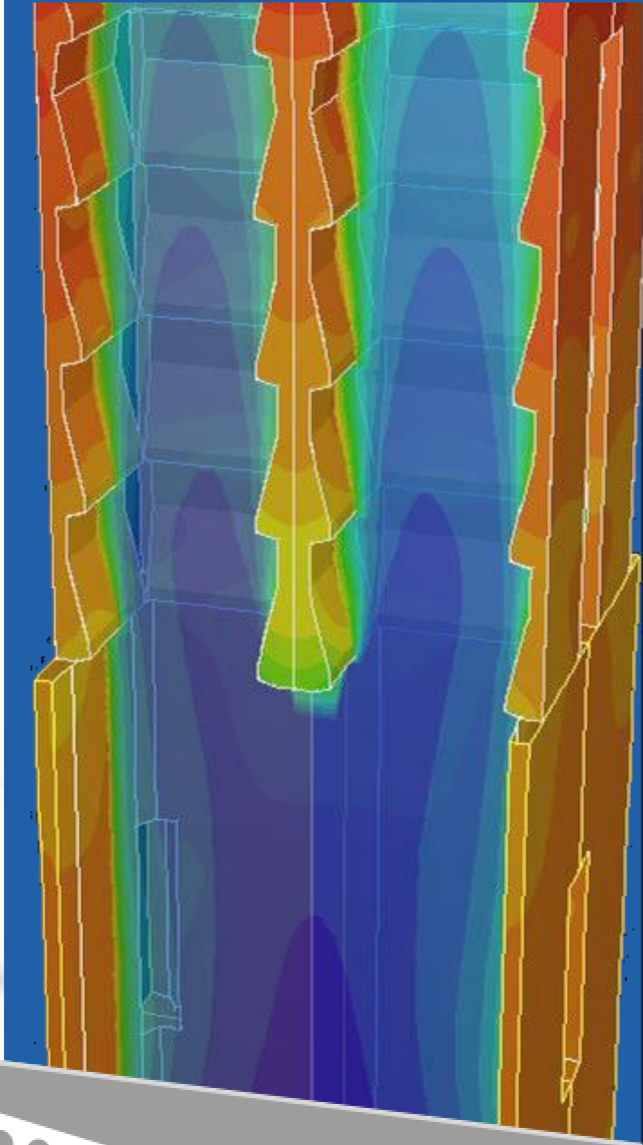
Glass Furnaces' Regenerators Performance and Optimization For Energy Savings



Sebastien Bourdonnais

Bali, September 17th 2013

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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?

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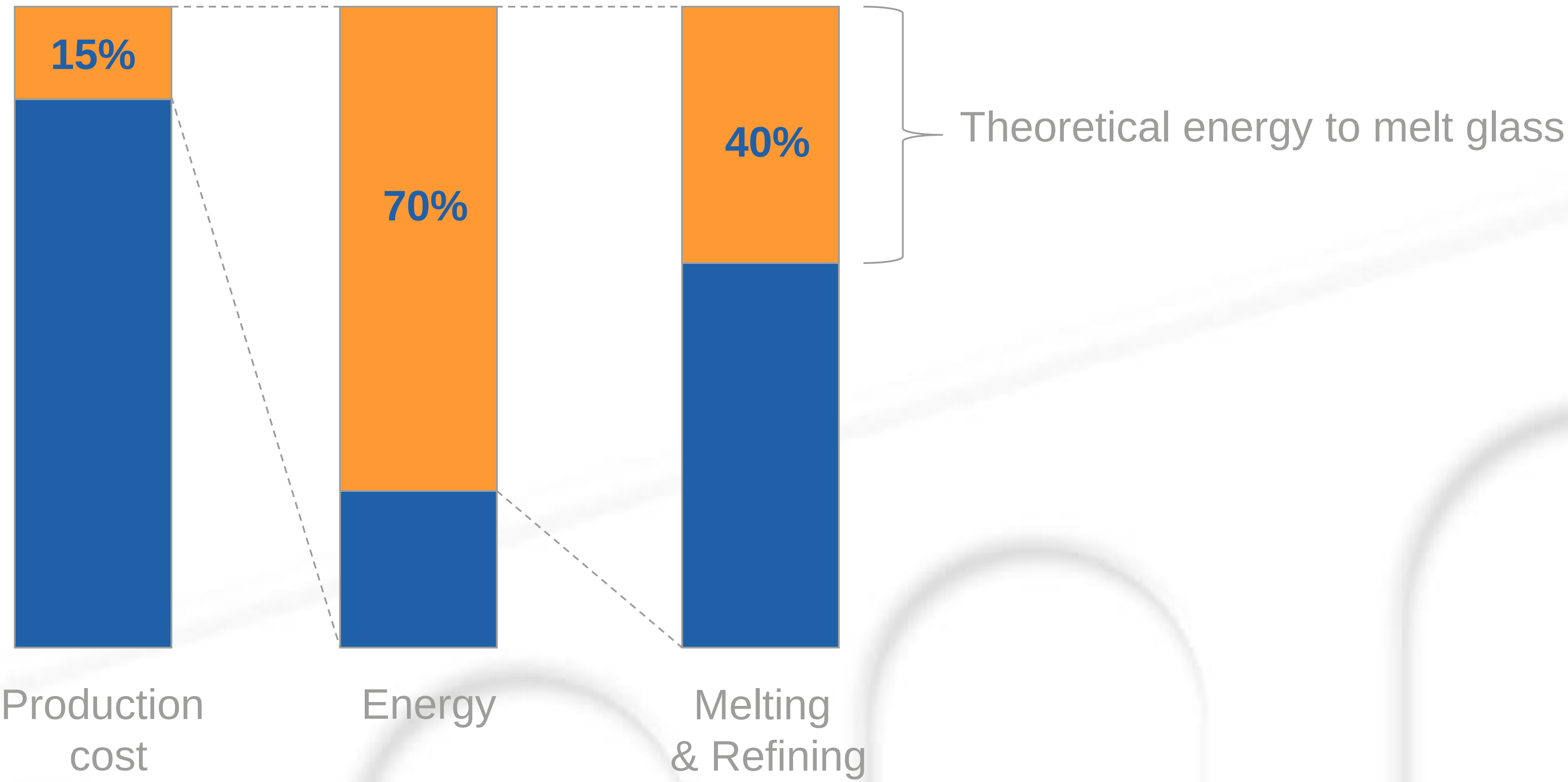
Energy in The Glass Industry



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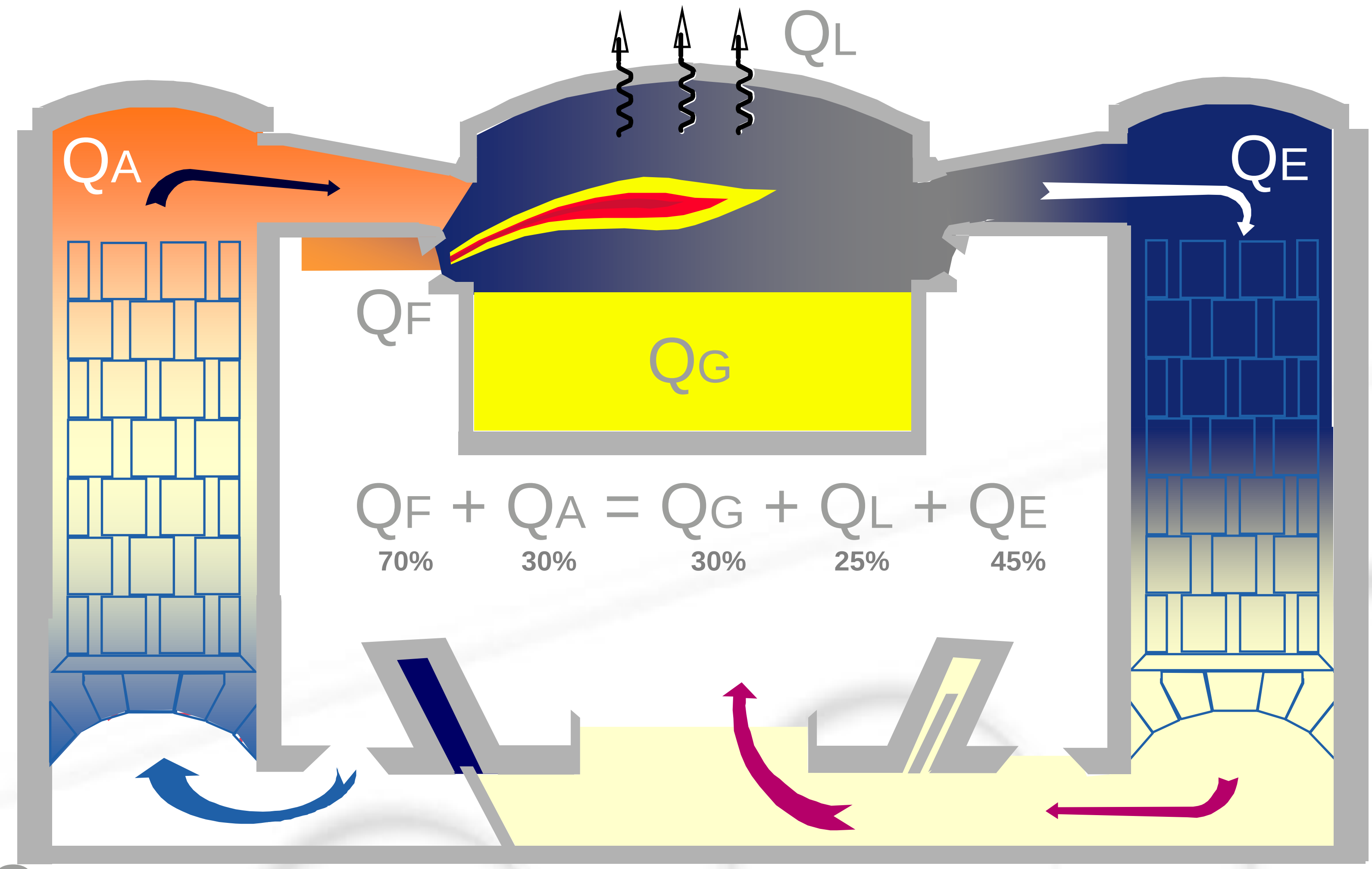
Importance of heat recovery from fumes



