Duplex™ Technology

Presentation by:
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South Coast Air Quality Management District
PR 1118.1 Working Group Meeting
Diamond Bar, CA
October 24, 2017
ClearSign’s Duplex™ technology improves combustion system performance:

- Reduced emissions
- Improved operational performance
ABOUT CLEARSIGN – COMPANY OVERVIEW

• Seattle based
• NASDAQ: CLIR
• Focused on industrial combustion solutions and innovations
• Experienced management team
ULTRA LOW NOx BURNERS

NOx Reduction Strategies:
- Fuel Staging
  - Fuel Lean Primary
  - Fuel Rich Secondary
- Control Peak Flame Temperatures
  - Fuel Dilution by IFGR
  - Delayed Mixing (Stretched Flames)
  - Increase Flame Volume
  - Radiation Cooling

Typical NOx Guarantee: 15-25 ppm

Disadvantages:
- Long Lazy Flames (Coalescing/Impingement)
- Large Burner Throat
- Cannot Meet Most Stringent Regulations
DUPEX™ FEATURES

• High Temperature Porous Ceramic Matrix
• Flame Confined Within Duplex
• NOx Levels Below 5 ppm
• Surface Radiation vs. Gas Radiation
• Enhanced Fuel/Air Mixing
• Improved IFGR (Entrainment Length)
• Bluff Body Stabilization
• Noise Reduction
DUPLEX™ MODES OF OPERATION

Burner Mode (Warm Up)  Transition  Duplex Mode
DUPLEX BURNER IN OPERATION

→ Duplex Operation Enabled
How DUPLEX Technology Reduces NOx

Mechanism 1: Reduction of the flame temperature through increased radiation to the process tubes.

Website [www.chec.kt.dtu.dk](http://www.chec.kt.dtu.dk)
Technical University of Denmark
CHEC Research Centre, Dept. of Chemical & Biochemical Engineering.
FLAME VS. SOLID SURFACE EMISSIVITY

\[ Q_{\text{rad}} \propto \varepsilon \cdot (T_2^4 - T_1^4) \]

“Heat Transfer in Industrial Combustion,”
C.E. Baukal, Jr., Published by CRC Press, 2000

“Thermal Radiation Heat Transfer,”
DUPLEX™ WALL IN OTSG
DUPLEX™ IN 62.5 MMBTU/H OTSG
DUPLEX™ IN AN OTSG
NOx Performance

QLN
- 45 MMBtu/hr
- NOx: 14.2 ppm corrected 3% O2

Duplex™
- 55 MMBtu/hr
- NOx: 4.7 ppm at 3% O2
- NOx: 3.5 ppm at 3.50% O2

Duplex™
- 45 MMBtu/hr
- NOx: 4.1 ppm at 3% O2
- NOx: 3.1 ppm at 3.50% O2

Stack Oxygen Concentration

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**DUPLEX IN A REFINERY HEATER**

**REFORMER SPLITTER REBOILER HEATER**

- Vertical Cylindrical Heater
- Maximum Capacity = 11.25 MMBtu/hr
- Dimensions:
  - Shell OD 9’ 6 ½”
  - Height 17’ 8 ½”
- Three ULN Burners
- Refinery Fuel

<table>
<thead>
<tr>
<th></th>
<th>H2 (vol. % @ STP)</th>
<th>CH4 (vol. % @ STP)</th>
<th>LHV (Btu/scf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>68.7</td>
<td>55.6</td>
<td>1462</td>
</tr>
<tr>
<td>Minimum</td>
<td>22.8</td>
<td>12.3</td>
<td>636</td>
</tr>
<tr>
<td>Average</td>
<td>43.8</td>
<td>31.7</td>
<td>892</td>
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DUPLEX IN A REFINERY HEATER

- Duplex Surface
- Ceramic structure
- Support (welded to furnace shell)
DUPLEX IN A REFINERY HEATER

Furnace side port  Furnace floor  Burner bottom plate

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NOX as a function of Reformer Unit Charge Rate

- NOx Average = 3.6 ppm
PLUG-AND-PLAY DUPLEX™
FLARING – SOME FACTORS TO CONSIDER

• Process vs. Emergency
• Enclosed vs. Open Flaring
• Fuel Characteristics
  ✓ Composition
  ✓ Heating Value
  ✓ Contaminants
  ✓ Liquids
• DRE
• NOx/CO/VOCs
DESTRUCTION EFFICIENCY (DRE)

• 3 Ts
  ✓ Temperature
  ✓ Time
  ✓ Turbulence
NOX FORMATION

• Three Mechanisms
  ✓ Thermal NOx (Zeldovich)
  ✓ Prompt NOx (Fenimore)
  ✓ Fuel Bound NOx

\[ C_{NO} = A C_{N2} \int e^{ \frac{b}{T} C_{O2}^2 } dt \]

- \( C_{N0} \) = Concentration of nitric oxide
- \( C_{N2} \) = Concentration of nitrogen
- \( C_{O2} \) = Concentration of oxygen
- \( T \) = Temperature
- \( t \) = Time
- \( A \) = Constant
ENCLOSED FLARES
DUPLEX IN ENCLOSED FLARES

DUPLEX™ WAFER

TYPICAL INCINERATOR STACK
DUPLEx IN ENCLOSED FLARES
DUPLEX IN ENCLOSED FLARES

- Incineration of stranded gas in oil production
- 1500-1700 Btu/scf gas

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<tr>
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<th>Permit</th>
<th>Performance After Duplex™</th>
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<tbody>
<tr>
<td>NOx</td>
<td>6.5 ppm</td>
<td>&lt; 4 ppm</td>
</tr>
<tr>
<td>CO</td>
<td>3.5 ppm</td>
<td>0-3 ppm</td>
</tr>
<tr>
<td>VOCs</td>
<td>5.0 ppm</td>
<td>&lt; 4 ppm</td>
</tr>
<tr>
<td>DRE</td>
<td>99.9 %</td>
<td>&gt; 99.999 %</td>
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100 MMBtu/hr Single-burner Water tube boiler (China district heating application)
60 MMBtu/hr Single-burner Water tube boiler (California refinery)
150 MMBtu/hr Multiple-burner Water tube boiler – sponsored by SCAQMD (California refinery)
C'est fini!