Process Integration in Coal based Oxy-Combustion Power Plants

Chao Fu, Truls Gundersen

Department of Energy and Process Engineering (EPT), Norwegian University of Science and Technology (NTNU), Trondheim, Norway
Thermal efficiency penalty for oxy-combustion*

- Air fired case: 39.8% (HHV: higher heating value)
- Oxy-combustion case: 29.8%

An expected target (by the year 2020): penalty < 6% points

- Optimal design of CO₂-enriched boilers: O₂ excess, recycling of flue gas
- Technology shift for ASU: membrane separation
- Process integration (PI): optimal design of ASU and CPU, heat integration

*Chao Fu, Truls Gundersen. Submitted to Energy&Fuels, 2013
PI study on the compression heat

• Compression heat: removed by cooling water and wasted

• Possible ways for utilizing compression heat
  - Regeneration of molecular sieves in the ASU and the CPU
  - Preheating recycled flue gas
  - Preheating boiler feedwater in the steam cycle

• Challenges for the integration study
  - Optimal supply and target temperatures of the compressed gases
  - Reasonable temperature differences in gas/water heat exchangers
  - New configuration of the steam cycle (steam extraction, feedwater heaters, steam preheating process)
  - Varying compressor efficiency
  - Site location and investment cost
Decompose the heat loads
Illustration of heat contribution (e.g. FWH2)

N28: steam from SSR

N26: steam extracted

N25: steam condensate

N24: steam condensate

N4 & N5: BFW
Integrating the ASU with the steam cycle

• Case studies:
  - Case 1: three-stage compression (“isothermal” compression)
  - Case 2: two-stage compression
  - Case 3: one-stage compression (adiabatic compression)

• Steps for the integration:
  (1) Calculate the supply temperature of compression heat
  (2) Draw the Grand Composite Curve (GCC) that includes compression heat and the heating demand of boiler feedwater
  (3) Calculate the demand for steam extraction
  (4) Further cooling of the compressed gases by cooling water
Case 1: three-stage compression

1.01 bar, 25°C
1.77 bar, 88.9°C
1.77 bar, 35°C
3.13 bar, 101.1°C
3.13 bar, 35°C
3.13 bar, 101.1°C
5.6 bar, 35°C
5.6 bar, 35°C

Heat demands

<table>
<thead>
<tr>
<th></th>
<th>Without integration</th>
<th>With integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWH1</td>
<td>35432</td>
<td>0</td>
</tr>
<tr>
<td>FWH2</td>
<td>36427</td>
<td>6691</td>
</tr>
<tr>
<td>FWH3</td>
<td>38957</td>
<td>31085</td>
</tr>
</tbody>
</table>
New decomposed heat loads (e.g. FWH2)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Temperature</th>
<th>Heat Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>N28</td>
<td>383.5°C</td>
<td>6691 kW</td>
</tr>
<tr>
<td>N26</td>
<td>97.4°C</td>
<td>2673 kW</td>
</tr>
<tr>
<td>N25</td>
<td>81.5°C</td>
<td>1129 kW</td>
</tr>
<tr>
<td>N24</td>
<td>81.5°C</td>
<td>2858 kW</td>
</tr>
<tr>
<td>N5</td>
<td>81.5°C</td>
<td>44611 kW</td>
</tr>
<tr>
<td>N4</td>
<td>81.5°C</td>
<td>44611 kW</td>
</tr>
<tr>
<td>N4</td>
<td>84.1°C</td>
<td>66.6°C</td>
</tr>
<tr>
<td>N4</td>
<td>66.6°C</td>
<td>66.6°C</td>
</tr>
</tbody>
</table>

**Compression heat is added**

**Steam flow is reduced**

**Condensate flows**

- Blue: Boiler feed water
- Green: Steam
- Red: Compression heat
New heat balance after integration

Heat balance is achieved when the compression heat is added

- **Boiler feed water**
- **Steam**
- **Compression heat**
The new preheating process

