Energy Management and Efficiency Improvement for Oxy-fuel Power Generation Systems with CO$_2$ Capture: An Exergy-based Approach

3rd Oxyfuel Combustion Conference

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Agenda

- Background and Motivation
- Power Generation and CO$_2$ Capture
- Integrated Oxy-fuel Power Generation System
- Process Simulation and Integration
- Exergy Analysis
- Results
- Conclusions
Power Generation and CO₂ Capture

- Fossil Fuel Power Generation with Carbon Capture & Storage (CCS)

**Post-Combustion Technology**

- Air-Combustion
  - Power & Heat
  - CO₂ Capture
  - Flue gas 5-15% CO₂

**Pre-Combustion Technology**

- Gasification
  - Syngas 20-40% CO₂
  - CO₂ Capture
  - H₂
  - Combustion
  - Power & Heat
  - CO₂ Compression and Transport for Storage

**Oxy-Combustion Technology**

- Oxy-Combustion
  - Power & Heat
  - Flue gas >80% CO₂
  - CO₂ Capture
  - CO₂
Oxy-fuel Power Generation

- Integrated Oxy-fuel Power Generation System with CO₂ Capture

Diagram:
- Air Separation Unit (ASU)
- Boiler
- Flue Gas
- N₂, Ar
- Air
- Fuel (Coal)
- O₂
- Oxy-fuel Combustion and Boiler Section
- Flue Gas Recycle
- Process Condensate
- Generator
- Condenser
- Flue Gas Polishing
- Multi-Stage CO₂ Capture & Compression Unit
- CO₂ Capture and Compression Unit
- Balance of Plant (BOP)
Proposed Approach

Robust modeling with a systematic exergy analysis to identify the optimum options for process integration to achieve maximum energy efficiency. The approach involves the following steps:

1. Develop a model of an integrated oxy-fuel power plant comprised of a combustion boiler, flue gas section, BOP, ASU and CO$_2$ capture and compression unit (CO$_2$CCU);

2. Perform an exergy analysis to identify the quantity and location of exergy losses;

3. Minimize the exergy destruction rate; and,

4. Perform a sensitivity analysis to investigate the effect of fuel type and other relevant process parameters on the process.
Process Simulation, Modeling and Integration

- **Steady state process modeling:**
  - Power plant capacity: $786 \text{ MW}_\text{gross}$
  - Types of coal used: “lignite” and “bituminous”
  - Boiler, BOP, ASU, and CO$_2$CCU are coupled to form an integrated model
  - Aspen HYSYS process simulation platform

- **Advantages of the proposed model:**
  - Scale-up/scale-down of the integrated model is instantaneous
  - Sensitivity analysis is instantaneous
  - User friendly interface to change input parameters
Integrated Model Development

ASU (Air Separation Unit)

Balance of Plant (BOP)

CO2 Capture and Compression Unit (CO2CCU)

N2

Ar

O2

Flue Gas

Fuel (Coal)

Oxy-fuel Combustion and Boiler Section

Impurities

Process Condensate

Input/Output Block
ASU and BOP Models in Aspen HYSYS

**ASU Model**

- ASU (Air Separation Unit)
- Boiler
- Flue Gas
- N₂
- Ar
- Air
- Fuel (Coal)
- FGD / Flue gas Polishing
- Multi-Stage CO₂ Capture & Compression Unit
- CO₂ Generator
- O₂
- Flue Gas Recycle
- Turbine
- Boiler Feed Pump (BFW)
- Condenser
- Process Condensate
- Dry-Salt Combustion and Boiler Section

**BOP Model**

- ASU (Air Separation Unit)
- Boiler
- Flue Gas
- N₂
- Ar
- Air
- Fuel (Coal)
- FGD / Flue gas Polishing
- Multi-Stage CO₂ Capture & Compression Unit
- CO₂ Generator
- O₂
- Flue Gas Recycle
- Turbine
- Boiler Feed Pump (BFW)
- Condenser
- Process Condensate
- Dry-Salt Combustion and Boiler Section
Oxy-fuel Boiler Section and CO₂CCU Models

Boiler Section Model

CO₂CCU Model

CanmetENERGY
Main Input Parameters

- Plant capacity
- Coal composition
- Cooling water temperature
- Environment condition for exergy analysis

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<tr>
<th>Lignite Coal composition</th>
<th>BOP Parameters</th>
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<tbody>
<tr>
<td><strong>Coal Parameters</strong></td>
<td><strong>Stream Parameters</strong></td>
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<tr>
<td>Component</td>
<td>Value</td>
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<tr>
<td>Carbon</td>
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<td>Hydrogen</td>
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<td>Sulphur</td>
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<td>LHV (as received)</td>
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### Results: Exergy Analysis for Boiler and BOP Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Power Generation</th>
<th>Power Consumption</th>
<th>Exergy Destruction</th>
<th>Exergy Efficiency</th>
<th>Exergy Destruction Percent</th>
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<tr>
<td></td>
<td>kW</td>
<td>kW</td>
<td>E_in (kW)</td>
<td>E_out (kW)</td>
<td>J (kW)</td>
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### BOP Model

### Boiler Model

Exergy destruction ranking in boiler

R1  
R2  

Leadership in ecoInnovation
Results: Exergy Analysis of the ASU and CO₂CCU Components

### ASU Model

<table>
<thead>
<tr>
<th>Component</th>
<th>Power Generation (kW)</th>
<th>Power Consumption (kW)</th>
<th>Exergy Destruction (kW)</th>
<th>Exergy Efficiency</th>
<th>Exergy Destruction Percent (%)</th>
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<tr>
<td>Compr CV 301</td>
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<td>47052</td>
<td>129382</td>
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<td>Dryer CV 302</td>
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<td>LNG CV 303</td>
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### CO₂CCU Model

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<tr>
<th>Component</th>
<th>Power Generation (kW)</th>
<th>Power Consumption (kW)</th>
<th>Exergy Destruction (kW)</th>
<th>Exergy Efficiency</th>
<th>Exergy Destruction Percent (%)</th>
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<tr>
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<td>Expander K106</td>
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</table>
Process Improvements: sample result for boiler

- All the exergy destruction in all sections are ranked.
- PC Boiler Section exergy analysis indicates that the process gas cooler (PGC 1) has some potential to improve exergy after the main boiler as the exergy destruction rate is ranked “2” in the PGC 1.
- Integrating a Close Cooling Water (CCW) Loop in PG Cooler 1 in Boiler section and the 1\textsuperscript{st} Air Cooler in ASU section will save net electrical power of 350 kW.
- This integration decreases the load on the cooling water loop significantly for the Boiler section.
- Improvements in other sections will also be significant when the overall process improvement and integration will be completed.
Summary of Findings

- **BOP**: The maximum exergy destruction occurs in the turbine island (59%) and the Steam Condenser (22%)
- **Boiler**: All exergy destruction occurs in the Combustion boiler (99%)
- **ASU**: The low pressure distillation column accounts for most of the exergy destruction (58%)
- **CO₂CCU**: Most exergy destruction occurs in the medium pressure compressor island (48%)
Conclusions

- An integrated model of an oxy-fuel power plant including BOP, Boiler, CO$_2$CCU and ASU was developed.
- Exergy analysis was used to analyse the performance of the plant.
- Major exergy destruction pathways were identified and quantified.
- Research work is ongoing to identify the best approach to mass and energy integration to achieve maximum exergy efficiency.
Acknowledgement

- This research work was funded by the “Program of Energy Research and Development (PERD)”, Natural Resources Canada.
Reference-BOP
Air Separation Unit
550n/786g Oxy-fuel plant
Reference - CO2CCU