Enhanced Furnace Energy Efficiency with OPTIMELT™ TCR System

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Praxair, Inc.

Glasstec
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LIFE15 CCM/NL/000121
OPTIMELT™ Thermo-Chemical Regenerator

- High efficiency non-catalytic reforming process
- Recycled flue gas with CO₂ and water vapor is used for CH₄ reforming
- Regenerative system allows high operating temperatures/reforming rate
- Regenerators roughly 1/3 the size of air-fired regenerators

TCR Reduces fuel consumption by 20 to 30%
OPTIMELT™ Process

- Injection of Natural Gas into Flue Gas Recirculation
- Preheating of Mixture
- Endothermic Reaction to Syngas (CO and H₂)
- Hot Syngas to Furnace
OPTIMELT™ Process

Combustion of Syngas with Oxygen Jets in the Wall

Reforming Regenerator

Heating Regenerator
OPTIMELT™ TCR Operation

Right TCR Port  Flue Gas Opening  Left TCR Port

10-23-2014 Thu 20:47:28
Commercial Installation

- TCR system installed and started on Pavisa Furnace 13, Sep 2014
  - 50tpd container glass furnace
    • Specialty glass and crystal products for wine, liquor, food, cosmetic, and pharmaceutical industries
  - Six Praxair oxy-fuel burners in the breast walls
  - Two regenerators added to the end wall
  - Very challenging site integration with little space
    • Led to unique regenerator design

Outstanding collaboration on this new technology project!
TCR Installation on Furnace 13

- Furnace
- Existing Control Room
- Existing Stack
- TCR Flue Gas Recirculation Skid
- Left Regenerator
- Right Regenerator
- Sloped Port Necks
- Side Wall Oxy-fuel Burners

building wall removed for this view
Flue Gas Recirculation Skid

Bottom of Regenerator Tower

Top of Right Regenerator Tower
## Fuel Savings: Clear Flint Production

<table>
<thead>
<tr>
<th></th>
<th>Oxy-fuel firing</th>
<th>OPTIMELT firing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull Rate (t/d)</td>
<td>50.5</td>
<td>52.5 (+4%)</td>
</tr>
<tr>
<td>Cullet Rate (% of feed)</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Furnace Wall Temperature (°C)</td>
<td>1529</td>
<td>1524 (-5)</td>
</tr>
<tr>
<td>Furnace Glass Temperature (°C)</td>
<td>1314</td>
<td>1312 (-2)</td>
</tr>
<tr>
<td>Excess Oxygen (% wet)</td>
<td>2.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Total Fuel Average ($m_{N_3}/hr$)*</td>
<td>375</td>
<td>308*</td>
</tr>
<tr>
<td>Fuel Savings (%)</td>
<td>base</td>
<td>-18%</td>
</tr>
<tr>
<td>Seed Count (1/oz)</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>Bottles with Stones (%)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dominant Wavelength (nm)</td>
<td>571.6</td>
<td>568.9</td>
</tr>
<tr>
<td>Transmittance (%)</td>
<td>81.00</td>
<td>80.97</td>
</tr>
<tr>
<td>Fe$^{2+}$/Fe$^{3+}$ redox ratio</td>
<td>0.278</td>
<td>0.285</td>
</tr>
<tr>
<td>Fraction of Fe$_2$O$_3$ (%)</td>
<td>78.25</td>
<td>77.80</td>
</tr>
</tbody>
</table>

*Notes: Fuel consumption of melter and forehearth. TCR fuel consumption corrected to lower pull rate of oxy-fuel baseline.

**Demonstrated fuel savings**
Low NOx Emission From OPTIMELT

NOx emissions in line with oxy-fuel low NOx burners
0.2-0.4 kg/t expected at typical 5-10% wet N2 in furnace
Emission Summary

- TCR emissions at Pavisa are in the range of the measured emissions for Low NOx glass oxy-fuel burners.
- Emission trend of NOx versus Nitrogen in the furnace for TCR is similar to other oxy-fuel burners.
- Pavisa F13 has relatively high nitrogen concentration due to air inleakage.
  - Measured emissions at Pavisa had to be corrected for lower Nitrogen partial pressure due to elevation in Mexico City (~0.76 bar$_{abs}$).
- The typical nitrogen range for large commercial furnaces with low air leakage is 5 to 10% wet.
- Flue gas NOx concentrations for the technology are projected to be 0.1 kg/GJ$_{LHV}$, or about 0.4 kg/t at 10% N$_2$ in the furnace.