$$\varepsilon = \frac{Q_A}{Q_E}$$

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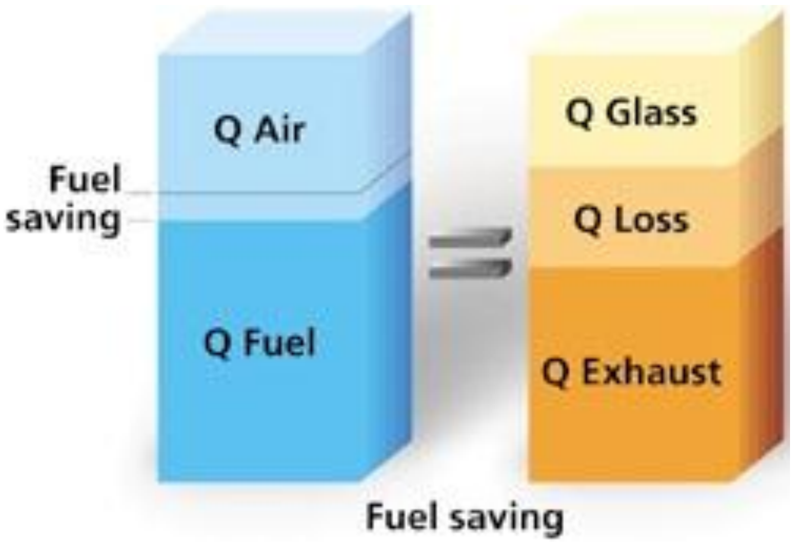
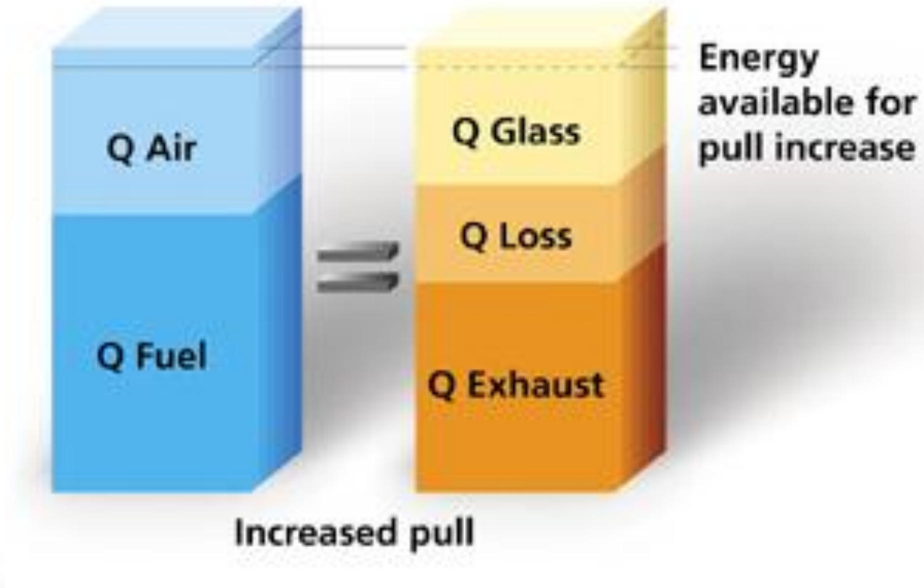
Importance of high efficiency packing

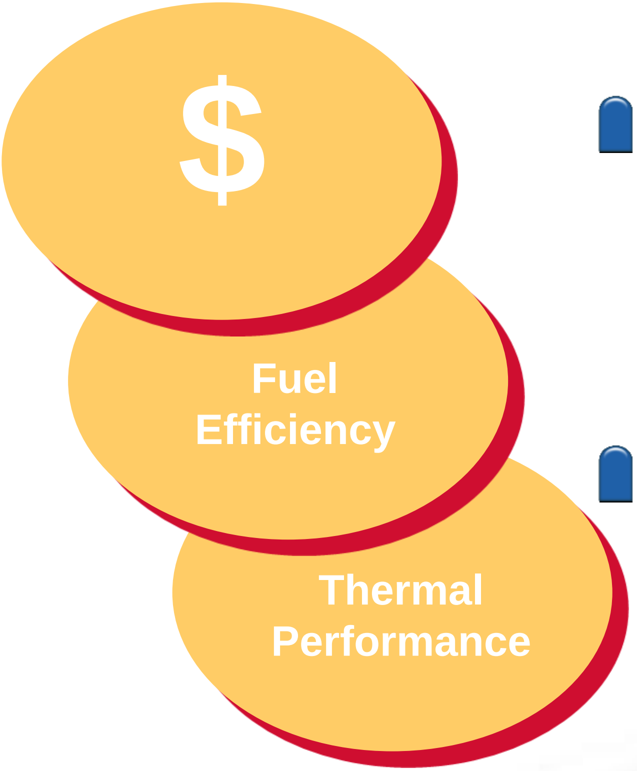


OR



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

Magnitude of fuel savings

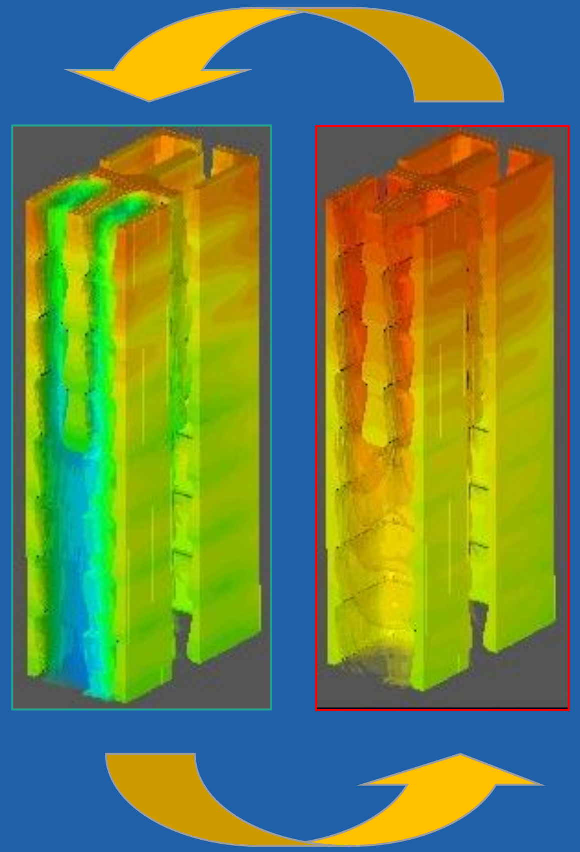


- **Container glass, 300 T/day, 950 kCal/kg**
  - 1% saving ⇔ 30 to 40 k$/year
  - 5% saving ⇔ 140 to 210 k$/year

- **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_x and CO_2
- Exhaust fumes are released colder in atmosphere
- Particules are filtred and kept inside….etc…

