Combustion Optimization of Panshan Unit 4 for Energy Savings & NO\textsubscript{x} Emissions Reduction

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Panshan Plant, Datang Int. Power Generation
Outline

- About Xi’an Xingyi
- Introduction
- Combustion Optimization
- ERC Approach and Boiler OP
- Panshan Unit 4 Combustion Optimization Results
- Questions/Answers
Xi’an Xingyi Technology Co., Ltd. (XXC) is a Hi-tech corporation approved by Shaanxi provincial government on December 28, 2000.

Its main business scope is to provide the whole range service of control system design, panel and console manufacturing in the field of industrial automation system and intelligent building automation control.

From early 2006, XXC began to cooperate with Energy Research Center, Lehigh University (ERC) in Boiler Combustion Optimization in China.

Combustion optimization of Datang International Power Generation Company’s Panshan Power Plant was the first project performed by ERC & XXC in China.
Pollution from Power Plants

Power stations impact the environment in various ways:

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Derived from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Rain</td>
<td>NO$_x$, SO$_2$</td>
</tr>
<tr>
<td>Ozone</td>
<td>NO$_x$, HC, VOCs</td>
</tr>
<tr>
<td>Greenhouse Gases</td>
<td>CO$_2$, CH$_4$, N$_2$O</td>
</tr>
<tr>
<td>Solid/Liquid Effluents</td>
<td>FGD, Acid Cleaning</td>
</tr>
<tr>
<td>Particulate</td>
<td>Fly Ash, NO$_x$, SO$_2$</td>
</tr>
<tr>
<td>Noise</td>
<td>Machinery, Boiler</td>
</tr>
</tbody>
</table>

NO$_x$ arises form two sources in fossil-fired combustion systems:
- The nitrogen in the fuel (Fuel NO$_x$)
- The nitrogen in the combustion air (Thermal NO$_x$)
Combustion Optimization

**Combustion optimization**: Modifications to the boiler control settings to achieve a particular objective (target emission level) with minimum heat rate penalty, subject to operational and/or environmental constraints.

**Sample Objectives**:
- NO\(_x\) reduction
- Improvements in unit heat rate
- Improve slagging situation of difficult fuels
- Improve mill performance

**Typical Constraints**: CO emissions, opacity, FEGT, non-reducing environment, fly ash LOI, etc.

Combustion optimization represents an alternative to hardware modifications for emissions reduction or performance improvement, or it can be used in conjunction with hardware modifications and post-combustion systems to maximize their effectiveness.
Combustion Optimization Approach

Number of boiler control parameters, typically involved in a combustion optimization process, is large.

Manual determination of optimal boiler control settings is not possible.

A systematic approach, consisting of:
- Parametric field tests
- Correlation of test data using artificial neural networks (ANNs)
- Determination of optimal boiler settings by a mathematical optimization algorithm
Lehigh University Energy Research Center combustion optimization approach is comprised of seven steps as follows:

- **Step 1**: Test Preparations, Boiler Inspection, Calibrate and Repair Pertinent Equipment, etc.
- **Step 2**: Combustion Tuning
- **Step 3**: Parametric Tests and Creation of Database
- **Step 4**: Correlation of Test Data (Creation of ANNs)
- **Step 5**: Determination of Optimal Boiler Control Settings
- **Step 6**: Implementation of Optimal Control Settings: Control Curves Modifications, Advisory Software, Closed-Loop Control
- **Step 7**: Maintaining Optimal Control Settings
Expert System - Guides Engineer Through a Series of Boiler Tests, Builds the Database.

Neural Networks - Correlate Test Data.

Optimization Algorithm - Determines Best Control Settings Satisfying Optimization Goal and Operational/Environmental Constraints.

Boiler OP runs under Windows operating system.

Implementation of Optimal Settings:
- Program optimal settings into the plant DCS.
- Open-Loop Operator Advisory.
- Closed-loop control for key operating parameters.
Panshan Unit 4 Results
Parametric Test Results: Baseline

Fuel SO₂ Emissions and Heating Value vs. Total Fuel Flow

Total Fuel Flow Rate vs. Total Air Flow and NOₓ Emissions
Parametric Test Results: Baseline

NO\textsubscript{x} Emissions versus OFA Register Opening

Unit Heat Rate versus OFA Register Opening
Parametric Test Results: Baseline

**NO\textsubscript{x} Emissions vs. Windbox-to-Furnace Differential Pressure**

\[ y = 12.88x + 110.51 \]

\[ R^2 = 0.4239 \]

**Impact of E-Mill Bias on NO\textsubscript{x} Emissions**
ANN Architecture and Comparison of Measured and Predicted NO\textsubscript{x} Values

Network Architecture for Panshan Models

Comparison Between Measured and Predicted NO\textsubscript{x} Emissions
Determination Of Optimal Boiler Control Settings

NO\textsubscript{X} Emissions vs. Unit Heat Rate Penalty

Boiler Optimization Result
NO\textsubscript{X} Emissions vs. Net Unit Heat Rate Penalty
Determination Of Optimal Boiler Control Settings

Optimal Excess $O_2$ and OFA Register Control Settings

Optimal Burner Tilt and Windbox-to-Furnace Differential Pressure
Implementation of Optimal Settings

• The **real-time** advisory software provides expert-system advice to the operators on the optimal boiler control settings for operation under conditions of **fuel variability**.

• Operation with the advisory software allows **better compliance** with the unit’s environmental **restrictions**, while maintaining optimal unit **thermal performance**.

