2</th>
<th>Industrialization &amp; Transfer</th>
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<tr>
<td>2010</td>
<td>2020</td>
<td>2030</td>
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NEDO Project

<table>
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<th>Phase 1 Step 1 (2008~12)</th>
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<td>2008</td>
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| 2011                      | 2012                      |
| 2 – 3                     | 2 – 3 (billion yen)       |

(Phase 1: 2008~12, Phase 2: 2013-17)
Sub Projects

1. Development of technologies to utilize hydrogen for the reduction of iron ore.
2. Development of technologies to reform coke oven gas (COG) through the amplification of hydrogen.
3. Development of technologies to produce coke for hydrogen reduction of iron ore.
5. Development of technologies to recover unused sensible heat.

* COURSE 50 Committee at the Japan Iron and Steel Federation (JISF) supports the 6 companies’ R&D activities.
COURSE 50 Committee
Chairman: Keisuke KUROKI (Nippon Steel)
Vice Chairman: Takashi SEKITA (JFE Steel)

Project Management

Project Leader: Takashi MIWA (Nippon Steel)
Deputy Project Leader: Haruji OKUDA (JFE Steel)

Assistant Project Leaders

Secretaries

Project Management Meeting

Total Systems WG

Intellectual Property Meeting

6 Sub Projects
Development of Technologies for Environmentally Harmonized Steelmaking Process

(1) Technologies to reduce CO₂ emissions from blast furnace

- Iron ore pre-reduction technology
- H₂ amplification
- Coke production technology for BF hydrogen reduction
- Coke substitution: reducing agent production technology
- Reaction control technology for BF hydrogen reduction
- CO₂ capture technology

(2) Technologies for CO₂ capture

- Chemical absorption
- Physical adsorption

- CO₂ storage technology
- Regeneration Tower
- Absorption Tower
- Reboiler
- CO₂ capture technology

- Steam
- Electricity
- Hot metal
- BOF

COURSE50 / CO₂ Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50
Sub Projects 1 & 3

- Identification of feeding conditions of preheated gas, aiming at controlling increase of ore degradation by reduction associated with enhanced reduction by hydrogen.

- Quantification of improved reducivity of iron ore when feeding reformed COG.
- Evaluation of effects of accompanying reactions under hydrogen-co-existent gas conditions.

- Combustion simulation of tuyere raceways under hydrogen-co-existence.
- Evaluation of balances of energy and CO₂ for an entire steelworks.

- Development of high strength coke to deal with feeding of reformed COG.

- Clarification of optimal feeding conditions of reformed COG.
  - Model experiments
  - Simulation

- Development of an operation design model for reformed COG usage based on the heat & mass balance model.
  *FY2010 onwards

- Identification of issues to be solved by reviewing past knowledge regarding blast furnace operations with higher hydrogen feeding.
- Quantification of results of reduction in carbon supply.
  *FY2010 onwards

- Pre-heated gas (N₂, etc.)

- Gas Flow

- Reformed COG
BIS: Blast furnace Inner reaction Simulator

Characteristics of BIS furnace
- Pseudo-counter flow moving bed
- Possible to simulate endothermic reaction associated with gasification and hydrogen reduction, as well as heat exchange.

Experiment under bosh gas conditions adjusted to hydrogen supply conditions

Evaluation of thermal reserve zone

Heating at 100 °C to prevent condensation of water
Changes in rate of iron ore reduction estimated by gas analysis - BIS experiment -

- Total Reduction Rate increases with hydrogen supply; presumably by
  - enhanced hydrogen reduction in thermal reserve zone and upper cohesive zone, and
  - increased CO + CO\(_2\) due to the gasification of carbon by H\(_2\)O.

Supply gas composition: 60% H\(_2\), 30% CO, 10% N\(_2\).
Summary Results

2) Supplying reformed COG into shaft

Findings
- Improved reduction clearly observed by holistic process evaluation (BIS, BIS+Test of high temperature properties under load).
- Desirable supplying conditions; Reformed COG feeding rate >200 Nm$^3$/tp and Interior Distribution Ratio* >20%)
- Interior Distribution Ratio* found low in preliminary testing.

Issues
- Measures to improve Interior Distribution Ratio: Supplying height, velocity, nozzle shape and injection angle.

1) Supplying reformed COG through tuyeres

Findings
- Possibility to reduce CO$_2$ emissions by 10% at feeding rate of 200 Nm$^3$/t.
- Determination of testing conditions for combustions experiments.

Issues
- Adequate supplying conditions (feeding rate and gas analysis)
- Hydrogen behavior in raceways.