Thermal Fundamentals for Regenerators



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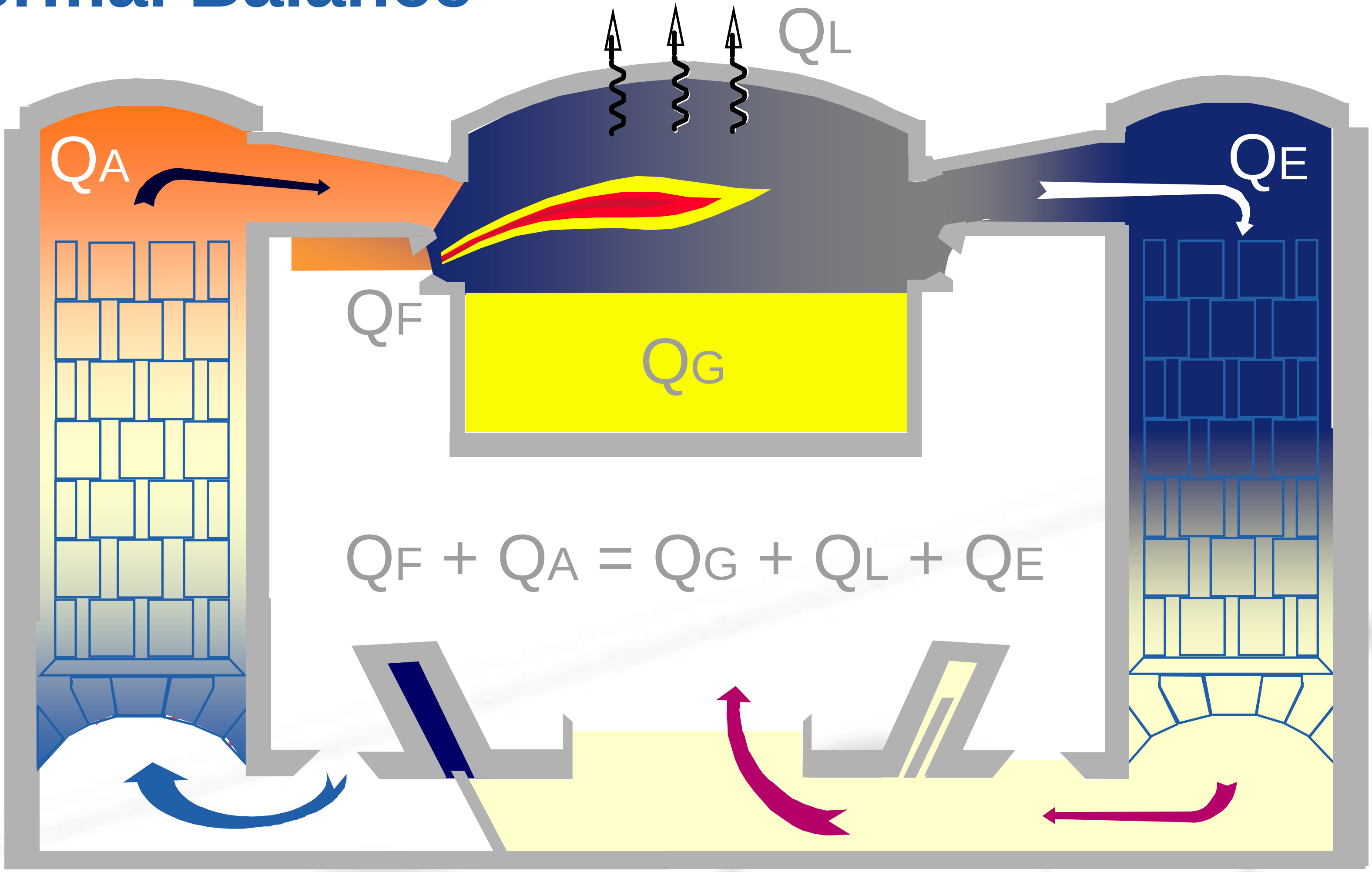
Thermal Balance



$$Q_F + Q_A = Q_G + Q_L + Q_E$$

$$\varepsilon = \frac{Q_A}{Q_E}$$

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Heat Exchange Law

$$Q = K . S . \Delta\theta$$

Heat quantity exchange per cycle

Global heat exchange coefficient

Heat exchange surface

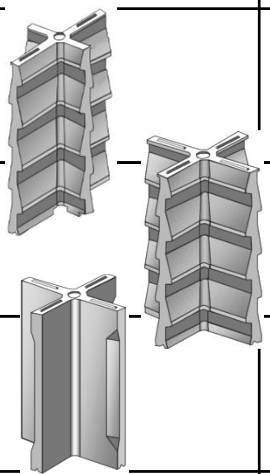
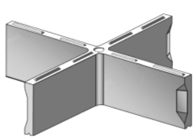
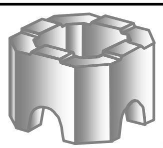
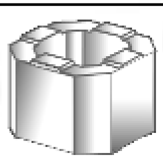
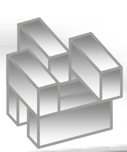
$\Delta\theta = (\Delta\theta1 - \Delta\theta2) / [\mathrm{Ln}\ (\Delta\theta1 / \Delta\theta2)]$

$\Delta\theta1 = \Delta$ fumes - air at the top

$\Delta\theta2 = \Delta$ fumes - air at the bottom

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

Materials Specific Surfaces

Shape	Name	Thickness	Typical Flue Size	Specific Surface
	Cruciform Type 8	30 mm	150 x 60 mm	26.0 m^2/m^3
	Cruciform Type 4	30 mm	150 x 150 mm	18.1 m^2/m^3
	Cruciform Type 3	30 mm	150 x 150 mm	15.5 m^2/m^3
	Cruciform Type 6	30 mm	330 x 330 mm	9.3 m^2/m^3
	Chimney Block TL	40 mm	140 x 140 mm	16.9 m^2/m^3
	Chimney Block TG	40 mm	140 x 140 mm	15.9 m^2/m^3
	Bricks (Basket Weave)	64 mm	150 x 150 mm	11.0 m^2/m^3

Heat Exchange Law

$$Q = K \cdot S \cdot \Delta\theta$$

Heat quantity exchange per cycle

Global heat exchange coefficient

Heat exchange surface

$\Delta\theta = (\Delta\theta 1 - \Delta\theta 2) / [\mathrm{Ln}\,(\Delta\theta 1 / \Delta\theta 2)]$

$\Delta\theta 1 = \Delta$ fumes - air at the top

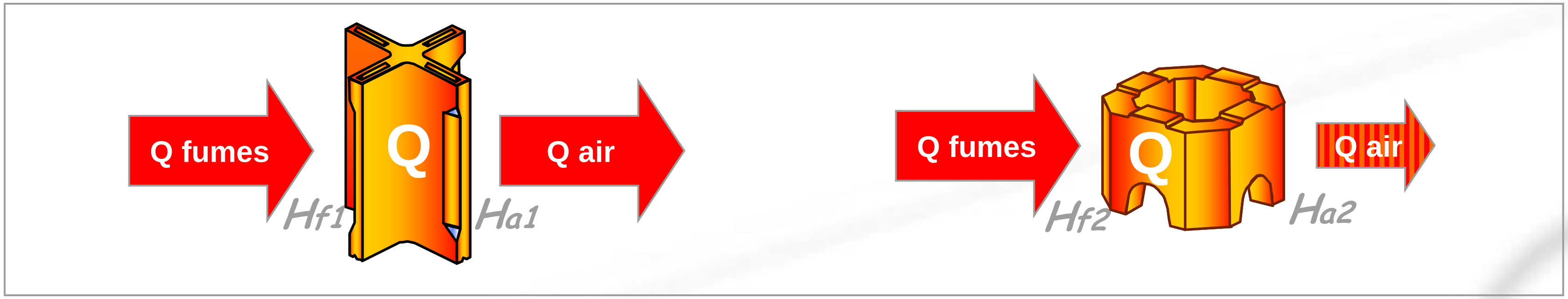
$\Delta\theta 2 = \Delta$ fumes - air at the bottom

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

Heat Exchange Coefficient

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

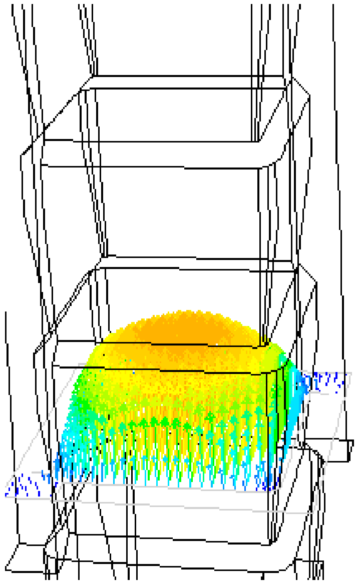
t = half cycle
e = wall thickness
λ = heat conductivity
Hf = heat exchange coefficient fumes - refractory
Ha = heat exchange coefficient refractory - air



