Glass Furnaces’ Regenerators Performance and Optimization For Energy Savings

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Outline

- Energy savings in glass furnaces: what is at stake?
- Thermal fundamentals for regenerators
- Regenerators solutions
- Industrial references & service offers
Energy Savings in Glass Furnaces:
What is at Stake?
Energy in The Glass Industry

Production cost: 15%
Energy: 70%
Melting & Refining: 40%

Theoretical energy to melt glass
Importance of heat recovery from fumes

\[ Q_F + Q_A = Q_G + Q_L + Q_E \]

- \( Q_F \): 70%
- \( Q_A \): 30%
- \( Q_G \): 30%
- \( Q_L \): 25%
- \( Q_E \): 45%

\[ \varepsilon = \frac{Q_A}{Q_E} \]
Importance of high efficiency packing

- Higher efficiency (ε) could be used to reduce fuel quantity required
- Or to increase the pull (higher energy supply)
Magnitude of fuel savings

- **Container glass**, 300 T/day, 950 kCal/kg
  - 1% saving  ➞ 30 to 40 k$/year
  - 5% saving  ➞ 140 to 210 k$/year

- **Float Furnace**, 700 T/day, 1300 kCal/kg
  - 1% saving  ➞ 100 to 140 k$/year
  - 5% saving  ➞ 490 to 700 k$/year

Efficient regenerator is an important contributor for a greener process:
- Less fuel consumption means fewer emissions such as NO\textsubscript{x} and CO\textsubscript{2}
- Exhaust fumes are released colder in atmosphere
- Particules are filtred and kept inside….etc….
Thermal Fundamentals for Regenerators
Thermal Balance

\[ Q_F + Q_A = Q_G + Q_L + Q_E \]

\[ \varepsilon = \frac{Q_A}{Q_E} \]
Heat Exchange Law

\[ Q = K \cdot S \cdot \Delta\theta \]

- Heat quantity exchange per cycle
- Global heat exchange coefficient
- Heat exchange surface

\[ \Delta\theta = \frac{(\Delta\theta_1 - \Delta\theta_2)}{[\ln (\Delta\theta_1 / \Delta\theta_2)]} \]

\[ \Delta\theta_1 = \Delta \text{fumes} - \text{air at the top} \]
\[ \Delta\theta_2 = \Delta \text{fumes} - \text{air at the bottom} \]

- Heat exchange is not only a function of specific surface
- Heat exchange coefficient is also very important
## Materials Specific Surfaces

<table>
<thead>
<tr>
<th>Shape</th>
<th>Name</th>
<th>Thickness</th>
<th>Typical Flue Size</th>
<th>Specific Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="image">Cruciform Type 8</a></td>
<td>30 mm</td>
<td>150 x 60 mm</td>
<td>26.0 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Cruciform Type 4</a></td>
<td>30 mm</td>
<td>150 x 150 mm</td>
<td>18.1 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Cruciform Type 3</a></td>
<td>30 mm</td>
<td>150 x 150 mm</td>
<td>15.5 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Cruciform Type 6</a></td>
<td>30 mm</td>
<td>330 x 330 mm</td>
<td>9.3 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Chimney Block TL</a></td>
<td>40 mm</td>
<td>140 x 140 mm</td>
<td>16.9 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Chimney Block TG</a></td>
<td>40 mm</td>
<td>140 x 140 mm</td>
<td>15.9 m²/m³</td>
<td></td>
</tr>
<tr>
<td><a href="image">Bricks (Basket Weave)</a></td>
<td>64 mm</td>
<td>150 x 150 mm</td>
<td>11.0 m²/m³</td>
<td></td>
</tr>
</tbody>
</table>
Heat Exchange Law

\[
Q = K \cdot S \cdot \Delta \theta
\]

- Heat quantity exchange per cycle
- Global heat exchange coefficient
- Heat exchange surface

\[
\Delta \theta = \frac{(\Delta \theta_1 - \Delta \theta_2)}{\ln \left( \frac{\Delta \theta_1}{\Delta \theta_2} \right)}
\]

- \( \Delta \theta_1 = \Delta \) fumes - air at the top
- \( \Delta \theta_2 = \Delta \) fumes - air at the bottom

Heat exchange is not only a function of specific surface
Heat exchange coefficient is also very important
Heat Exchange Coefficient

\[ K = \frac{t}{1 + \frac{1}{Ha} + \frac{e}{Hf} + \frac{3\lambda}{Hf}} \]

- \( t = \) half cycle
- \( e = \) wall thickness
- \( \lambda = \) heat conductivity
- \( Hf = \) heat exchange coefficient fumes - refractory
- \( Ha = \) heat exchange coefficient refractory - air

Fumes cycle \( Hf_1 \approx Hf_2 \)

Air cycle \( Ha_1 > Ha_2 \)

Cruciforms are more efficient in terms of energy restitution
Checker surface as a function of the height

Packing top
Forced Convection
\( V_{\text{gas}} = f(\Delta P, V_0) \)

Packing bottom
Free convection
\( V_{\text{gas}} = f(\Delta T) \)

Corrugated is better!