*Interior Distribution Ratio: gas distribution ratio inside the furnace
Changes in energy input into ironmaking system being studied associated with supplying reformed COG to BF.

Substitution with:
1. Coke
2. Sensible heat of hot air
3. Pulverized coal

+$\quad$Supplying r. COG through tuyeres
+$\quad$Supplying r. COG into lower shaft

Energy balance at a steelworks with the introduction of reformed COG process.
Development of coke-making technology by utilizing high performance caking additive (HPC)

Blended coal  HPC  Strong coke

HPC starts softening and melting at low temperatures below 300 °C, packing together coal particles effectively by filling gaps in between them, consequently realizing increased coke strength.

• Possible to increase coke strength without relying on blending centered on coking coal, thus realizing diversified use of coal.
• Enhanced compatibility with raw materials at the time when hydrogen reduction is put in practical use.
HPC manufacturing test with high ash content

Set suitable conditions for slurry extraction from settling tank to overflow part of residual coal (RC) to include in HPC.

0.1t/d HPC continuous manufacturing test plant (BSU)

Ash combined with residual organic components
Coke strength when blended with high-ash HPC for 8 different coals under simulated industrial conditions.

(50kg furnace, B.D. 720kg/m³)

High strength coke produced with high-ash HPC
(320kg furnace)
COG Reforming Technology

- Steam reforming technology for tar etc. in COG, using COG thermal energy (part of results of past national project)
- Newly developed catalyst
Development of chemical absorbents to reduce energy consumption for CO₂ capture

1. Development of chemical absorbent to reduce energy consumption for CO₂ capture
   ① Identification of reaction mechanisms of chemical absorbents using quantum chemistry and molecular dynamics, as well as component designing.
   ② Designing of high-performance amine compounds by chemoinformatics (analysis by multivariable regression model) with the existing amine database.
   ③ Examination of synthesis technologies for mass production of high-performance amines.
   ④ Exploration of absorbents other than amines.
   ⑤ Evaluation of chemical absorbents by laboratory experiments and process models.

2. Testing of new chemical absorbents for industrial application
   ① Evaluation of new absorbents in terms of corrosivity and long-term stability.
   ② Support for experiments with real gas by model simulations.
Development of chemical absorbents
(Collaborative Research with RITE) <continued>

- Synthesis of new amines

Apparatus for gas-liquid equilibrium

Measuring device for absorption and diffusion
Development of the chemical absorption process

Strategy for the Cost Reduction

- CO₂ Separation Cost (JP ¥/t-CO₂)
- Heat Unit Consumption (GJ/t-CO₂)

2004Fy

Waste heat recovery

Development of the chemical absorbent

Present

Optimization of the chemical absorption process

Optimization of the entire system (with the improvement of steel-making process)

Goal

- 3.0
- 2.5
- 2.0

2004Fy
## Development of the chemical absorption process

### Test Plants Construction & Research Schedule

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### Development Highlights
- **2009 Q3**: Transfer, Assembly, and Adjustment of 1t/D Bench Plant
- **2009 Q4**: Construction of 30t/D Process Evaluation Plant
- **2010**: Trial Run
- **2010 Q4**: Test new Solvents

**Solvents**
- Solvent A
- Solvent B
- MEA

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**Notes:**
- The diagram illustrates the timeline for the development of the chemical absorption process, focusing on both construction and research activities.
- The 1t/D Bench Plant is initially focused on transfer, assembly, and adjustment, followed by the introduction of Solvent A and MEA.
- The 30t/D Process Evaluation Plant is under construction and will undergo a trial run.
- The introduction of new solvents is scheduled for the last quarter of 2010.
Development of the chemical absorption process

Test Equipment : Bench Plant (1t/D)

Adjacent to No.4 BF at NIPPON STEEL Kimitsu Works
Development of the chemical absorption process

Test Equipment: Process Evaluation Plant (30t/D)

November 11, 2009
Characteristics and Performance of Solvent A

CO₂ Recovery Rate, Heat Unit Consumption

Stripper Bottom Temperature (℃)

CO₂ Recovery Rate, Heat Unit Consumption (GJ/t-CO₂)

- Lean Amine Loading

<Fixed Condition>

Stripper Bottom Temperature

- CO₂ Recovery Rate
- Heat Unit Consumption
Development of the chemical absorption process

Characteristics and Performance of Solvent A

CO2 Recovery Rate, Heat Unit Consumption

- Lean Amine Loading
- Stripper Bottom Temperature
Development of the chemical absorption process

Characteristic and Performance of Solvent A

Optimum Point of Heat Unit Consumption = 2.8~2.9 GJ/t-CO₂
Aim: Capture CO₂ and N₂ separately from BFG by using physical adsorption technology.