- LP Generator
- FWH4
- FWH3
- FWH2
- FWH1
- Gland Seal
- Condenser
- Condensate Pump
- Gland Seal Condenser
- N1, N2, N3, N4, N5, N6, N7, N24, N25, N26, N28, N29, N30, N31, N32, N33, N34
- N4-1, N4-2
- To Flue Gas Recycle Reheater
- From Flue Gas Recycle Reheater
- Ambient Air
- Compressed Air
- Cooling Water
- Cooling Water
- 25°C
- 35°C
- 101.1°C
- 88.9°C
- 76.6°C
- 56.8°C
- 101.1°C
- 25°C
- 88.9°C
- 101.1°C
- 35°C
- 101.1°C
- 101.1°C
- 25°C
- 88.9°C
- 76.6°C
- 56.8°C
- 101.1°C
Integrating the ASU with the steam cycle (continued)

**Case 2: two-stage compression**

- The compression heat can be used in FWH1-4

**Case 3: one-stage compression (adiabatic)**

- The compression heat can be used in FWH1-4 and FWH6-7
## Heat integration opportunities

<table>
<thead>
<tr>
<th>Cases</th>
<th>Work in the ASU, kW</th>
<th>Work in the CPU, kW</th>
<th>Gross power, kW</th>
<th>Net power output, kW</th>
<th>Thermal efficiency (HHV), % points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air fired case without CO₂ capture</td>
<td>0</td>
<td>0</td>
<td>585,228</td>
<td>553,563</td>
<td>39.75</td>
</tr>
<tr>
<td>Base case</td>
<td>124,005</td>
<td>69,315</td>
<td>791,953</td>
<td>560,017</td>
<td>29.81</td>
</tr>
<tr>
<td>“Isothermal” compression in the ASU and CPU</td>
<td>119,029</td>
<td>63,813</td>
<td>791,953</td>
<td>570,495</td>
<td>30.37</td>
</tr>
<tr>
<td>Case 1 (three-stage in the ASU: “isothermal”)</td>
<td>119,029</td>
<td>63,813</td>
<td>799,133</td>
<td>577,675</td>
<td>30.75</td>
</tr>
<tr>
<td>Case 2 (two-stage in the ASU: base case)</td>
<td>124,005</td>
<td>63,813</td>
<td>804,512</td>
<td>578,078</td>
<td>30.77</td>
</tr>
<tr>
<td>Case 3 (one-stage in the ASU: adiabatic)</td>
<td>140,038</td>
<td>63,813</td>
<td>821,730</td>
<td>579,263</td>
<td>30.84</td>
</tr>
<tr>
<td>Case 4 (CPU: “isothermal”)</td>
<td>119,029</td>
<td>63,813</td>
<td>797,032</td>
<td>575,574</td>
<td>30.64</td>
</tr>
<tr>
<td>Case 5 (CPU: adiabatic)</td>
<td>119,029</td>
<td>75,329</td>
<td>806,535</td>
<td>573,561</td>
<td>30.53</td>
</tr>
<tr>
<td>Case 6 (ASU: adiabatic; CPU: “isothermal”)</td>
<td>140,038</td>
<td>63,813</td>
<td>827,654</td>
<td>585,187</td>
<td>31.15</td>
</tr>
</tbody>
</table>

- **Favourable compression:**
  - Adiabatic for the ASU
  - “Isothermal” for the CPU

- **The maximum improvement by heat integration:** 0.78% points
Further work

• Mathematical optimization models for heat integration

• Benchmarking study (thermodynamic, technical and economic limitations) - A targeting approach

• Assessment of advanced CO₂ recovery methods
  - PSA separation of CO₂ + inert gases recycled to the ASU
  - Membrane separation of CO₂ + inert gases recycled to the burner
Conclusions

• For a coal based oxy-combustion power plant:
  - the thermal efficiency penalty related to CO₂ capture is around 10% points
  - the theoretical minimum is around 3.4% points

• Integrating the compression heat with the steam cycle:
  - “maximum” gain in thermal efficiency: 0.78% points

• A mathematical model is being developed for further heat integration studies

Acknowledgements

This publication has been produced with support from the BIGCCS Centre, performed under the Norwegian research program Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Aker Solutions, ConocoPhillips, Gassco, Shell, Statoil, TOTAL, GDF SUEZ and the Research Council of Norway (193816/S60).

More details: chao.fu@ntnu.no