Fundamentals of NO\textsubscript{X} Control for Coal-Fired Power Plants

CastleLight Energy Corp

Re-Engineering Coal-Fired Power Boilers for Improved Efficiency, Low Pollutant Emissions and Reduced Operating Cost

By
Keith Moore - President

www.Castle-Light.com

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CastleLight Energy Corp.
A Technology Management Company

- Couples a fast, low cost **Coal Beneficiation** process ............
- With a **Hybrid of Coal Gasification** for strong $SO_2$ and $NO_x$ emissions control and high efficiency for coal-fired power plants.
- Technology evolved from coal combustion research at **Rockwell International**.
- Some $60$ million in Utility peer reviewed R&D, field demonstrations & commercial programs
- Patented Technology
- **CastleLight Energy** provides Power Plant Re-Engineering:
  - Overall Technology Management
  - System Engineering, Design, CFD & PEPSE Analysis
  - All Hardware, Equipment, Instrumentation, and Controls including supervision of customer installation.
  - Commercial Warrantee & Technology License
OBSERVATION

Technology does not evolve……..it
“LEAP FROGS”

When was the last time you flew
on a commercial piston engine airplane?
Objective

- **McIlvian** seeks NO$_x$ control technologies for **Pacific Corp’s** coal-fired tangential boilers at Hunter and Huntington stations.
- NO$_x$ emissions target: 0.07 lb/MMBTU (~50 ppm)
- It is problematic that these low NO$_x$ emission levels can be met with conventional technology.
- Estimates for an SCR/ammonia system: ~$215$/kW
- **CastleLight Energy** suggest a review of the fundamentals of NO$_x$ formation and its destruction.
In coal combustion, the nitrogen in the coal (~1%) is the major source of NO\textsubscript{x} (~85%).

In the late 70’s, Dr. Axworthy at Rocketdyne showed that the nitrogen in the coal forms NO\textsubscript{x}, or the precursors of NO\textsubscript{x} - such as ammonia (NH\textsubscript{3}), and cyanide (HCN), at the same time and place as the carbon is oxidized.

Further, he showed that there is no way that this fuel-NO\textsubscript{x} can be avoided; such as low temperature combustion, as used when firing natural gas to avoid thermal NO\textsubscript{x} formation.

However, observations of Fluid Bed Combustion (FBC) showed that something was effectively reducing the fuel-NO\textsubscript{x} levels in the bed.

A theory evolved - look for a NO\textsubscript{x} destruct catalysis in the combustion step.
NO_x Destruction

- A lab furnace was set up to duplicate the FBC combustion bed conditions.
- The minerals and compounds found in in coal were exposed to NO_x under combustion conditions and any change in NO_x inlet / outlet levels were noted.
- It was determined that calcium sulfide (CaS) is a gang buster NO_x destruct catalysis, especially under the fuel-rich, high-temperature conditions such as found in an FBC bed.
- This was a remarkable discovery, as Rockwell was developing a new coal-fired burner for SO_2 control; fuel-rich combustion featuring sulfur capture with calcium (limestone - CaCO_3).
- Calcium sulfide is a very reactive compound; it quickly oxidizes to H_2S in air, so it must be created when needed.
- In fuel-rich combustion (no oxygen) sulfur reacts with calcium to form CaS. – a solid particle even at high temperatures.
- We observed that the CaS destroyed fuel-NOx to “single digit ppm levels” right in the initial combustion step - 20 to 30 inches from the burner face.
- Rockwell now had a new coal-fired burner concept with SO_2 and synergistic NO_x control.
- We now describe it as the CLEAN COMBUSTION SYSTEM.
Schematic
Hybrid of Coal-Gasification & OFA Combustion
( $SO_2$ and $NO_x$ control )

Meter ALL the coal with very little hot combustion air

New Coal Burners & refractory lined Gasification Chamber replaces original wind box & coal burners

Existing Boiler Furnace with new OFA Ports
CCS Process Steps

SO\textsubscript{2} & NO\textsubscript{x} emissions control right in the combustion step

- Coal is fired with very limited hot air in an entrained-flow gasifier
- In the initial combustion step, the carbon consumes all the oxygen and creates a hot, fuel-rich gas and frees the sulfur from the coal,
- Limestone (CaCO\textsubscript{3}) provides calcium as CaO
- Sulfur reacts with CaO to form calcium sulfide (CaS) - a solid particle at these temperatures,
- CaS destroys the NO\textsubscript{x} (NO\textsubscript{x} < 10 ppm) to form elemental nitrogen (N\textsubscript{2})
- At the high temperatures, coal ash (alumina & silica) mix with the CaS and melts to form a slag product; the sulfur is thereby encapsulated in the slag
- About half the slag drains from the chamber to a water quench slag tank.
- Clean red-hot gases enter the furnace & cool to < 2300 F, where thermal NO\textsubscript{x} formation is frozen. Any slag particles solidify to a fine fly ash
- Staged over-fire air is then carefully added to complete combustion in the furnace to CO\textsubscript{2} & H\textsubscript{2}O and to avoid any thermal NO\textsubscript{x} formation.
- The hot exhaust gases exit the furnace to the back pass at the original design conditions.
LNS-CAP Facility
ESSO Site, Cold Lake, Alberta Canada
50 mmBtu/hr – 3T/hr PRB Coal; 1992
LNS-CAP
Top of LNS Burner
LNS-CAP
Slag to Water Trough
Boiler Radiant Section
View Forward: OFA Pipes and Burner (note the white ash)
Demonstrated Emissions

