Development of Evaluation Technology on Various Phenomenon in Coal Gasifier

May 9, 2007

S. Hara
Energy Engineering Research Laboratory, Central Research Institute of Electric Power Industry

2nd International Freiberg Conference on IGCC & XiL Technologies
# Development of Air Blown IGCC Technology

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<td><strong>200T/D Pilot Plant</strong></td>
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<td><strong>250MW IGCC Demonstration Plant</strong></td>
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2
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Concept of Air Blown Two-stage Entrained Flow Gasifier

Char or Ash
Char Gasification
Char
Reapid Pyrolysis
Pulverized Coal

Product Gas + Char

Reductor
Char + CO₂ → 2CO
Char + H₂O → CO + H₂
CO + H₂O ↔ CO₂ + H₂
Coal → VM + Char

Coal Transport Gas

Combustor
VM + O₂ → CO₂ + H₂O
Char + O₂ → CO + CO₂

Air

Slag
Slag Hole

1000°C ~ 1400°C
1600°C ~ 1700°C

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Test Research using 2T/D Gasifier

- Capacity : 2.4T/D
- Pressure : 2MPa
- Tested Coal : 20 types
- Location : Yokosuka Lab.
- Development of Air-blown Entrained Flow Gasifier, Ceramic Filter and Fixed Bed Desulfurizer
- Support of Design and Operation of Pilot Plant
Summary of 200T/D Pilot Plant Project

- Project Funding:
  - Government 90%
  - Electric Utility Companies 10%


- Tested Coal: Domestic Coal, 2 Australian Coals

- Location: Nakoso, Fukushima

- Good performance of the system which consists of gasifier, hot gas cleanup, gas turbine

- The longest run of 789 hr
### Schedule of IGCC Demonstration Plant Project

<table>
<thead>
<tr>
<th>Year</th>
<th>Design</th>
<th>Environmental Impact Assessment</th>
<th>Construction</th>
<th>Operation</th>
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<tbody>
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<td>2001</td>
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<td>2004</td>
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<td>2010</td>
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- Civil construction work began in August 2004.
- Installation of gasifier structure started in May 2005.
- Operation will start in 2007.
Clean Coal Power R&D Co. Ltd. has been established on June 15, 2001 by the nine electric power companies, EPDC and CRIEPI to conduct the demonstration plant project.
Outline of IGCC Demonstration Plant Project

- Output: 250MW (1700T/D)
- Target Net Thermal Efficiency: 42% (LHV)
- Plant System
  - Gasifier: Dry Feed Air-blown Entrained Flow Gasifier
  - Clean-up: MDEA Chemical Absorption
    Limestone-gypsum Method
  - Gas Turbine: 1200°C Class
- Project Funding: Electric Utility Companies 70%
  Government 30%
- Location: Nakoso, Fukushima
Research Activities of CRIEPI on Gasification Technology

1. Stable Operation at a High Performance
2. Expansion of Coal Types
3. Cost Reduction

Development of Tool to Optimize Design and Operation of Coal Gasifier

- Experimental Study for the Clarification of phenomenon in gasifier
- Numerical simulation technology
- Experimental study using Bench scale gasifier
- Basic properties and characterization of coal/ash

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Concept of Evaluation Tool for Design and Operation of Gasifier

Experimental Study
- Clarification and modeling of individual phenomenon
- Pressurized TG

Numerical Simulation
- Numerical analysis of phenomenon
- Evaluation of gasifier shape and scale, operating condition etc.

Analysis
- Clarification of coal/ash properties
- CCSEM
- High temperature DTA

Bench Scale Gasifier
- Reproduction of complex phenomenon in actual plant
- Development of special equipments for detailed measurement in gasifier

Pressurized DTF

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Numerical Simulation Technology for Coal Gasifier

Flow Field: Three-Dimensional Weakly Compressible
Solver/Scheme: Finite Volume Method
Hybrid Upwind Differencing Method
SIMPLEC Algorithm
Turbulence: $k-e$ 2 Equations Model
Gas Particle Flow: Eulerian-Lagrangian Method
Radiation: Discrete Transfer Method
Pyrolysis: $C_mH_nO_l \rightarrow (CH_4, H_2, CO, CO_2, H_2O)$
Gas Reactions:
- $CH_4 + 1/2 O_2 \rightarrow CO + 2 H_2$
- $H_2 + 1/2 O_2 \rightarrow H_2O$
- $CO + 1/2 O_2 \rightarrow CO_2$
- $CH_4 + H_2O \rightarrow CO + 3 H_2$
- $CO + H_2O \rightarrow CO_2 + H_2$
Char Gasification:
- $C + (1-f/2) O_2 \rightarrow f CO + (1-f) CO_2$
- $C + H_2O \rightarrow CO + H_2$
- $C + CO_2 \rightarrow 2 CO$
Computational Grid: Multi Block, Body Fitted Coordinates

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Outline of 2T/D Gasifier

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Simulation Results of 2T/D Gasifier

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Gasification Rate Analysis of Coal Char with a Pressurized Drop Tube Furnace

Temperature Max. 1800°C
Pressure Max. 2.5MPa
Gas Atmosphere Oxidation Reduction Inactive Gas
Fuel Feed Rate 30 ~ 500g/h
Gas Analysis MS, FT-IR, etc.