Smooth is better!
Open channels versus closed channels

Open channels lead to a more homogeneous flow and less "cold spot".
From pilot plant to performance prediction

Regenerator pilot plant for Cruciform development

State of the art thermal simulation software

Customized thermal performance simulation and report with benchmark between several solutions
Pilot scale test unit: unique in the world

- « GRETh » is an independent research center, specialized in thermal exchanges, belonging to the CEA (French National Agency for Nuclear Power)

- The test loop has been designed to reproduce industrial regenerators conditions:
  - Temperature levels
  - Height (to combine natural and forced convection)
State of the art numerical simulation

Alternate calculations until convergence

Convergence of total wall heat flow

- Heat Flow Air/exhaust
- average

1/2 cycle #
On-site measurements VS simulations

Our numerical approach has been validated with various on site thermal measurements with good fit

| Float Lux. Port 1 | Cruciforms Type 2 | 1551 | 524 | 540 | 160 | 1385 | 1352 |
| Float Lux. Port 2 | Cruciforms Type 2 | 1579 | 623 | 645 | 178 | 1397 | 1368 |
| End Fired Spain Right | Cruciforms Type 3&6 | 1236 | 635 | 608 | 268 | 1136 | 1119 |
| End Fired Spain Left | Cruciforms Type 3&6 | 1225 | 622 | 596 | 249 | 1106 | 1104 |
| Float Germany | Cruciforms Type 2 | 1406 | 634 | 662 | 148 | 1217 | 1197 |
| Float Germany | Chimney Blocks | 1388 | 576 | 596 | 175 | 1165 | 1155 |
| Container USA | Cruciforms Type 3&4 | 1392 | 566 | 543 | 101 | 1290 | 1318 |
| Container USA | Maerz Bricks | 1359 | 505 | 524 | 96 | 1201 | 1191 |
| Container Germany 1 | Cruciforms Type 3&4 | 1460 | 575 | 551 | 75 | 1385 | 1405 |
| Container Germany 2 | Cruciforms Type 3&4 | 1445 | 525 | 506 | 60 | 1365 | 1379 |
Regenerators Solutions
Some checkers common solutions

**BRICKS**
(typical Maerz design)

- Efficiency: LOW
- Lifetime: 5 y
- Installation: LONG
- Maintenance: HARD

**CHIMNEY BLOCKS**

- Efficiency: MODERATE
- Lifetime: VARIABLE 5-10 y
- Installation: FAST
- Maintenance: DIFFICULT

**CRUCIFORMS**

- Efficiency: HIGHEST
- Lifetime: 15+ y
- Installation: FAST
- Maintenance: EASY
Beyond thermal performance

Critical criteria
- Lifetime: corrosion and mechanical resistance

Secondary criteria
- Installation: easy, reliable and fast
- Maintenance: partial repair, thermal cleaning

To reach the best technical and economical compromise
Lifetime criteria: typical checker stresses

- **BATCH & FUMES**
  - $SiO_2$, $NaOH$, $CaO$, $SO_x$, $V_2O_5$...

- **CHECKERWORK**
  - Mecanisms are function of:
    - Carry-over quantity and nature
    - Fuel type and purity
  - Mecanisms change with:
    - Temperature level
    - Atmosphere (oxydizing/reducing)
    - Height in the checkerwork

- **ABRASION / EROSION**
- **CHEMICAL ATTACKS**
- **CONDENSATION**
- **MECHANICAL LOAD**
- **THERMAL CYCLING**
Cruciforms range: 40 years of innovations to meet market expectations

Wide range of cruciform designs

as well as materials for specific applications

AZS ER 1682 RX, Alumina ER 5312 RX, Spinel ER 55XX RX
**Cruciforms range: standard design**

**TOP & HOT ZONE:** abrasion by gas and carry-over particules. High alumina provides excellent resistance to these corrosions.

**CONDENSATION ZONE:** chemical resistance to various corrosive agent such as sodium sulfates or hydroxides. Fused cast spinel is a must.

**BOTTOM PART:** area mainly exposed to mechanical load of the package and thermal cycling (cold air entrance).
Latest evolution: Type 8 for top courses

- Type 8 « half channels » patented design
- For high performance regenerators
- Significant fuel consumption reduction (from 2% to 8%)
- Gaz emissions reduction as a consequence
- Design has been allowed by fused casting process
‘On site’ *Type 8* validation

5 layers of Type 8 topping are located on Port 4 in a flat glass furnace.

The performances of Port 4 and Port 3, once fully instrumented and monitored, have been compared.

*Type 8* effect on industrial furnace reached +5% of regenerator efficiency vs standard.
Type 8 has already convinced the glass industry WW
Full scale calculations on standard cases

140/40 mm CHIMNEY BLOCKS

TYPE 4
8,4 m

150/30 mm

TYPE 6
2100 mm

150/30 mm

TYPE 3
150/30 mm

TYPE 4

150-60/30 mm

8,4 m

2100 mm

Regenerator Efficiency

74 %

72 %

71 %

67 %

Specific Weight

935 Kg/m³

870 Kg/m³

790 Kg/m³

1020 Kg/m³

SAINT-GOBAIN
MATEMUA HAUTE PERFORMANCE
Industrial References Worldwide
Cruciforms application area

Cruciforms solutions largely referenced worldwide in all sodalime furnaces technologies
Since 2000, 170 000 tons sold
More than 1 400 furnaces equipped in the world
Industrial successes in container industry

11% fuel savings (France)

Les trophées des technologies économiques et propres

11% fuel savings (France)

11% fuel savings (France)

Improving regenerator efficiency
2% fuel savings (Portugal)

Corrugated cruciform packing in a glass furnace regenerator

7.7% fuel savings (UK)
SEFPRO Services beyond products:

- On site assistance and measurement
- Refractory expertise in R&D
- Thermal performance simulation
- .... And more!
Conclusions
Conclusions

- **Regenerators are key** to control thermal efficiency
- **Specific surface and optimized design** of checkers are the key
- Experimental and analytical tools led to the development of the **cruciform range**
- **Payback can be precisely calculated** taking into account the fuel savings generated
- **New Type 8 for topping** is a new step forward into efficiency improvement
- Cruciforms range offers **a tailor-made experience** meeting the right technical and financial positioning
- **Some specificities may apply to your case**: please contact your SEFPRO representative
Thank you!

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