At Panshan:
• \( \text{NO}_x \) emissions reductions of at least 85 mg/Nm\(^3\), or 20 percent from the baseline.
• Heat rate reduction of 20 kJ/kWh or 0.2 percent from the reference heat rate value.
• Estimated maximum achievable heat rate improvement is 80 kJ/kWh or 0.8 percent from the average baseline heat rate level.
• Maximum achievable \( \text{NO}_x \) emissions reduction is 30 percent.
Implementation of Optimal Settings

Impact of Optimal Settings on NO$_x$ Emissions

Baseline Settings:
- $P = 599.90 \pm 0.79$ MW
- Coal Flow = $244.02 \pm 1.19$ t/hr
- $O_2 = 3.63 \pm 0.37\%$
- Burner Tilt = $49.77 \pm 0.02\%$
- WB Press = $0.95 \pm 0.03$ kPa
- OFA Avg. = $29.94 \pm 0.3\%$
- Top Sec. Air = $4.93 \pm 0.02\%$

<table>
<thead>
<tr>
<th>Time</th>
<th>Baseline</th>
<th>Lowered $O_2$ 3.6 to 2.7%</th>
<th>Opened OFA 30 to 70%</th>
<th>Lowered Burner Tilt 50 to 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00</td>
<td>$NO_x = 82.7$ mg/Nm$^3$</td>
<td>$NO_x = 31.5%$</td>
<td>$NO_x = 31.5%$</td>
<td>$NO_x = 31.5%$</td>
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<tr>
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</tr>
</tbody>
</table>

LOI = 5.9\% HR

LOI = 10.13\% ΔHR = +18 Btu/kWh
Our Experience

The ERC’s combustion optimization approach and Boiler OP has been used to optimize more than 30 utility boilers in the United States, Mexico, Canada and Asia.

These boilers include T-fired and W-fired designs, ranging in size from 80 to 750 MW which fire varieties of fuels.

The average NO$_x$ emissions reduction achieved by applying the ERC combustion optimization approach to T-fired boilers, is 26 percent, while for W-fired boilers, is 29 percent.

Performance improvements for the units are in the range from 53 to 127 kJ/kWh range.
## Combustion Optimization Projects

<table>
<thead>
<tr>
<th>Unit No.</th>
<th>Boiler Characteristics</th>
<th>Fuel Type</th>
<th>Unit Size [MW]</th>
<th>Baseline NO&lt;sub&gt;x&lt;/sub&gt; [mg/Nm&lt;sup&gt;3&lt;/sup&gt;]</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt; Reduction [%]</th>
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</thead>
<tbody>
<tr>
<td>1-5</td>
<td>4-Corner, Conventional Burners</td>
<td>BIT</td>
<td>100</td>
<td>835</td>
<td>25</td>
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<tr>
<td>6,7</td>
<td>8-Corner, LNCFS Level III, LNB</td>
<td>BIT</td>
<td>600</td>
<td>976</td>
<td>40</td>
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<td>8</td>
<td>4-Corner, LNCFS Level III, LNB</td>
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<td>10</td>
<td>Twin-Furnace, LNCFS, LNB</td>
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<td>315</td>
<td>551</td>
<td>23</td>
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<td>14,15</td>
<td>8-Corner, LNCFS Level III, LNB</td>
<td>BIT</td>
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<td>608</td>
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<td>20</td>
<td>Separate Furnaces, TFS2000, LNB</td>
<td>BIT, SUB-BIT</td>
<td>285</td>
<td>400</td>
<td>21</td>
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<td>21</td>
<td>8-Corner, LNB</td>
<td>BIT, SUB-BIT</td>
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<td>8-Corner, LNB</td>
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<td>23</td>
<td>4-Corner, TFS2000, LNB</td>
<td>BIT, SUB-BIT</td>
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<tr>
<td>25</td>
<td>4-Corner (SNCR)</td>
<td>BIT, COG</td>
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<td>26</td>
<td>8-Corner (wet FGD)</td>
<td>Lignite</td>
<td>560</td>
<td>740</td>
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<td>9</td>
<td>Opposed Wall-Fired, DR-LNB, OFA</td>
<td>BIT</td>
<td>650</td>
<td>976</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>Front Wall-Fired, Twin Furnace, CB</td>
<td>BIT, SUB-BIT</td>
<td>280</td>
<td>1335</td>
<td>31</td>
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<td>12</td>
<td>Opposed Wall-Fired, DR-CB</td>
<td>SUB-BIT</td>
<td>600</td>
<td>495</td>
<td>34</td>
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<td>13</td>
<td>Front Wall-Fired, CB</td>
<td>Oil, BIT, SUB-BIT</td>
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<td>29</td>
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<td>16,17</td>
<td>Front Wall-Fired, CB, FGR</td>
<td>BIT</td>
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<td>1316</td>
<td>21</td>
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<tr>
<td>18</td>
<td>Opposed Wall-Fired, LN Cell Burners</td>
<td>BIT, SUB-BIT</td>
<td>750</td>
<td>901</td>
<td>33</td>
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<tr>
<td>19</td>
<td>Opposed Wall-Fired, DRB-XCL LNB</td>
<td>SUB-BIT</td>
<td>650</td>
<td>712</td>
<td>37</td>
</tr>
</tbody>
</table>

LNB: Low-NO<sub>x</sub> Burner  
DR: Double Register Burner  
FGR: Flue Gas Recirculation Fan  
SNCR: Selective Non-Catalytic Reduction  
COG: Coke Oven Gas  
LNCFS: Low-NO<sub>x</sub> Concentric Firing System  
TFS: Tangentially-Fired System  
OFA: Overfire Air  
FGD: Flue Gas Desulphurization  
BIT: Bituminous Coal  
SUB-BIT: Sub-bituminous Coal
Questions ...