Fumes cycle $H_{f1} \approx H_{f2}$
Air cycle $H_{a1} > H_{a2}$

- Cruciforms are more efficient in terms of energy restitution

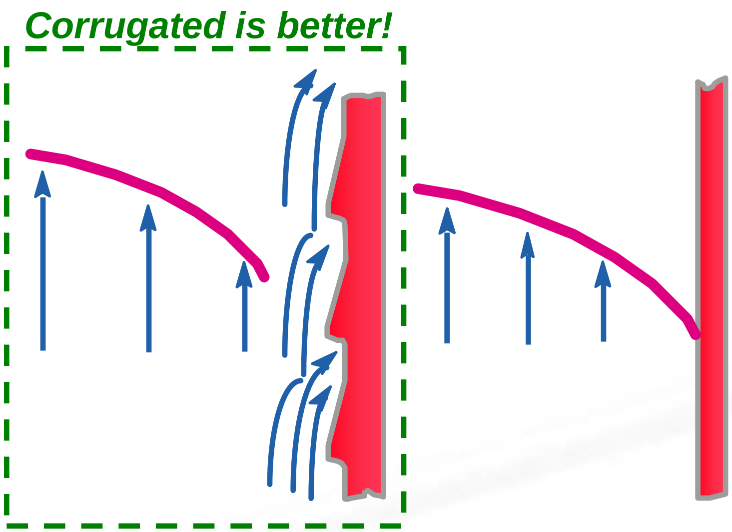
Checker surface as a function of the height

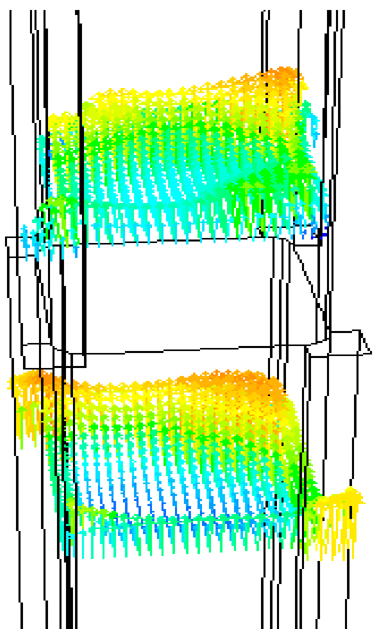


Packing top

Forced Convection

$V_{gas} = f(\Delta P, Vo)$

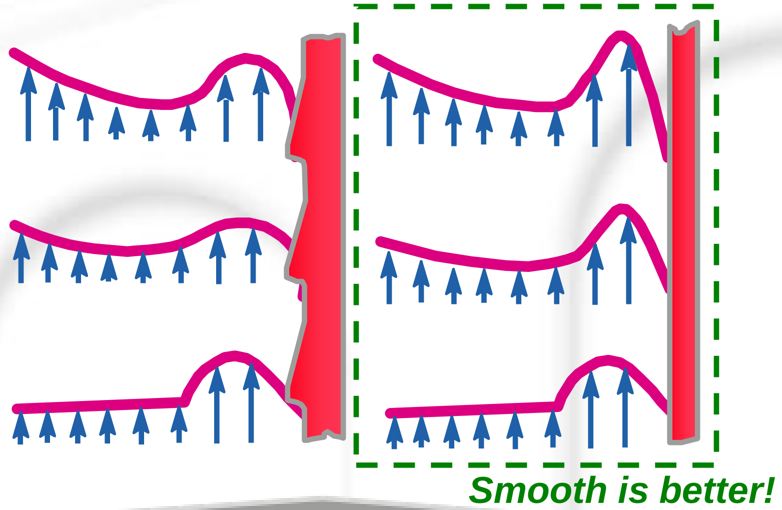




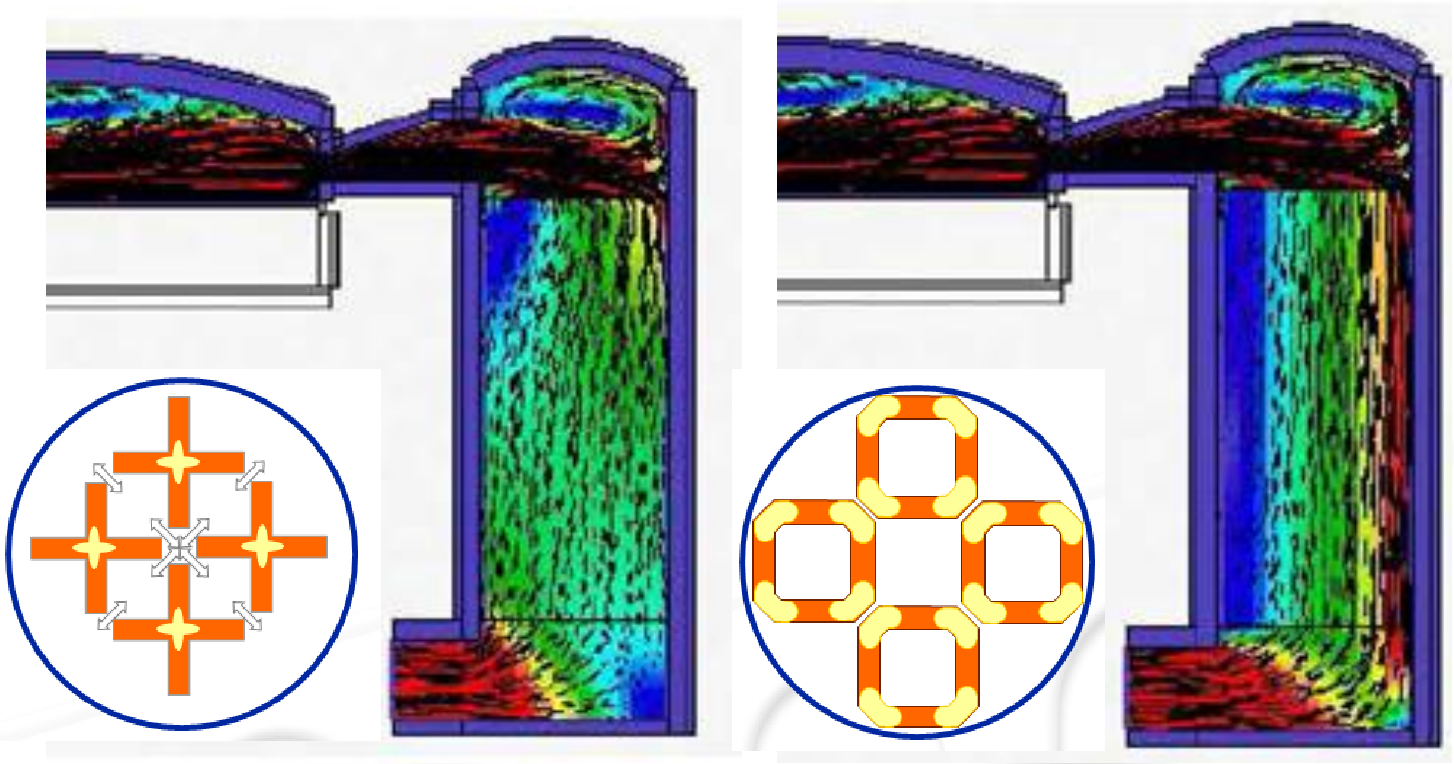
Packing bottom

Free convection

$V_{gas} = f(\Delta T)$



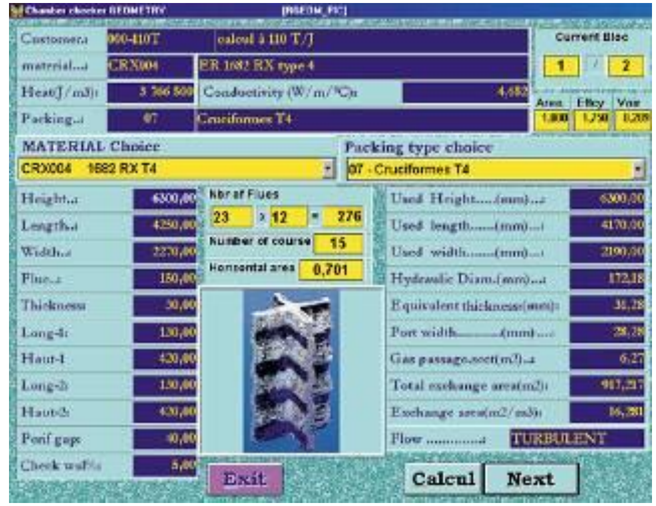
Open channels versus closed channels



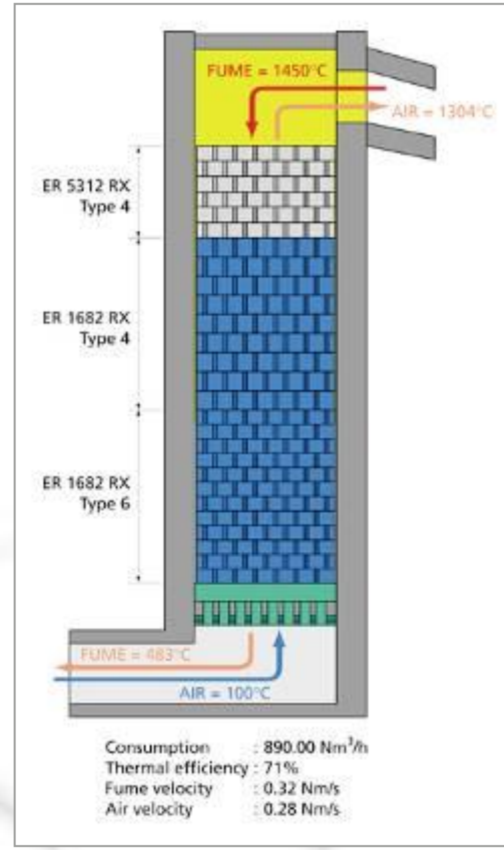
- Open channels lead to and more homogeneous flow repartition less “cold spot”

