Oxyfuel retrofit to coal power plant (Part 1)
- FS of 500MW class plant

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1. Introduction

- Hitachi has been developing CO2 capturing technologies; oxy-fuel combustion, scrubbing, IGCC

- For Oxy-fuel combustion, Hitachi and Fortum are carrying out feasibility studies for retrofit of 500MW class coal fired boiler and combustion tests using 4MWth furnace.

Current Thermal Power Plant

- Step-1
- Step-2

CO2 Emission

2000 2020 2035 2050

High Efficiency

- 700C A-USC
- IGCC

CO2 Capturing

- OxyfuelCombustion
- Scrubbing
- IGCC-CO2

CCS approach of Hitachi
2.1 Development Subjects in Oxyfuel Combustion

This Study

Boiler
- High radiation intensity: CO₂, H₂O
- Same heat absorption to air combustion
- Reduce oxygen consumption
- Corrosion, Slagging, Fouling

AQCS: Air Quality Control System
- Keep SCR, EP, FGD performance
- Installation of gas cooler

ASU: Air Separation Unit
- Reduce initial cost
- Reduce power consumption
- Compact & low power

Mill outlet pipe
- Keep temperature 70 – 90°C
- Re-circulation line
- Reduce corrosive gas: SO₃

CPU: CO₂ Compression and Purification Unit
- Reduce corrosion potential (SO₃, Cl etc)
- Reduce power consumption
- Compact & low power

Re-circulation line
- Reduce corrosive gas: SO₃
- Reduce power consumption
- Compact & low power
2.2 Development Process

Fundamental study
- Laboratory test
- Basic combustion test (0.4MWth test facility)

Verification study
- Large scale combustion test (4MWth test facility)
- Total system check (1.5MWth test facility)

Feasibility study
- Trial design of actual plant Retrofit, New
- Cost evaluation

1) Trial design
- System flow (Process analysis)
- Equipments design (Numerical analysis)
- Control system (Dynamic analysis)

2) Cost evaluation
- Initial cost (Construction, Equipment)
- Running cost (Utility check)
### 2.3 Subjects and measures in Oxyfuel Combustion

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Subjects</th>
<th>Measures</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total system</td>
<td>Safety operation</td>
<td>Alert and protection system</td>
<td>Dynamic control analysis (MATLAB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat loss reduction</td>
<td>Optimization of gas recirculation point</td>
<td>Process Simulator (CHEMCAD)</td>
</tr>
<tr>
<td>2</td>
<td>Boiler (Combustion, Heat transfer)</td>
<td>Adapt to a current (air comb.) boiler to oxyfuel comb.</td>
<td>Same heat absorption to air combustion</td>
<td>Combustion test (0.4MWth, 4MWth)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burner stability</td>
<td>Burner development</td>
<td>Combustion test (4MWth)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mill stability</td>
<td>Reduction of mill line O2</td>
<td>bench scale mill test</td>
</tr>
<tr>
<td>3</td>
<td>AQCS</td>
<td>Adapt to a current (air comb.) AQCS to oxyfuel comb.</td>
<td>- Keep SCR, EP, FGD performance&lt;br&gt;- installation of gas cooler</td>
<td>Combustion test (0.4MWth, 1.5MWth)</td>
</tr>
<tr>
<td>4</td>
<td>Gas recirculation System</td>
<td>Anticorrosion</td>
<td>Reduce corrosive gas: SO₃</td>
<td>Process Simulator (CHEMCAD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Combustion test (4MWth, 1.5MWth)</td>
</tr>
<tr>
<td>5</td>
<td>ASU, CPU</td>
<td>Compact and low power</td>
<td>Capacity up</td>
<td>Feasibility study</td>
</tr>
</tbody>
</table>
3.1 System Analysis Method (Process Simulator)

Material and Heat Balance Evaluation by Modeling Oxy-fuel Combustion System

<table>
<thead>
<tr>
<th>Utility</th>
<th>Unit Operation</th>
<th>Approach to Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler</td>
<td>Gibbs reactor, Heat exchanger</td>
<td>SPEC.: Eco outlet gas temperature (364deg-C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CALC.: Adiabatic flame temperature, Boiler heat input</td>
</tr>
<tr>
<td>Air Heater</td>
<td>Heat Exchanger</td>
<td>SPEC.: Heat transfer area, Overall heat transfer coefficient.</td>
</tr>
<tr>
<td>Cooler</td>
<td>Heat Exchanger</td>
<td>SPEC.: Outlet gas temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CALC.: Heat exchanger duty</td>
</tr>
<tr>
<td>EP</td>
<td>Component Separator</td>
<td>Dust removal (99%)</td>
</tr>
<tr>
<td>FGD</td>
<td>Mixer, Component Separator, Flash</td>
<td>Desulfurization rate (95%), Evaporation, Vapor-Liquid separation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-in view point of boiler output, SO3 content, ash, gas cooler power and FGD handling gas amount</td>
</tr>
</tbody>
</table>
3.1 System Analysis Method (FGD modeling)

- Essential unit operations were chosen from CHEMCAD defaults
- FGD model is configured by connecting them