Gas Separation Process (PSA)

Noncombustible gases

CO₂
N₂

Combustible gases

CO
H₂
PSA Laboratory Test Apparatus

- Adsorption Tower
- Pressure gauge
- Flow meter
- Automatic changeover valve
- Gas meter
Study on recovery amount of unused sensible heat & waste heat

【1st stage】
Generation of saturated steam at 140℃ to the lower temperature limit

Exhaust gas from processes

133℃

100℃

75℃

140℃ steam for chemical absorption

Heat pump for high temperature

Fuel reforming

Direct use of sensible heat

Rankine cycle for medium temperature

【2nd stage】
Recovery of waste gas after steam generation by new technologies

• Heat accumulation with PCM (Phase Change Material)
• Heat pump
• Power generation with low b.p. medium

PCM heat accumulation

Transport

140℃ steam for chemical absorption

Thermal catalyst for chemical absorption

Organic Rankine Cycle

Kalina Cycle

Power for physical adsorption

Heat pump
## Technological issues

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Heat pump</th>
<th>PCM</th>
<th>Power generation with low boiling point medium</th>
<th>Direct use of heat</th>
<th>Fuel reforming</th>
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<tr>
<td>Common issues</td>
<td>Specific issues</td>
<td>Common issues</td>
<td>Specific issues</td>
<td>Common issues</td>
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<td>✓ Improvement of heat exchanger</td>
<td>✓ Enhancement of chemical heat pump reaction</td>
<td>✓ Improvement of heat exchanger</td>
<td>✓ Development of catalysts</td>
<td>✓ Improvement of system efficiency</td>
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<tr>
<td>✓ Increased heat transfer rate</td>
<td>✓ Development of catalysts</td>
<td>✓ Compactification</td>
<td>✓ Improvement of reactors</td>
<td>✓ Technology to prevent thermal decomposition of working medium</td>
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<tr>
<td>✓ Compactification</td>
<td>✓ Improvement of system efficiency</td>
<td>✓ Prevention of corrosion &amp; clogging</td>
<td>✓ Development of catalysts</td>
<td>✓ Technology to prevent leakage</td>
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<tr>
<td>✓ Improvement of reactors</td>
<td>✓ Development of PCM</td>
<td>✓ Thermal insulation technology</td>
<td>✓ Development of catalysts</td>
<td>✓ Development of PCM</td>
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<td>✓ Extension of temperature range</td>
<td>✓ Reduction in equipment cost</td>
<td>✓ Reduction in equipment cost</td>
<td>✓ Technology to prevent thermal decomposition of working medium</td>
<td>✓ Development of PCM</td>
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<td>✓ Improvement of heat accumulation density</td>
<td>✓ Optimization of recovery technologies for various waste heat (including combination with heat accumulation)</td>
<td>✓ Optimization of recovery technologies for various waste heat (including combination with heat accumulation)</td>
<td>✓ Technology to prevent leakage</td>
<td>✓ Development of catalysts</td>
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<tr>
<td>✓ Control of expansion</td>
<td>✓ Improvement of system efficiency</td>
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<td>✓ Optimal reaction conditions (steam ratio, etc)</td>
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Technology development for sensible heat recovery from steelmaking slag

- Regeneration of chemical absorbent in CO₂ capture process requires energy.
- Sensible heat recovery from steelmaking slag is targeted.

**Project Scope**

- **Roll forming process**
  - Solidified slag 3~5mm
  - CaO+H₂O ⇒ Ca(OH)₂

- **Sensible heat recovery process**
  - Heat recovery equipment
  - Air ≥200℃

- **Heat recovery equipment**
  - Air
  - (Direct aging)

- **Regeneration of CO₂ absorbent**
  - Recovered gas temperature >140℃
  - Heat recovery efficiency > 30%

**Target**

1. Recovered gas temperature >140℃
2. Heat recovery efficiency > 30%

**Technology development for sensible heat recovery from steelmaking slag**

- *Approx. 1 t/min*

**Diagram Notes**

- Molten slag
- Slag pot
- Trough
- Cooling roll
- Solidified slag 3~5mm
- Heat recovery equipment
- Air ≥200℃
- Regeneration of CO₂ absorbent

※ 表示温度は例
Melting steelmaking slag

- Laboratory-scale roll forming apparatus under construction
- Bench-scale roll forming equipment under designing