Development of High-Efficiency Oxy-fuel IGCC System

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2 Concept of High-Efficiency Oxy-fuel IGCC

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1) Experimental study using 3TPD gasifier

2) Modeling of $O_2/CO_2$ gasification reaction and numerical simulation of gasifier

3) Development of countermeasure for carbon deposition in hot gas clean-up system

4) Consideration toward next step
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Background and Objective

● To reduce GHG (CO₂) emission, Japanese utilities make efforts to

  → Improve thermal efficiency
    (250MW IGCC Demonstration Project)
  → Expand Biomass Co-firing
    (1~3wt%)

● CCS is regarded as an option to cope with global warming
  → However, decreases efficiency and increases its cost

Development of **Innovative Carbon capture system**

with **high efficiency**

Source: http://www.ccpower.co.jp/
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New IGCC system to capture CO$_2$

High efficiency Oxy-fuel IGCC

Existing IGCC with CO$_2$ Capture
Schematic Diagram of high-efficiency oxy-fuel IGCC System

Coal → Gasifier → Hot Gas Clean up system → Combustor

CO₂ → Air Separation Unit → Compressor → Regenerative heat exchanger → GT

Steam → Gas Cooler → HRSG → Mercury Removal

CO₂ Capture → Scrubber → Condenser

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Outline of high-efficiency oxy-fuel IGCC System

Gasifier performance is improved in O₂/CO₂ gasification system

Semi-closed cycle GT system improves efficiency

CO₂ separation unit is not required
Results of preliminary estimation
(CRIEPI Report : M07003)

Comparison between with CO₂ Capture and without CO₂ Capture (1300C class GT)

<table>
<thead>
<tr>
<th>CO₂ Capture</th>
<th>Gasifier</th>
<th>Net Power Output</th>
<th>Net Thermal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>GE</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>YES</td>
<td>SHELL</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>NO</td>
<td>CRI EPI</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td>60</td>
<td>60</td>
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</tbody>
</table>

Target efficiency 42%(HHV)

### Schedule of NEDO project (1st Phase)

<table>
<thead>
<tr>
<th>Task</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011～2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. O₂- CO₂ blown gasification technology</td>
<td></td>
<td></td>
<td></td>
<td>Mid-term evaluation ▼</td>
</tr>
<tr>
<td>✓ Experimental study by 3TPD gasifier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ Development of numerical simulation tool</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>✓ Clarification of basic gasification reaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Optimization of hot gas clean-up system at high CO concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. Feasibility study of practical scale plant</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>4. Basic design of bench scale plant system</td>
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</tbody>
</table>

**<Acknowledgement>**

Most of this project has been executed based on research funded by NEDO (New Energy and Industrial Technology Development Organization). Some works done by CRIEPI as in-house research.
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CRIEPI 3TPD entrained flow gasifier

- **Type**: Pressurized Entrained Flow
- **Fuel Feed**: Dry Feed System
- **Capacity**: 3 t/Day
- **Pressure**: 2 MPa
- **Fuel Types**: Coal (Including Low Rank Coal)
- **Gasifying Agent**: Air, O₂-enriched Air, O₂, Steam

![Diagram of CRIEPI 3TPD entrained flow gasifier](image)

Chemical reactions:
- \( C + CO_2 \rightarrow 2CO \)
- \( C + H_2O \rightarrow CO + H_2 \)
- \( CO + H_2O \leftrightarrow CO_2 + H_2 \)

Product gas + char

Cyclone system

Coal

Reductor

Coal → VM + Char

Combustor

VM + O₂ → CO₂ + H₂O

C + O₂ → CO + CO₂

Transportation gas

Gasifying agent

Liquid slag

Slag hole

Char

Transportation gas
Effect of CO$_2$ concentration

(CRIEPI Report : M10016)

Char production rate (%)

Oxygen ratio (-)

\[
\text{Char production rate} = \frac{\text{Char in product gas}}{\text{Carbon in coal fed to gasifier}}
\]
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Pressurized Drop Tube furnace

Max. Pressure  2.0 MPa
Max. Temp.  1,750°C
Reaction model for CO$_2$ gasification

(a) SF Char

Model 1

Proposed model

Model 2

(b) DT Char

Model 1

Proposed model

Model 2
Simulation result of commercial scale gasifier

70TPH commercial gasifier

- Oxygen ration: 0.45
- $O_2$ concentration: 25%
- Oxygen ration: 0.45
- $O_2$ concentration: 35%

$R/T=0.4$  $R/T=0.5$  $R/T=0.6$
Simulation result of commercial scale gasifier

Evaluation of another type of gasifier has started.