Praxair is confident that OPTIMELT will meet future emission NOx requirements.
Regenerator and Checker Performance

- Checker in very good condition after 22 months
  - Inspected Summer 2016
  - Passages were completely free
  - No signs of corrosion
  - Light deposits at bottom, easy to clean

- Port neck refractory was not the right choice for this application
  - Nepheline spalling of material in hottest zone
  - Better material identified, replacement 2016

- Regenerator walls and rider arches in very good condition

- Dampers, ducts and fan deposits
  - Cleaning no problem, no operational impact

Very encouraging results, valuable information for scale-up
Potential Fuel Savings

- Energy savings model validated with Pavisa data
- Pavisa savings in line with expectations
- Full scale furnace have larger savings potential
  - Savings depend on specific circumstances of furnace
  - Praxair has performed many analyses

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect on Savings</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace size</td>
<td>larger</td>
<td>higher</td>
</tr>
<tr>
<td>Pull rate</td>
<td>higher</td>
<td>higher</td>
</tr>
<tr>
<td>Cullet rate</td>
<td>higher</td>
<td>lower</td>
</tr>
<tr>
<td>Insulation quality</td>
<td>better</td>
<td>higher</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td>higher</td>
<td>higher</td>
</tr>
<tr>
<td>Electric boost</td>
<td>higher</td>
<td>lower</td>
</tr>
</tbody>
</table>

Big furnaces have relatively lower wall losses
Wall losses are constant
Less heat input and batch gases
More recoverable heat
Higher heat recovery potential
Less heat input
Many Options for Additional Heat Recovery, but …

TCR –O2 recuperator heat recovery

Challenges for additional heat recovery
- High CAPEX for relatively small incremental heat recovery
- O2 preheating to 500 °C provides only 2-3% incremental fuel savings

<table>
<thead>
<tr>
<th>Case</th>
<th>Heat Recovery Systems</th>
<th>Fuel Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oxy-fuel (baseline)</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>OPTIMELT Thermochemical Regen (TCR)</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>OPTIMELT Plus Dual TCR-O2 Regen</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>OPTIMELT TCR - Cullet PH</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>O2 REGEN (100% O2 purity PH Temp 1200 C)</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>O2 REGEN- Cullet PH</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>O2 REGEN-Batch/Cullet PH</td>
<td>28</td>
</tr>
</tbody>
</table>
OPTIMELT™ Plus Technology

- OPTIMELT coupled with regenerative oxygen preheating
- Recycled flue gas with CO₂ and water vapor is used for CH₄ reforming
- ~5% improvement of heat recovery versus OPTIMELT TCR

Oxy-fuel Glass Furnace

REEGENERATORS

1-TCR

1-O2

2-TCR

2-O2

Flue Gas
CO₂+2H₂O

Flue Gas Recycle (~20%)

NG (CH₄)

Oxygen (O₂)

US Patents 6,113,874 and 5,921,771

Hot Syngas
~1200°C
~2200°F

Hot Oxygen
~1200°C
~2200°F

~1500°C
~2700°F
Summary

- **Praxair’s OPTIMELT™ Thermochemical Regenerator (TCR)**
  - Reduces energy consumption
    (container furnace: ~20% vs oxy-fuel, ~30% vs. air-regenerative)
  - Reduces CO₂ emissions
  - Reduces air pollutants to the level of oxy-fuel performance
    (NOx, SOx, CO, etc.)

- **Successful commercial demonstration at Pavisa**
  - System in automatic and continuous operation
  - Fuel savings well within expectations for size of installation and
    operating conditions
  - Glass quality on same level as oxy-fuel combustion

- **Two commercial size projects in engineering phase**
  - Libbey L1: end-fired tableware furnace with side-fired oxy-burners
  - Customer 2: 240 tpd end-fired container furnace (flint glass) with end-
    fired oxy-burners
Thank You for your Attention!