Enhanced Furnace Energy Efficiency with OPTIMELT™ TCR System


Praxair, Inc.

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

- High efficiency non-catalytic reforming process
- Recycled flue gas with CO$_2$ and water vapor is used for CH$_4$ reforming
- Regenerative system allows high operating temperatures/reforming rate
- Regenerators roughly 1/3 the size of air-fired regenerators

**Diagram:**
- Oxy-fuel Glass Furnace
- FLUE GAS (CO$_2$+2H$_2$O)
- Flue Gas Recycle (~20%)
- NG (CH$_4$)

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
OPTIMEHLT™ Process

Combustion of Syngas with Oxygen Jets in the Wall

Heating Regenerator

Reforming Regenerator
OPTIMELT™ TCR Operation

Right TCR Port  Flue Gas Opening  Left TCR Port
OPTIMELT™ System at Pavisa

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

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

building wall removed for this view
Status Furnace 13

- OPTIMELT Operation
  - OPTIMELT in automatic and continuous operation since September 2014
  - No fundamental TCR technology issues identified
  - Glass pull rate and quality continue to be within Pavisa requirements
  - Energy reduction 15 to 18% - in line with expectations for 50tpd furnace

- End-firing of Oxy-fuel Combustion System as an alternative to the side-fired oxy-fuel burners installed in May

- Test of Wide Flame Burner for OPTIMELT use concluded (WFB Gen III with additional cooling)
  - Tested successfully two months, temperatures are within material limits
  - New cooling concept for future commercial projects

- Refractory testing in regenerators continues

Pavisa continues to support ongoing OPTIMELT development
## Fuel Savings: Clear Flint Production

<table>
<thead>
<tr>
<th>Flint glass</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 (mN³/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>
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<tr>
<td>Transmittance (%)</td>
<td>81.00</td>
<td>80.97</td>
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<tr>
<td>Fe²⁺/Fe³⁺ redox ratio</td>
<td>0.278</td>
<td>0.285</td>
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<tr>
<td>Fraction of Fe₂O₃ (%)</td>
<td>78.25</td>
<td>77.80</td>
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</table>

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

**Demonstrated fuel savings**
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>
Regenerator and Checker Performance

- Checker in very good condition after 22 months
  - Passages were free of deposits
  - 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
Refractory Test Program Continues

- Refractory selection program tests are ongoing
- Test Rounds:
  - 1 completed: 8 months
  - 2 completed: 1 month (quick screening test for exclusion of refractories)
  - 3 currently ongoing for ~9 months
  - 4 in preparation
- Round 1 and 2 results were used in the selection of the refractory for next commercial project
  - Observed corrosion patterns typical for glass furnace conditions
  - Hydrogen reduction from TCR process does not play a role in refractory degradation
  - Selection not a straightforward scientific process, experience is important
    - Very high alumina and Magnesia samples promising
    - Fused-cast AZS refractories superior to bonded material
  - Surprising differences in same classes or material, details in composition and manufacturing matter

Technology Development guided by Pavisa Refractory Exposure Tests
New OPTIMELT project

- >100 tpd tableware furnace with oxy-fuel combustion system and end-port OPTIMELT™ configuration
- Project is in the procurement phase
- OPTIMELT™ Startup middle 2017
- Pavisa’s refractory test data and operational experience was used in the design
- On-site Oxygen production by Praxair VPSA system

Project funded by European Union with LIFE grant (LIFE 15 CCM/NL/000121)
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.)

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
  • Project partially funded by EU (LIFE15 CCM/NL/000121)
- Customer 2: 240 tpd end-fired container furnace (flint glass) with end-
  fired oxy-burners
Thank You for your Attention!