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

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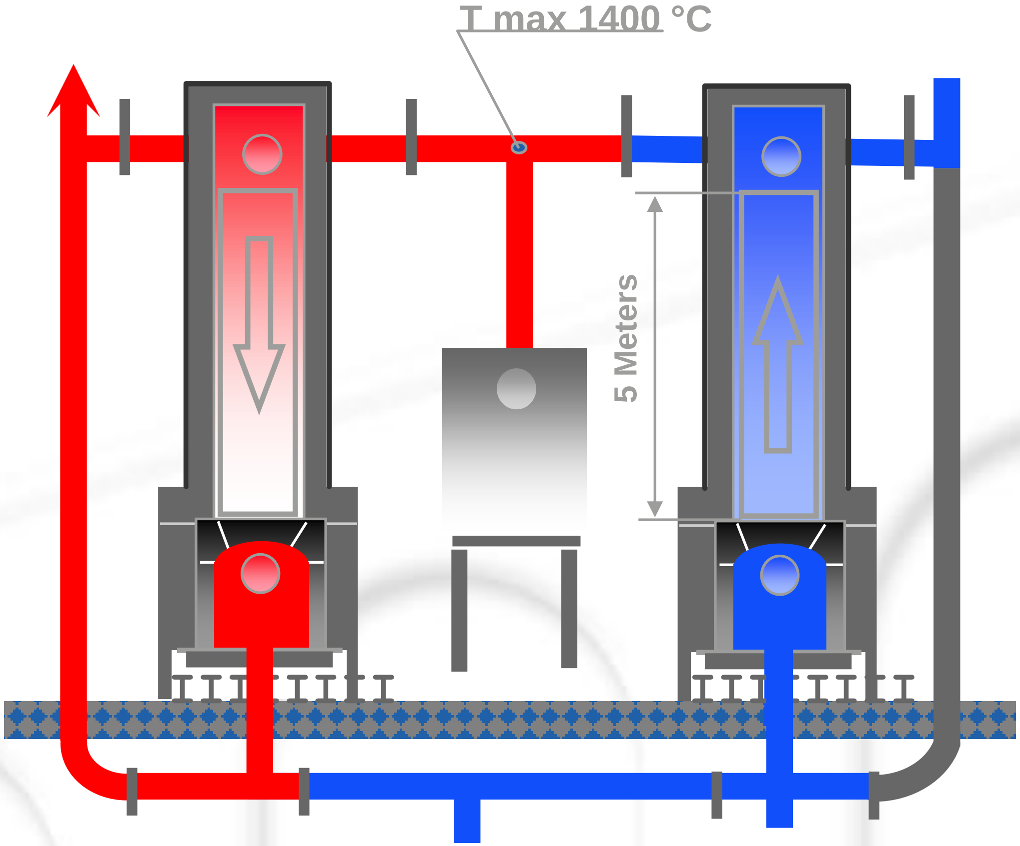
Pilot scale test unit: unique in the world

- « 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)



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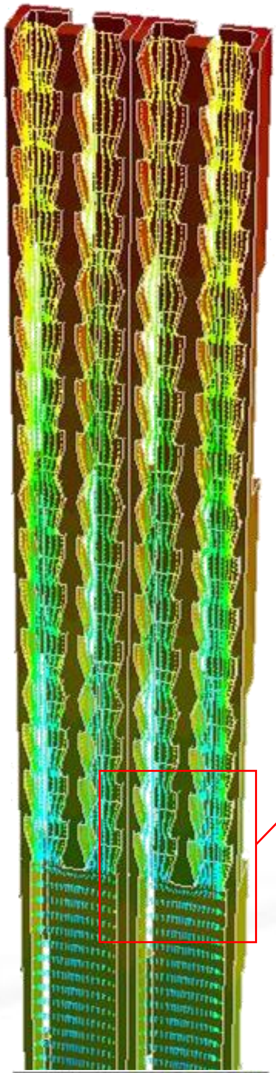
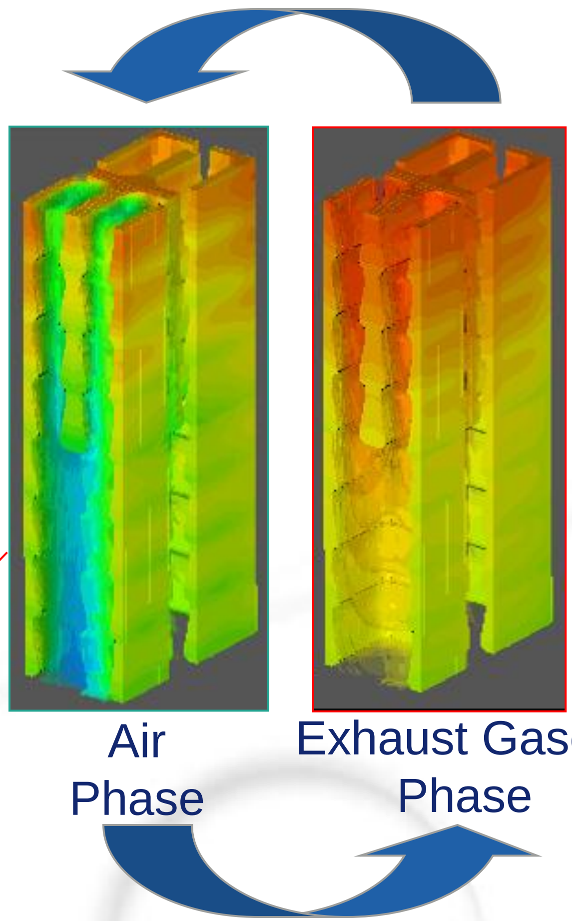
State of the art numerical simulation

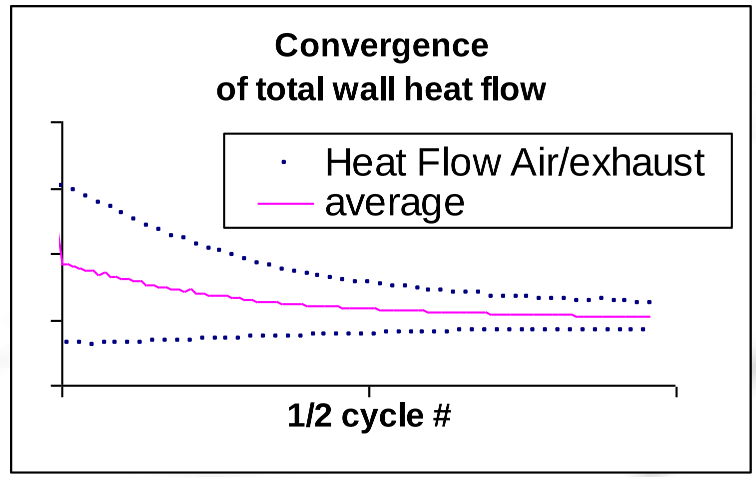




Air Phase

Exhaust Gases Phase

Alternate calculations until convergence



ANSYS FLUENT

On-site measurements VS simulations

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

Legend: Measured (green) / Calculated (yellow)

		FUMES			AIR		
		Entry	Exit (Measured)	Exit (Calculated)	*Entry*	Exit (Measured)	Exit (Calculated)
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

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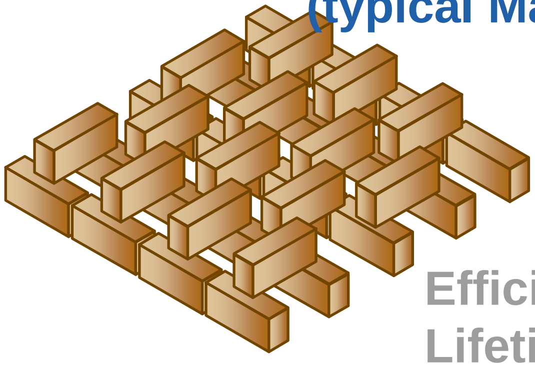
Some checkers common solutions