FGD (limestone-gypsum process)

- Lime-stone slurry
- Oxidant (air)
- Flue gas (90°C, SO2 Rich)
- Saturated by water

Clean gas
(95% S removal, water vapor
Saturation 72°C)

Component Separator
95% (partition coefficient) SO2 removal

Flash liquid-vapor separation

SO2 absorbed by spraying slurry, oxidized, neutralized and fixed as gypsum

FGD Model on CHEMCAD

Water
Mixing
Component Separator
Flash
Clean gas

90°C
## 3.1 Case studies

![Diagram of a power plant process flow](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Oxidant</th>
<th>GR point (@exit)</th>
<th>+Cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2ry(Combustion Air)</td>
<td>P'ry(Mill Air)</td>
</tr>
<tr>
<td>A-1</td>
<td>Air</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>O-1</td>
<td>Oxygen</td>
<td>EP</td>
<td>EP</td>
</tr>
<tr>
<td>O-2</td>
<td>↓</td>
<td>EP</td>
<td>EP</td>
</tr>
<tr>
<td>O-3</td>
<td>↓</td>
<td>EP</td>
<td>FGD</td>
</tr>
<tr>
<td>O-4</td>
<td>↓</td>
<td>FGD</td>
<td>FGD</td>
</tr>
<tr>
<td>O-5</td>
<td>↓</td>
<td>Eco</td>
<td>FGD</td>
</tr>
<tr>
<td>O-6</td>
<td>↓</td>
<td>Eco</td>
<td>Wet-EP</td>
</tr>
<tr>
<td>O-7</td>
<td>↓</td>
<td>EP</td>
<td>EP</td>
</tr>
<tr>
<td>O-8</td>
<td>↓</td>
<td>EP</td>
<td>FGD</td>
</tr>
<tr>
<td>O-9</td>
<td>↓</td>
<td>Eco</td>
<td>EP</td>
</tr>
<tr>
<td>O-10</td>
<td>↓</td>
<td>Eco</td>
<td>FGD</td>
</tr>
</tbody>
</table>

*GR: Gas recirculation*
3.2 Result of FS(1) ; Selected System Flow

(1) Same boiler output to air combustion
(2) LP turbine power increases because cooler preheats feed water
(3) SO₃ removal with 90 deg-C cooler

Case O-7
3.2 Result of FS(2) ; SO₃ Removal

- Below acid dew point (<160°C), SO₃ in flue gas changes to mist
- Mist sticks to ash and are neutralized by alkali contained in ash
- Ash are caught with EP

Location of gas cooler

SO₃ Concentration (\(\cdot\))

<table>
<thead>
<tr>
<th>SCR Outlet</th>
<th>EP Inlet</th>
<th>EP Outlet</th>
<th>FGD Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>with Cooler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without Cooler</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Result of FS(3) : Air Leakage

ASU : Specific energy of production=0.35kWh/Nm³-O₂ [@0°C,1atm] , CPU : CO2 recovery 90%
### 3.2 Result of FS(4) : Efficiency

<table>
<thead>
<tr>
<th>Co.</th>
<th>System Flow</th>
<th>Heat Transfer</th>
<th>SO$_3$</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHK (O-7R)</td>
<td><img src="image1.png" alt="Flow Diagram" /></td>
<td>1183</td>
<td>&lt; 5</td>
<td>30</td>
</tr>
<tr>
<td>Others (O-3)</td>
<td><img src="image2.png" alt="Flow Diagram" /></td>
<td>1163</td>
<td>&lt; 5</td>
<td>10</td>
</tr>
</tbody>
</table>
3.3 Numerical simulation(1); Tool (CRAFT)

Original simulation models
1. Char gasification model
2. Hydrocarbon NOx reduction model
3. Multi-grid discrete transfer radiation model

CRAFT:
Combustion, Radiation and water
Flow simulation
Tool

Predicted performances lead to technical solutions
- Temp.
- CO
- NOx
- Heat Flux
- VOC emission
- Unburned carbon
- Burner blowing off
- Furnace exit gas temperature
- Slagging
- H_{2}S and SO_{2} corrosion
Comparison between air combustion and oxy-fuel combustion. Parameter: $O_2$ concentration 21-35vol\%wet
3.3 Numerical simulation (3);

Structure

Grid of the analysis

XYZ = 20 × 70 × 132: 184,800
### 3.3 Numerical simulation(4); Coal

<table>
<thead>
<tr>
<th>(1) HHV</th>
<th>kJ/kg</th>
<th>26,691</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) Proximate analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total moisture</td>
<td>WT%wet</td>
<td>11.80</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>WT%wet</td>
<td>46.80</td>
</tr>
<tr>
<td>Volatiles</td>
<td>WT%wet</td>
<td>32.50</td>
</tr>
<tr>
<td>Ash</td>
<td>WT%wet</td>
<td>8.90</td>
</tr>
<tr>
<td>(3) Ultimate analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>WT %dry</td>
<td>81.99</td>
</tr>
<tr>
<td>H</td>
<td>WT %dry</td>
<td>5.62</td>
</tr>
<tr>
<td>O</td>
<td>WT %dry</td>
<td>9.94</td>
</tr>
<tr>
<td>N</td>
<td>WT %dry</td>
<td>0.87</td>
</tr>
<tr>
<td>S</td>
<td>WT %dry</td>
<td>1.58</td>
</tr>
</tbody>
</table>
Oxyfuel combustion at $O_2=27 \sim 30$ vol%-wet take same heat absorption as Air.

