IPRO 302 –
Analysis of Water Recovery from Power Plants for Recycling

Final Presentation
December 5, 2008

Presented by:
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Dave Malon
Sponsor

Sponsor Contacts:
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Dave Stopec
Problem

- Analyze different methods of removing water from flue gas after coal combustion (750 MW plant)
- Why? Limited water resources in various locations around the country that require water for pollution control
SO₂ Pollution Control & Purpose

FGD (Flue Gas Desulfurization)

- Reaction occurs between Limestone and SO₂
Objectives

- Analyze and Cost different methods for removing water
- Determine:
  - Rate of $H_2O$ consumption from FGD
  - Amount of $H_2O$ produced for each technology
  - Cost of $H_2O$ produced ($/1000gal H_2O$)
  - Quality of water recovered
Organization

TEAM LEADER
Don Dornbusch (CHE)

DIRECT CONTACT TEAM
Alex Kolbasov (MMAE)
Sithambara Kuhan (CHE)
Jesse Reinhardt (BIOCHEM)
Sajid Ali Khan (MMAE)

INDIRECT CONTACT TEAM
Dave Malon (CHE)
McLain Hubbard (MMAE)
Wai Kit Ong (CHE)
Kwong Hann Tan (MMAE)

Don Chmiewlewski
Faculty Advisors
Myron Gottlieb
Project Planning

- Establishing common goals
  - Quality of Work
  - Ethical Research
- Team Code of Conduct
  - Honest, Reliable, Respectful
- Project Schedule
  - Dates for Achievements
  - Allow for Adjustments
Related Projects

- Various Separation Techniques
  - Desiccant *Siemens*
  - Spray Towers (Used in FGD)
  - Heat Exchanger *US Department of Energy (DOE)*
Spray Tower

- Advantages
  - Simple maintenance
  - Low risk of fouling and corrosion
  - Low pressure drop
# Design Parameters

<table>
<thead>
<tr>
<th>Part</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>Height</td>
<td>7 meters</td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>2 meters</td>
</tr>
<tr>
<td></td>
<td>Primary Material for Construction</td>
<td>Carbon Steel</td>
</tr>
<tr>
<td>Nozzles</td>
<td>Type</td>
<td>Flat cone</td>
</tr>
<tr>
<td></td>
<td>Droplet diameter</td>
<td>750 microns</td>
</tr>
<tr>
<td></td>
<td>Operating flow rate</td>
<td>9000 gpm/nozzle</td>
</tr>
<tr>
<td></td>
<td>Operating pressure</td>
<td>470 psi</td>
</tr>
<tr>
<td>Pump</td>
<td>Type</td>
<td>Condensate pump</td>
</tr>
<tr>
<td></td>
<td>Total flow rate</td>
<td>90000 gpm</td>
</tr>
<tr>
<td></td>
<td>Power requirements</td>
<td>8995 HP</td>
</tr>
<tr>
<td>Cost</td>
<td>Capital Cost</td>
<td>$218,000</td>
</tr>
<tr>
<td></td>
<td>Annual Operating Cost</td>
<td>$3,273,400</td>
</tr>
</tbody>
</table>
Obstacles

- Wide array of variables
- Lack of literature to compare assumptions
- Use of spray systems for pollution control processes rather than cooling
- Low tolerance to pressure drops
Indirect Contact Team

Condensers

Direct Contact
- Pool
- Spray
- Packed column

Indirect Contact
- Shell-and-tube
- Extended surface

Process industry
- Tube-fin air-cooled condenser

Power industry
- Surface condenser
- Feedwater heater

E
- One pass shell

G
H
J
X

Total condensation
- Reflux
- Knockback
Compact Shell-and-Tube Heat Exchanger

\[ h_i A_i \approx h_o A_o \]

- Heat transfer coefficient
- Heat transfer area
- Tube-side
- Shell-side

- Large surface-to-volume ratio
- Increased contact with flue gas
- Largest average temperature difference
- Minimized thermal stress
- Overall cost, weight, volume savings
Design

Q = UAΔT
Overall heat transfer coefficient, U = 700 W/m²°C
Corrected temperature difference, ΔT = 10.7 °C
Heat removed, Q = 2.010x10⁸ W
Area required, A = 26832 m²

Fan power required = 4320 kW
Pump power required = 678 kW
## Design Parameters

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<tr>
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<th>Tube-side</th>
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<tbody>
<tr>
<td><strong>Fluid</strong></td>
<td>Flue Gas</td>
<td>Water</td>
</tr>
<tr>
<td><strong>Total Flow [kg/h]</strong></td>
<td>4,017,500</td>
<td>20,124,000</td>
</tr>
<tr>
<td><strong>Vapor (in/out) [kg/h]</strong></td>
<td>4,017,500</td>
<td>3,750,000</td>
</tr>
<tr>
<td><strong>Liquid (in/out) [kg/h]</strong></td>
<td>0</td>
<td>267,500</td>
</tr>
<tr>
<td><strong>Temperature (in/out) [°F]</strong></td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td><strong>Heat Duty [kJ/h]</strong></td>
<td></td>
<td>7,235,000</td>
</tr>
<tr>
<td><strong>Area [m²]</strong></td>
<td></td>
<td>26,832</td>
</tr>
<tr>
<td><strong>Capital Cost [US$]</strong></td>
<td></td>
<td>836,939¹</td>
</tr>
<tr>
<td><strong>Annual Operating Cost [US$]</strong></td>
<td>Fan 2,649,004</td>
<td>Pump 415,955</td>
</tr>
</tbody>
</table>