$SO_2 \sim 0.2 \text{ lb.}/\text{mmBtu} \ & \ NO_x \sim 0.15 \text{ lb.}/\text{mmBtu} \ (110 \text{ ppm})$

ESSO LNS-CAP Facility, Cold Lake, Alberta, Canada
CCS-Stoker® Retrofit
30 MW (Thermal) - 125 mmBtu/hr – 5 T/hr Coal ;2008
Gasification Chamber Installation
Hybrid Coal Gasifier
Chamber Installation on Boiler

- Shop fabricated membrane wall, studded and refractory lined for coal gasification.
- Natural circulation water cooling connection to the boiler drums
CCS-Stoker® Operation Observations

Operation @ MCR – NO$_x$ < 88 ppm
## CCS-Stoker® Retrofit Performance

Preliminary Results – Full Load Operation

<table>
<thead>
<tr>
<th>Item</th>
<th>Stoker Base Line Test</th>
<th>Preliminary CCS Performance</th>
<th>% Change from Base Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$ Stack Emissions (lb/MMBtu)</td>
<td>1.80</td>
<td>0.72</td>
<td>- 67.0 %</td>
</tr>
<tr>
<td>NO$_x$ Stack Emissions (lb/MMBtu)</td>
<td>0.50</td>
<td>0.14 (88 ppm)</td>
<td>- 72.0 %</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>77.0</td>
<td>86.9</td>
<td>+ 12.8 %</td>
</tr>
<tr>
<td>CO$_2$ Emissions - Ton/yr GW credits (% Reduction)</td>
<td>94,019</td>
<td>73,720</td>
<td>20,300T/y (- 21.6 %)</td>
</tr>
<tr>
<td>Project Cost Recovery (from firing lower cost coal)</td>
<td>~ 3 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example: Opposed-Wall Fired Boiler
500 MW – 5 Mills & 24 PC Burners (Remove Burners & Wind box)

WITH CCS, NO SCR REQUIRED
Re-Engineered Wall-Fired Boiler
Install 6 Gasification Chambers & OFA, 24 Burners, 6 Bag houses
Re-Engineered Tangential™ Boiler

Example: 100 MW

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CCS Features
Improved Operability, Availability & Reliability

- All equipment off-the-shelf & familiar to the operators
  - Safe, stable burner operation,
  - Same startup, shutdown and turndown as the PC plant
- Bottom Ash (slag) removed before furnace
  - low particulate/ash load; clean furnace, less soot blowing
- Sulfur removed from furnace gases - near-zero SO$_3$:
  - Allows for lower furnace exit temperatures
  - Minimize water-wall wastage & corrosion,
    - Can use hot boiler exhaust for pulverizer sweep air:
      - Dry the coal – reject moisture
      - Improves coal pulverizer safety from fire & puffs (low O$_2$)
- Improved Boiler Efficiency (2 to +10%)
  - Reduce CO$_2$ emissions
  - High combustion efficiency (LOI < 1%)
- Limestone is only “chemical” required
- No waste water for disposal
- Construction permit with waiver of NSPS & PSD
  – No New Source Review (NSR) Trigger!
CCS Summary
(Key Strategic Issues)

- From Fundamental Combustion Theory to Commercial Operation
- Meets EPA’s new stringent regulations for $\text{SO}_2$, $\text{NO}_x$ & now $\text{CO}_2$
- Allow power plant upgrade with waiver of NSPS & PSD - No NSR
- Low Retrofit Cost; maintains older, smaller plants competitive
- Lower coal consumption - reduce plant operating cost
- Improve plants capacity factor & dispatch
- Fits within plant & boiler site footprint
- Ash products have value (sell bottom ash & fly ash)
- No hazardous or toxic chemicals required

It’s ADVANCED COAL GASIFICATION TECHNOLOGY!
CastleLight Energy Corp.
Power Plant Re Engineering Program

For Technical Presentations and Plant Surveys:
Contact CastleLight Energy Corp.
Keith Moore - President
Phone: 805-551-0983
E-mail: keith@castle-light.com
Visit Web Site: www.Castle-Light.com

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