<table>
<thead>
<tr>
<th>$O_2$ (vol%)</th>
<th>Air combustion</th>
<th>Oxyfuel combustion (wet GR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21</td>
<td>21 27 35</td>
</tr>
<tr>
<td>FEGT (deg-C)</td>
<td>1163</td>
<td>1104 1163 1202</td>
</tr>
<tr>
<td>$T$ (deg-C)</td>
<td>1800</td>
<td>1800 1800 1800</td>
</tr>
</tbody>
</table>
3.3 Numerical simulation(6); Heat Flux

Air combustion > Oxy-fuel combustion at $O_2$: 27vol%wet

![Graph comparing heat flux for Air combustion and Oxy-fuel combustion at $O_2$: 27vol%wet.](image)
3.3 Numerical simulation(7); Heat Absorption

Air combustion ≡ Oxy-fuel combustion at $O_2$:27vol%wet
### 3.4 Safety Operation at Oxy-Fuel Combustion

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Malfunction</th>
<th>Problem</th>
<th>Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O2 / Primary gas ratio (O2 concentration)</td>
<td>Too high</td>
<td>Fire in mill</td>
<td>According to deviation from set value, alert and protection actions will be initiated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Too low</td>
<td>Flame instability</td>
<td>1. Alert</td>
</tr>
<tr>
<td>2</td>
<td>O2 / Comb. gas ratio (O2 concentration)</td>
<td>Too high</td>
<td>Undesired combustion</td>
<td>2. Interlock action (Trimming O2 flow or recirculation gas flow)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Too low</td>
<td>Flame instability</td>
<td>3. MFT (Shut down of fuel and O2 supply)</td>
</tr>
<tr>
<td>3</td>
<td>FDF</td>
<td>Trip</td>
<td>High O2 concentration in primary gas and combustion gas consequently fire in mill and undesired combustion</td>
<td>MFT (Shut down of fuel and O2 supply)</td>
</tr>
<tr>
<td>4</td>
<td>PAF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IDF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MFT: Master fuel trip

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**Diagram:**

- **Coal**
- **Mills**
- **AAP**
- **Cooler**
- **EP**
- **IDF**
- **FGD**
- **PAF**
- **MOX**
- **ASU**
- **CPU**
- **Storage**
- **Flow fluctuation at changing Air to Oxy**
- **Higher O2**
- **Higher Gas temperature**
- **Air**
NOx removal efficiency under oxy-fuel combustion was slightly lower than that under air combustion.
SO₂ removal efficiency at a given L/G decreased under oxy-fuel combustion because of the higher slurry temperature and SO₂ concentration. However, higher removal efficiency can be expected at a given coal due to less flue gas volume.
3.6 Plant Layout

<table>
<thead>
<tr>
<th>Items</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal flow rate</td>
<td>t/h</td>
</tr>
<tr>
<td>Oxygen flow rate</td>
<td>t/h</td>
</tr>
<tr>
<td>Treatment gas flow rate</td>
<td>t/h</td>
</tr>
</tbody>
</table>

- Coal flow rate: 150 t/h
- Oxygen flow rate: 310 t/h
- Treatment gas flow rate: 520 t/h
4. Conclusion

- To establish suitable oxy-fuel combustion system for existing 500MW class plant, feasibility studies have been conducted.

- Suitable systems were proposed based on heat balance calculation results using process simulation software CHEMCAD.

- Key points of case studies are that checking system performance in view point of boiler output, SO₃ content, ash, gas cooler power and FGD handling gas amount.

- Among studied cases, recommended system is as follows;
  - Gas extraction point is from 2ry:EP outlet and
  - Pry: FGD outlet, cooler temperature: 90 C.
5. Future Works

- Reliability study of proposed system using 1.5MWth one-through combustion and AQCS test facility.
- Mill performance
- Total heat balance
- Dynamic control simulation
5. Future Work: 1.5MWth Combustion and AQCS Test Facility

Test items
1. AQCS system check
2. Recycle gas line corrosion potential
3. SOx, NOx and other acid gas control
4. Total system of oxy-fuel combustion
The objective is to evaluate the mill performance represented by the mill power and the pressure drop of mill in CO$_2$. These values are compared with those of air atmosphere of the primary gas.

**Bench scale mill facility**

**Mill**

**CO$_2$ supply system**
(Max.300kg/h CO$_2$ gas)

**Photos of bench-scale mill facility and CO$_2$ supply system**
Future Work: Total Heat Balance

3D-model for heat recovery area

Comb. simulator ‘CRAFT’

Water wall network model

Fig. 2.5.10 Schematic of BTG system calculator ‘Virtual Boiler’
Future Work: Dynamic analysis model
(ACTUALISE-MATLAB)
Thank you for your attention

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