Coal feed rate: 70TPH
Oxygen ratio: 0.41
$O_2$ concentration: 86%

$O_2$-CO$_2$ gasification
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Impact of carbon deposition on sorbent

Honeycomb desulfurization sorbent was cracked due to expansion of zinc ferrite particle through carbon deposition.
Countermeasure for carbon deposition

① Boudouard reaction
  \(- \text{CO} \rightarrow \text{CO}_2 + \text{C} \)

② Water gas shift reaction
  \(- \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \)

③ Methanation
  \(- \text{CO} + 3\text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \)

④ Reformation of methane
  \(- \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \)

\[ \text{REG} \text{ (Recirculated exhaust gas):} \quad \text{Mixture of CO}_2 \text{ & H}_2\text{O} \]
Effect of each countermeasure
(CRIEPI Report: M10012)

Assumed exhaust gas composition
CO$_2$ 69 vol%, H$_2$O 27 vol%,
O$_2$ 2 vol%, N$_2$ 2 vol%

*1: Weight of carbon deposition
   Weight of hole sample

*2: Flow rate of additional gas
   Flow rate of syngas

Gas mixing ratio*2 (%)
Comparison of each countermeasure  
(CRIEPI Report : M10012 ,M12001)

<table>
<thead>
<tr>
<th></th>
<th>Steam</th>
<th>CO₂</th>
<th>REG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect to prevent Carbon deposition</td>
<td>◎</td>
<td>▲</td>
<td>○</td>
</tr>
<tr>
<td>Necessary gas volume</td>
<td>◎</td>
<td>▲</td>
<td>○</td>
</tr>
<tr>
<td>Necessary heat and in house power</td>
<td>▲</td>
<td>○</td>
<td>◎</td>
</tr>
<tr>
<td>Deterioration of desulfurization sorbent</td>
<td>▲</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Total evaluation</td>
<td>◎</td>
<td>▲</td>
<td>◎</td>
</tr>
</tbody>
</table>
Result of plant efficiency analysis on 500MW High-efficiency oxy-fuel IGCC

Efficiency penalty of REG injection is quite small (about 0.2%).

Source: M. Kobayashi, et al., “Operational strategy for dry gas desulfurization process in an Oxy-fuel IGCC power generation that reconcile improved thermal efficiency and carbon dioxide separation from flue gas.”, the proceeding of the 8th Conference on Sustainable Development of Energy, water and Environmental Systems
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High feasibility was confirmed

<Examples of other reconsidered points>
- **Arrangement of heat exchangers of HRSG** (To mitigate temperature deviation between heat exchangers)
- **Temperature of HRSG exhaust gas** (To keep higher exhaust gas temperature than acid dew-point)
50tpd coal gasification equipment

The plan is under consideration for bench scale development project as next phase. For example, necessary equipment was considered supposing existing 50tpd pilot scale gasification equipment.

http://www.mhi.co.jp/discover/story/project02/story02.html
Necessary equipment for pilot scale gasification test

Case 1: CE Method
- Cold Evaporator
- CO₂
- Vaporizer
- Compressor
- 50tpd Gasifier

Case 2: Tank truck Method
- Tank trucks
- Liquid CO₂ Pump
- Vaporizer
- 50tpd Gasifier

It was clarified that gasification tests itself are possible by installing minimum equipment to existing 50tpd gasifier.
Conclusion

1 Experiments using 3t/D entrained flow gasifier and numerical simulation results clarified the concept of this system.

2 Countermeasure for carbon deposition was found out.

3 System arrangements by feasibility studies done by heavy industry manufacturer made this system feasible.

4 Toward next step, preparation for bench scale experiments and additional considerations are underway.
<Acknowledgement>

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Thank you for your attention.