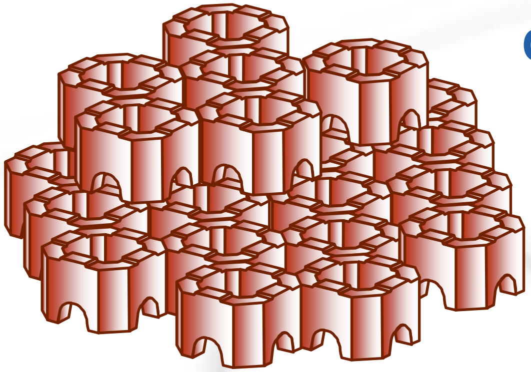
BRICKS
(typical Maerz design)



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

CRUCIFORMS

Efficiency: HIGHEST
Lifetime: 15+ y
Installation: FAST
Maintenance: EASY



CHIMNEY BLOCKS

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

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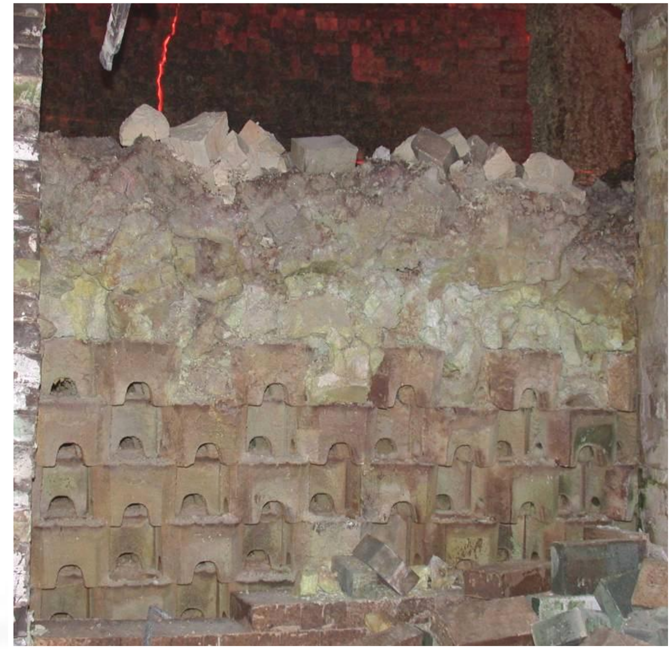
Beyond thermal performance

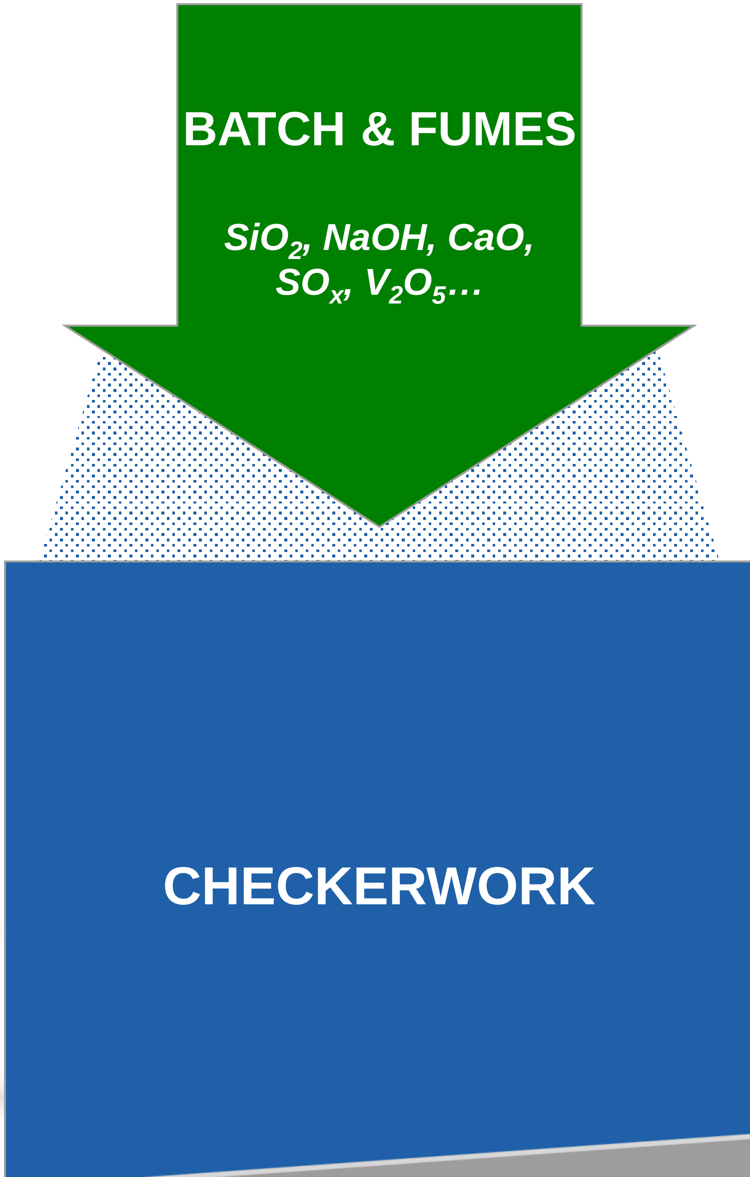


- **Critical criteria**
  - **Lifetime: corrosion and mechanical resistance**

- **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



- 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

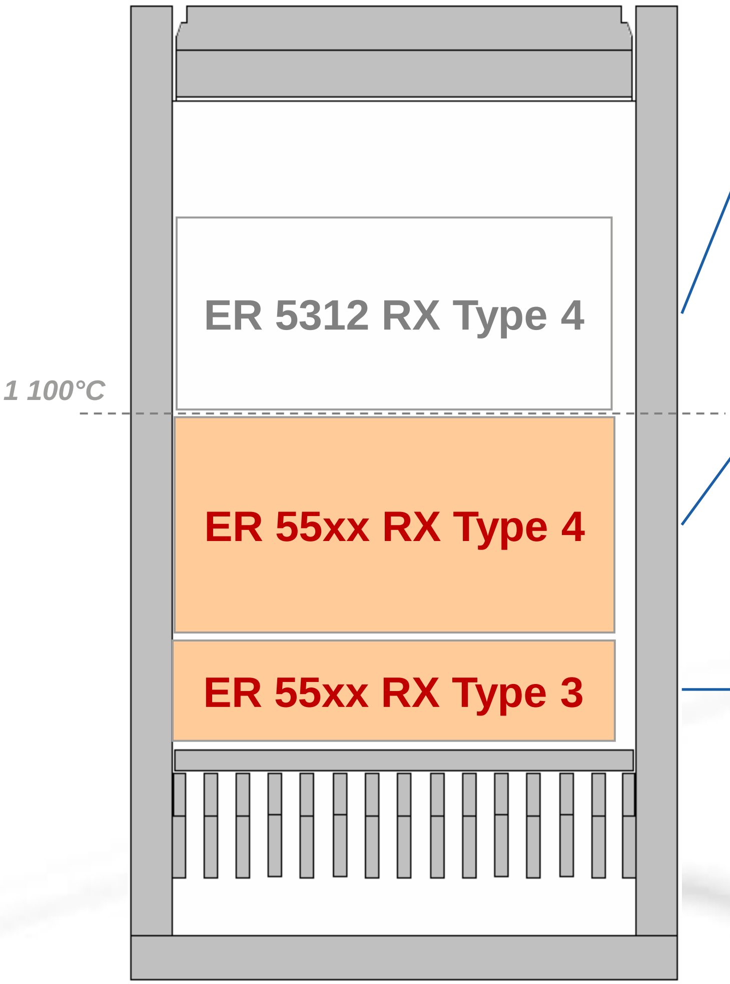
- **Wide range of cruciform designs**

Type 1	Type 2	Type 3	Type 4	Type 6	Type 8
1973	1975	1986	1990	1997	2009

- **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).