¹ Corrected 2008 value – CE index 746.4
That’s 5 Football Fields!
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</tr>
<tr>
<td><strong>Annual Operating Cost [US$]</strong></td>
<td>Fan</td>
<td>2,649,004</td>
</tr>
</tbody>
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\(^{1}\) Corrected 2008 value – CE index 746.4
Obstacles

- Heat exchanger information not readily available
- Determining actual overall heat transfer coefficient
- Sizing of heat exchanger
  - Tubes
    - Diameter, thickness, length
  - Fins
    - Thickness, height, number of fins per inch
Results and Recommendations

- Indirect heat exchange is more cost effective overall (neglecting maintenance costs due to fouling and corrosion)

Indirect cost: $1.35/m³
Direct cost: $1.39/m³

Environment Canada 2008 Data
# Economics

<table>
<thead>
<tr>
<th>Cost</th>
<th>Direct Contact (US$)</th>
<th>Indirect Contact (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>218,000</td>
<td>836,939</td>
</tr>
<tr>
<td>Operational Cost</td>
<td>3,273,400</td>
<td>3,064,959</td>
</tr>
<tr>
<td>Annualized Cost</td>
<td>3,299,500</td>
<td>3,165,392</td>
</tr>
<tr>
<td>Cost per 1000 Gallons H₂O Recovered</td>
<td>5.28</td>
<td>5.10</td>
</tr>
</tbody>
</table>
Quality of Water Recovered

Temperature = 85 °F  
Pressure = 1 atm

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass Flows (kg/h)</th>
<th>Mass Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>268,000</td>
<td>99.67</td>
</tr>
<tr>
<td>Oxygen</td>
<td>854.72</td>
<td>0.32</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>28.144</td>
<td>0.01</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.8981</td>
<td>0.00</td>
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<tr>
<td>Sulfur Dioxide</td>
<td>0.1782</td>
<td>0.00</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.00265</td>
<td>0.00</td>
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<tr>
<td>Argon</td>
<td>0.000462</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>268,406</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Ethical Issues

- Concerns
  - Environmental impact
  - Economics & Resource management
  - Societal impact
  - Sponsor’s needs

- Responsibilities
  - Intra-group
  - Inter-communal
Conclusions

- Was enough water produced for FGD? YES
- Was the price competitive? NO

Feasible?

- Only under restrictive circumstances (ex. scarce resources)
Recommendations

• Analyze other technologies

• Only apply one of our methods when resources are scarce.
IPRO 302 – Analysis of Water Recovery from Power Plants for Recycling

Questions/Comments?
References


# Chemical Engineering Plant Cost Index (CEPCI)

(1957-59 = 100)

<table>
<thead>
<tr>
<th></th>
<th>Aug.'08 Prelim.</th>
<th>Jul.'08 Final</th>
<th>Aug.'07 Final</th>
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<tbody>
<tr>
<td><strong>CE INDEX</strong></td>
<td></td>
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</tr>
<tr>
<td>Equipment</td>
<td>619.3</td>
<td>608.8</td>
<td>531.5</td>
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<tr>
<td>Heat exchangers &amp; tanks</td>
<td>761.0</td>
<td>746.4</td>
<td>632.9</td>
</tr>
<tr>
<td>Process machinery</td>
<td>734.2</td>
<td>760.1</td>
<td>602.9</td>
</tr>
<tr>
<td>Pipe, valves &amp; fittings</td>
<td>680.6</td>
<td>669.5</td>
<td>601.5</td>
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<tr>
<td>Process instruments</td>
<td>881.5</td>
<td>875.5</td>
<td>747.4</td>
</tr>
<tr>
<td>Pumps &amp; compressors</td>
<td>457.8</td>
<td>459.0</td>
<td>428.6</td>
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<tr>
<td>Electrical equipment</td>
<td>872.9</td>
<td>869.9</td>
<td>836.1</td>
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<tr>
<td>Structural supports &amp; misc</td>
<td>468.1</td>
<td>468.2</td>
<td>434.5</td>
</tr>
<tr>
<td>Construction labor</td>
<td>843.9</td>
<td>815.8</td>
<td>669.9</td>
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<tr>
<td>Buildings</td>
<td>325.1</td>
<td>322.1</td>
<td>317.4</td>
</tr>
<tr>
<td>Engineering &amp; supervision</td>
<td>529.7</td>
<td>521.5</td>
<td>478.6</td>
</tr>
</tbody>
</table>

Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics.
Project Sponsor:

Informational Resources:
Calculations