Fuel Savings and Operating Experience with \textit{OPTIMELT}™

#1: 50 tpd Container Glass Furnace; Mexico

#2: New >100 tpd Tableware Glass Furnace; Europe

LIFE15 CCM/NL/000121

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OPTIMELT™ Process Basics (I)

Exhaust Cycle from Oxy-fuel furnace

- Hot Flue (CO₂, H₂O, O₂)
  1500-1600 C (~ 2800 F)

- Cold Flue
  500-700 C (900-1300 F)

- Exhaust

Heating/Reforming Cycle from Oxy-Fuel

- Furnace
  Reformed Gas (CO, H₂ Rich)
  1200-1300 C (~ 2300 F)

- Recycled Flue (CO₂, H₂O, O₂)
  425 C (~ 800 F)

- NG 25 C

Endothermic reforming reactions

\[ \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \quad 2060 \text{ kcal/Nm}^3 \quad \text{CH}_4 \ (215 \text{ Btu/scf-CH}_4) \]

\[ \text{CH}_4 + \text{CO}_2 \rightarrow 2\text{CO} + 2\text{H}_2 \quad 2630 \text{ kcal/Nm}^3 \quad \text{CH}_4 \ (275 \text{ Btu/scf-CH}_4) \]
OPTIMELT™ Process Basics (II)

- 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

**Endothermic reforming reactions**

- CH₄ + H₂O → CO + 3H₂  2060 kcal/Nm³  CH₄ (215 Btu/scf-CH₄)
- CH₄ + CO₂ → 2CO + 2H₂  2630 kcal/Nm³  CH₄ (275 Btu/scf-CH₄)

**Diagram**

- Oxy-fuel Glass Furnace
- Regenerators
- Flue Gas CO₂+2H₂O
- Flue Gas Recycle (~20%)
- NG (CH₄)
- Hot Syngas (1250°C ~2300°F)
- O₂

**Notes**

US Pat. 6,113,874 / EP 0953543B1

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OPTIMELT™ Process Basics (III)

- Small amount of flue gas is recycled, mixed with NG and introduced at the inlet of the checker stack.
- This mixture absorbs energy stored in the refractory bricks, gets preheated, resulting in an endothermic chemical reaction.
- The gases are converted into a hot syngas (H2, CO).
- When flow reverses, control systems automatically prepare new inlet stack and process resumes in opposite direction.
OPTIMELT™ Process Basic (IV)

Injection of Natural Gas into Flue Gas Recirculation

Preheating of Mixture

Endothermic Reaction to Syngas (CO and H2)

Hot Syngas to Furnace
From Innovation to Commercial Offer

OPTIMELT™ Technology Development Path

- Bench Scale: 2011-2012
  - Patent
  - United States Patent
  - Kobayashi
  - THERMOCHEMICAL REGENERATIVE HEAT RECOVERY PROCESS

- Pilot Scale Tests: 2012-2013
  - 10 TPD equivalent

  - LIFE15 CCM/NL/000121

- >100 TPD: 2016-2017
  - LIBBHEY HOLLAND L1
  - LIFE15 CCM/NL/000121

- >200 TPD: 2017-2018
  - Container Furnace
  - Engineering Phase

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#1 OPTIMELT™ Project Background

- Pavisa
  - Specialty glass and crystal products for wine, liquor, food, cosmetic, and pharmaceutical industries
  - Several oxy-fuel furnaces supplied by 117tpd VPSA plus liquid oxygen backup
  - Strong long-term relationship between Pavisa and Praxair

- OPTIMELT™ TCR demonstration on Furnace 13
  - 50tpd container glass furnace
  - Six existing Praxair oxy-fuel burners in the breast walls
  - Two regenerators added to the end wall
  - Very challenging site integration with little space

Outstanding collaboration on a complex construction project!
#1 OPTIMELT™ Adaption to 50 tpd Furnace

Side-fired oxy-fuel furnace converted to end-port OPTIMELT™ TCR.