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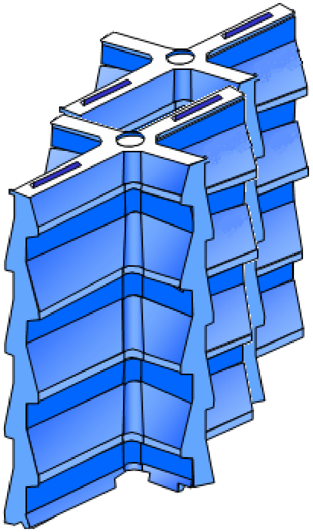
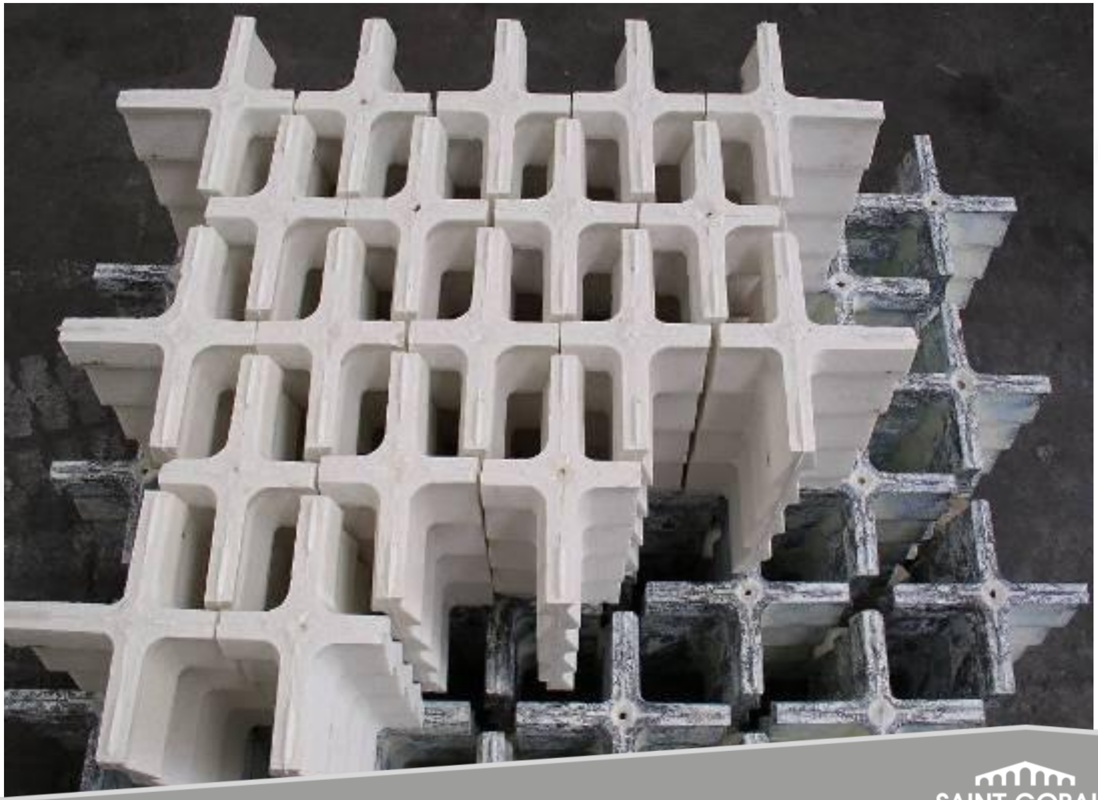
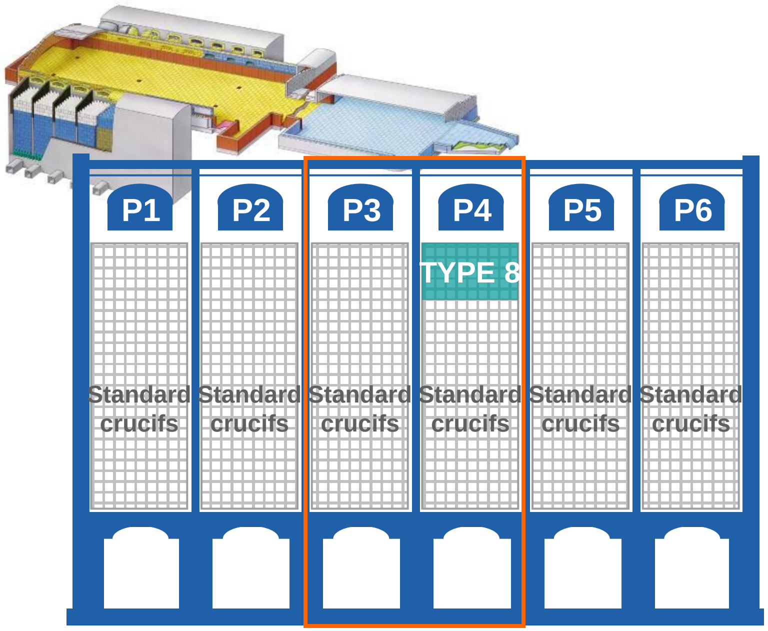
Latest evolution: Type 8 for top courses



- 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



Thermal balance comparison P3 vs P4

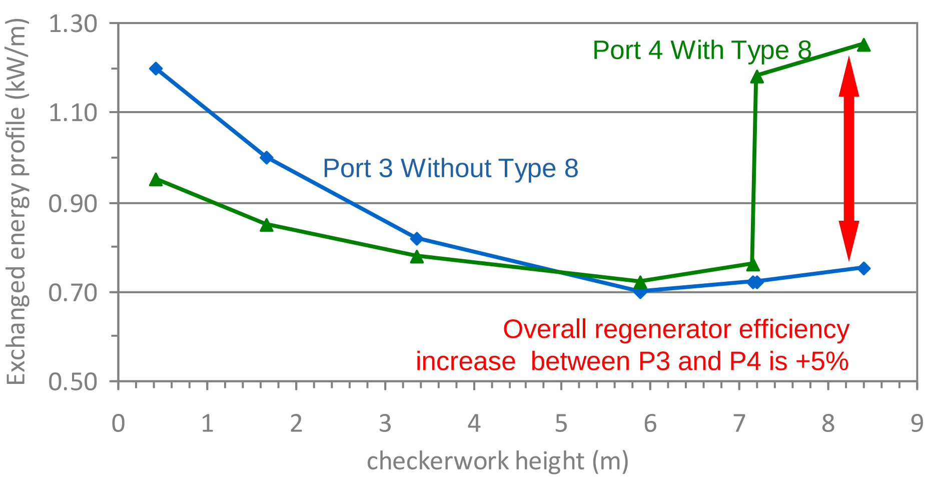
5 layers of Type 8 topping are located on Port 4 in a flat glass furnace

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

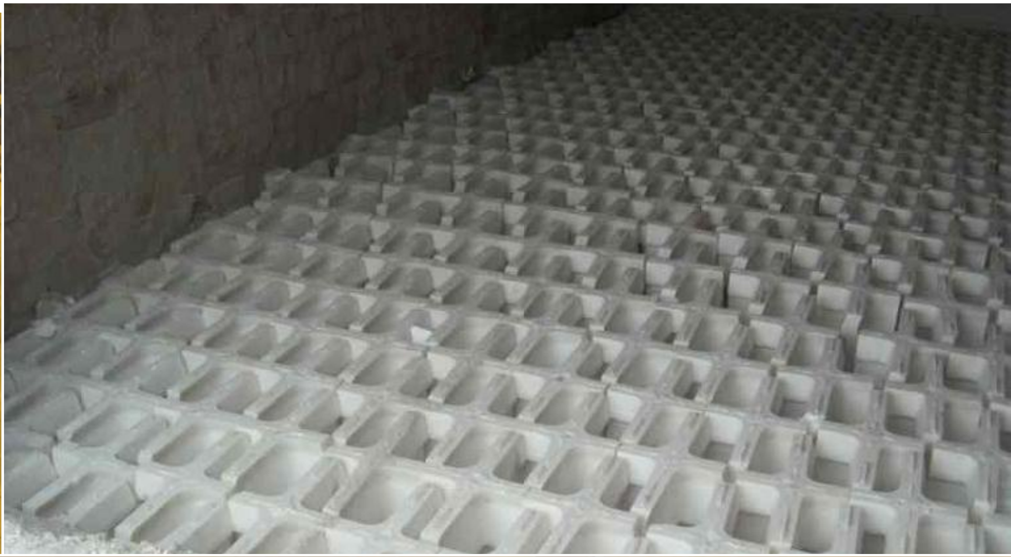
Type 8 effect on industrial furnace reached +5% of regenerator efficiency vs standard

