WASTE HEAT RECOVERY SEMINAR
15th November, 2016, SHEFFIELD
BRITISH GLASS

Operating Experience with OPTIMELT™

#1: 50 tpd Container Furnace; Mexico
#2: New Tableware Furnace; Europe

LIFE15 CCM/NL/000121 - LIFE OPTIMELT

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OPTIMELT™ Process Basic Video

Heating Regenerator

Reforming Regenerator

Combustion of Syngas with Oxygen Jets in the Wall
OPTIMELT™ Process Basics (I)

- 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**

\[
\begin{align*}
\text{CH}_4 + \text{H}_2\text{O} & \rightarrow \text{CO} + 3\text{H}_2 & 2060 \text{ kcal/Nm}^3 & \text{CH}_4 (215 \text{ Btu/scf-CH}_4) \\
\text{CH}_4 + \text{CO}_2 & \rightarrow 2\text{CO} + 2\text{H}_2 & 2630 \text{ kcal/Nm}^3 & \text{CH}_4 (275 \text{ Btu/scf-CH}_4)
\end{align*}
\]
OPTIMELT™ Process Basic (II)

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

Reforming Regenerator

Combustion of Syngas with Oxygen Jets in the Wall

Heating Regenerator
OPTIMELT™ Technology Development Path

From Innovation to Commercial Offer

Pilot Scale Tests
10 TPD equivalent
2012-2013

Bench Scale
2011-2012

Tableware furnace
50 TPD
2014-2015

>200 TPD
2017-2018

Container Furnace
Engineering Phase
LIBBEY HOLLAND L1
LIFE15 CCM/NL/000121

Patent
United States Patent
Kobayashi
[19] THERMOCHEMICAL REGENERATIVE HEAT RECOVERY PROCESS

F13 - Commercial Demonstration
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™ Installation on Furnace 13

- Furnace
- Existing Control Room
- Existing Stack
- TCR Flue Gas Recirculation Skid
- Left Regenerator
- Right Regenerator
- Building wall removed for this view
- Sloped Port Necks
- Side Wall Oxy-fuel Burners
- Existing Control Room

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Side-fired oxy-fuel furnace converted to end-port TCR
Oxy-fuel system on stand-by as backup
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 ($m_{N_3}$/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.
  OPTIMELT fuel consumption corrected to lower pull rate of oxy-fuel baseline
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
- 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
#1 OPTIMELT™ Results on Furnace 13 (VI)

Door 1
Door: 660 mm x 760 mm
Port: 260 mm ID

Glass

Charger

Left TCR
Right TCR

132 test samples from major refractory suppliers placed for evaluation.
#1 OPTIMELT™ Results on Furnace 13 (VII)

- 132 samples removed for evaluation after 8 months
- Round 3 testing ongoing
#1 OPTIMELT™ Results on Furnace 13 (VIII)

- 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
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
#2 OPTIMELT™ at Libbey, Holland (I)

- New OPTIMELT project
  - New tableware furnace with oxy-fuel combustion system and end-port OPTIMELT™ configuration
  - Project is in the procurement phase
  - OPTIMELT™ Startup 2017
  - On-site Oxygen production by Praxair VPSA system

- Project partially funded by European Union with LIFE grant (LIFE 15 CCM/NL/000121)
OPTIMELT™ Summary

- Praxair’s OPTIMELT™
  - Reduces energy consumption (~20% vs oxy-fuel, ~30% vs. air-regenerative)
  - Reduces CO₂ emissions
  - Reduces air pollutants to the level of oxy-fuel performance (NOₓ, 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 tableware furnace Libbey OPTIMELT™ startup 2017
- New >200 tpd OPTIMELT™ furnace in detailed engineering phase
- 300 tpd size OPTIMELT™ ready for commercial application
Thank You for your Attention!

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