Furnace can be operated with and without OPTIMELT™
#1 OPTIMELT™ 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

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The video shows the oxy-fuel burners in service and the transition to syngas burner (oxy-fuel burners off).
#1 OPTIMELT™ Results on Furnace 13 (I)

- **Operation**
  - More than 23 months in operation. Start up Sep 2014
  - No fundamental TCR technology issues identified

- **Results at Pavisa**
  - Glass pull rate and quality required achieved
  - No production was lost during this 2 years of operation
  - Slight increase in pull rate possible with OPTIMELT™ Integration of TCR into furnace has positive effect on glass quality
  - Measured energy consumption at Pavisa -15 to -18% lower than oxy-fuel for this small 50 tpd furnace (About 20% projected for 300 tpd)
  - Low NOx emissions, 0,3-0,7 kg/mt with high air leakage (0,2-0,4 kg/mt expected with normal air leakage)
  - Low CO emissions, <80 ppm (flue gas O2 4% dry)

Overall a very successful technology demonstration
#1 OPTIMELT™ Results on Furnace 13 (II)

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

* Notes: Fuel consumption of melter and forehearth.
  OPTIMELT fuel consumption corrected to lower pull rate of oxy-fuel baseline
Careful analysis required to compare oxy-fuel and OPTIMELET™ consumptions due to color and pull changes. Necessary to use controlled data sets with same glass to compare and calculate fuel savings.
#1 OPTIMELT™ Results on Furnace 13 (IV)

- Averaged measurements during OPTIMELT™ operation (left or right)
- Furnace nitrogen content was calculated with a mass balance model using known furnace pull, cullet ratio, and the measured CO$_2$ and O$_2$ concentrations
- NOx well below 0.8 kg/t, even with un-optimized operating conditions
- Furnace N$_2$ varied from ~20% to ~31% wet
- NOx variation due to left and right fire difference and deliberate excess O$_2$ tuning during tests
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

#1 OPTIMELT™ Results on Furnace 13 (V)

Typical NOx range for low air leakage

Pipe-in-pipe
A Burner
JL Burner
TCR

NOx OPTIMELT Furnace 13

Ultra low NOx
Praxair A Burner

NOx Emission (kg/t or ½ lb/ston)

N2 in the Furnace (% wet, or 1 kPa partial pressure)
Averaged measurements during TCR operation (left or right)

CO was below 80 ppm when flue gas O2 was above 4 % (dry), which is the recommended excess O2 level.

Higher CO with lower excess O2 is consistent with typical oxy-fuel combustion
132 test samples from major refractory suppliers placed for evaluation.
132 samples removed for evaluation after 8 months
Round 3 testing ongoing
#1 OPTIMELT™ Results on Furnace 13 (IX)

- Checker in very good condition after 22 months
  - 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
  - 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
Next Inspection in July 2017
#2 OPTIMELT™ at Libbey, Holland (I)

- 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)
#2 OPTIMELT™ at Libbey Holland (II)

- V-40 XL VPSA plant
  - O2 capacity: 56,1 t/d (contained)

- OPTIMELT™ project
  - >100 tpd tableware furnace
  - Startup middle 2017
OPTIMELT™ Comparison with Available Data

Primary energy consumption container glass furnaces (123) versus production rate and furnace type in 1999
(Data from CelSian presentation)
**OPTIMELT™ Summary**

- **Praxair’s OPTIMELT™**
  - Reduces energy consumption (~20% vs oxy-fuel, ~30% vs. air-regenerative)
  - Reduces CO$_2$ emissions
  - Reduces air pollutants to the level of oxy-fuel performance (NO$_x$, CO, etc)
  - Reduces flue gas volume and enables smaller air pollution control

- **Successful 50 tpd demonstration at Pavisa**
  - System in automatic and continuous commercial operation
  - Performance as expected for this furnace scale
  - Increase of furnace capacity

- **New >100 tpd Libbey OPTIMELT™ startup middle 2017**
- **New >200 tpd OPTIMELT™ furnace in detailed engineering phase**
- **300 tpd size OPTIMELT™ ready for commercial application**
Thank you for your attention!

Have you heard about Praxair’s new OPTIMELT™ TCR Technology?
Learn about it at Glasstec
Düsseldorf, 20-23rd September, 2016

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