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Arrhenius Plots of Gasification Rate of Coal Chars

Reaction Rate Equation based on Random Pore Model

\[
\frac{dx}{dt} = A_0 \cdot P_A^n \cdot e^{-\frac{E}{RT}} \cdot (1-x) \cdot \sqrt{1-\Psi \cdot \ln(1-x)}
\]

Gas Constant: \( R = 8.314 \times 10^{-3} \) kJ/mol K

\( x \): Conversion Ratio [-], \( t \): Time [s], \( P_A \): Partial Pressure of Gasifying Agent [MPa], \( T \): Temperature [K]
Experimental Study using Bench Scale Gasifier

Capacity: 2.4 T/D
Pressure: 2 MPa
Operation: 1983-1995
Tested Coal: Over 20 types
Development of Air-blown Entrained Flow Gasifier

CRIEPI has been carrying out a series of R&D including the experiments using 2.4 T/D coal gasifier 1983-1995 in order to support the design and operation of IGCC Pilot Plant (200 T/D).

Specifications of 3T/D New Coal Gasifier

- Gasifier Type: Pressurized Entrained Flow
- Fuel Feed: Dry Feed System
- Fuel Capacity: 3 T/D
- Operating Pressure: 2 MPa
- Fuel Types: Coal (Including Low Rank Coal)
- Gasifying Agent: Air, Oxygen, Steam

CRIEPI constructed the new gasifier to develop advanced IGCC technologies required to commercialize IGCC. The construction of the new gasifier was completed in February, 2004 and the adjustment run began in March.
Feature of 3T/D Coal Gasifier

- Wide range of the gasifying condition is achieved by the change of the oxygen concentration of the gasifying agent and the steam addition.

- Detailed measurement of the gas temperature, gas composition, char composition in the gasifier and the heat flux to gasifier wall is possible.

- It is possible to evaluate slag discharging characteristics by three dimensional slag monitoring device.

- In the heat exchanger section, char deposition and heat transfer characteristics can be evaluated.

- Burner configuration is variable and effect on gasification performance can be evaluated.
## Properties of Tested Coal (Chinese Coal)

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<tr>
<th>Proximate, air dry</th>
<th>Moisture</th>
<th>%</th>
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<tr>
<td>Ash</td>
<td>%</td>
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<td>5.8</td>
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<tr>
<td>VM</td>
<td>%</td>
<td></td>
<td>33.3</td>
</tr>
<tr>
<td>FC</td>
<td>%</td>
<td></td>
<td>55.3</td>
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<tr>
<td>Total-S</td>
<td>%</td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>HHV</td>
<td>cal/g</td>
<td></td>
<td>6810</td>
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<tr>
<td></td>
<td>J/g</td>
<td></td>
<td>28510</td>
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<tr>
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<table>
<thead>
<tr>
<th>Ultimate, dry</th>
<th>Ash</th>
<th>%</th>
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<tr>
<td>C</td>
<td>%</td>
<td></td>
<td>77</td>
</tr>
<tr>
<td>H</td>
<td>%</td>
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<td>4.56</td>
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<tr>
<td>O</td>
<td>%</td>
<td></td>
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<tr>
<td>N</td>
<td>%</td>
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<tr>
<td>S</td>
<td>%</td>
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<tr>
<td>JIS-M8813</td>
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Example of Test Results

- Coal Feed Rate: 100 kg/h
  (Combustor/Reductor=40/60)
- Pressure: 2 MPa
- Gasifying Agent: Air
- Air Ratio: 0.54

Gas temperature in gasifier

<table>
<thead>
<tr>
<th>Air ratio</th>
<th>Combustor</th>
<th>Diffuser</th>
<th>Reducor 1</th>
<th>Reducor 2</th>
<th>Reducor 3</th>
<th>Reducor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
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<td>1594</td>
<td>1348</td>
<td>1115</td>
<td>1067</td>
<td>987</td>
<td>900</td>
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Composition of product gas

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<thead>
<tr>
<th></th>
<th>CO</th>
<th>vol.%</th>
<th>16.69</th>
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<tbody>
<tr>
<td></td>
<td>H2</td>
<td>vol.%</td>
<td>7.04</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>vol.%</td>
<td>8.85</td>
</tr>
<tr>
<td></td>
<td>H2O</td>
<td>vol.%</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>CH4</td>
<td>vol.%</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>N2</td>
<td>vol.%</td>
<td>60.15</td>
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<tr>
<td></td>
<td>Ar</td>
<td>vol.%</td>
<td>0.73</td>
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<tr>
<td></td>
<td>HHV, wet</td>
<td>kcal/m3N</td>
<td>780</td>
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<tr>
<td></td>
<td>HHV, dry</td>
<td>kcal/m3N</td>
<td>829</td>
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Main Testing Items of 3T/D Coal Gasifier

• Clarification of behaviors of fly ash and char in gasifier and heat exchanger to ensure stable plant operation at a high performance

• Establishment of monitoring system for stable discharge of molten slag

• Setting of plant operating parameters corresponding to each coal brand in order to obtain the optimal gas products

• Reducing of char production for the higher performance and cost down
Key Technology for the Future of Coal Gasification

*Global warming and Energy security*

- **Improvement of efficiency**
  - High temperature gas turbine
  - Improvement of steam condition
  - Hot gas cleanup technology
  - IGFC

- **Expansion of coal type**
  - Efficient use of low rank coal such as brown coals
  - Synthesis of liquid fuel from low rank coal (GtL, Co-production)

- **CCS**
  - Establishment of storage technology
  - Development of new technology for higher efficiency and lower cost