Embedded thermocouples at 6 different heights

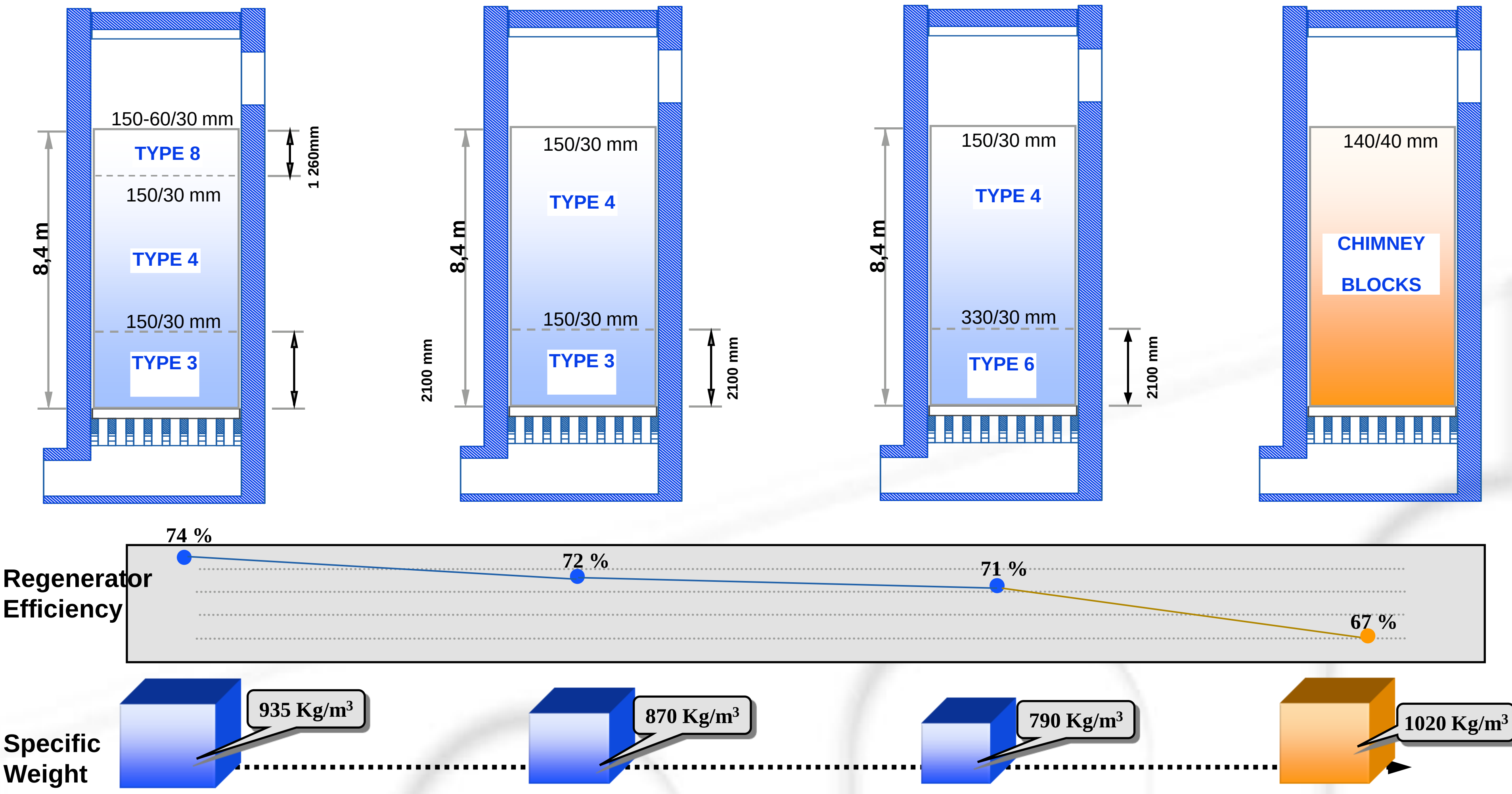
Aspiration pyrometer for gas analysis



Type 8 has already convinced the glass industry WW



Full scale calculations on standard cases



Industrial References Worldwide

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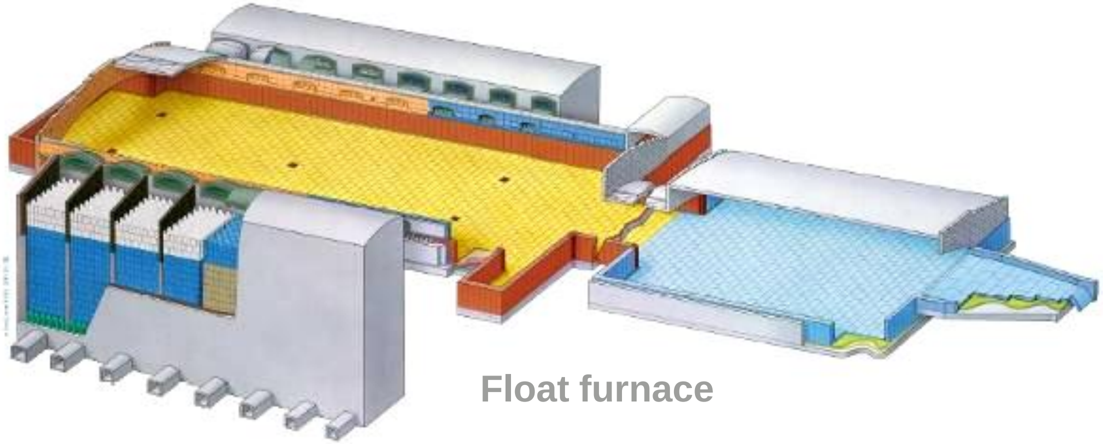
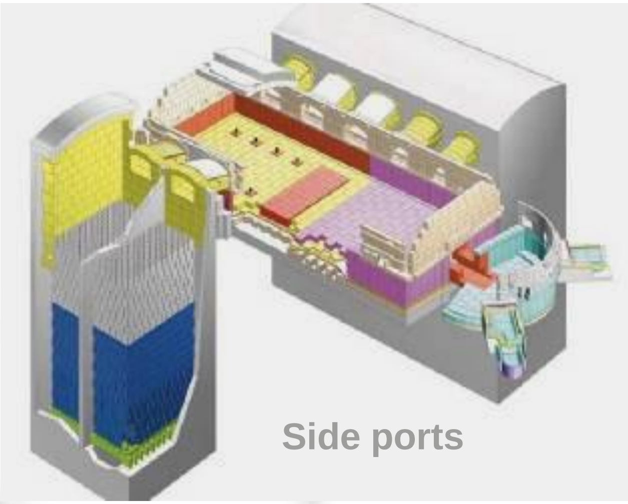
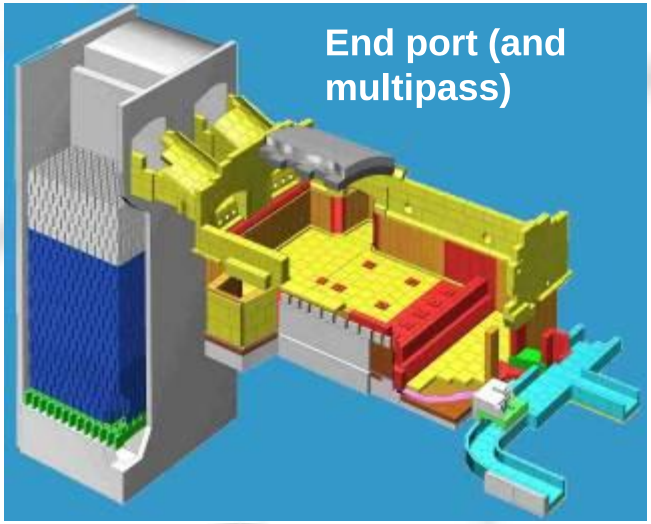
Cruciforms application area

Cruciforms solutions largely referenced worldwide in all sodalime furnaces technologies



Float furnace





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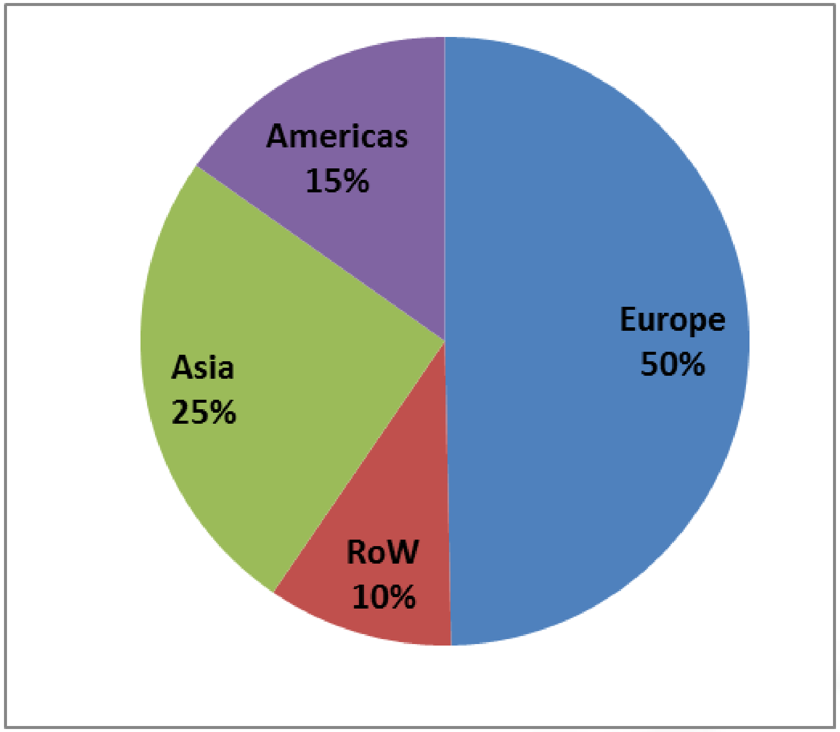
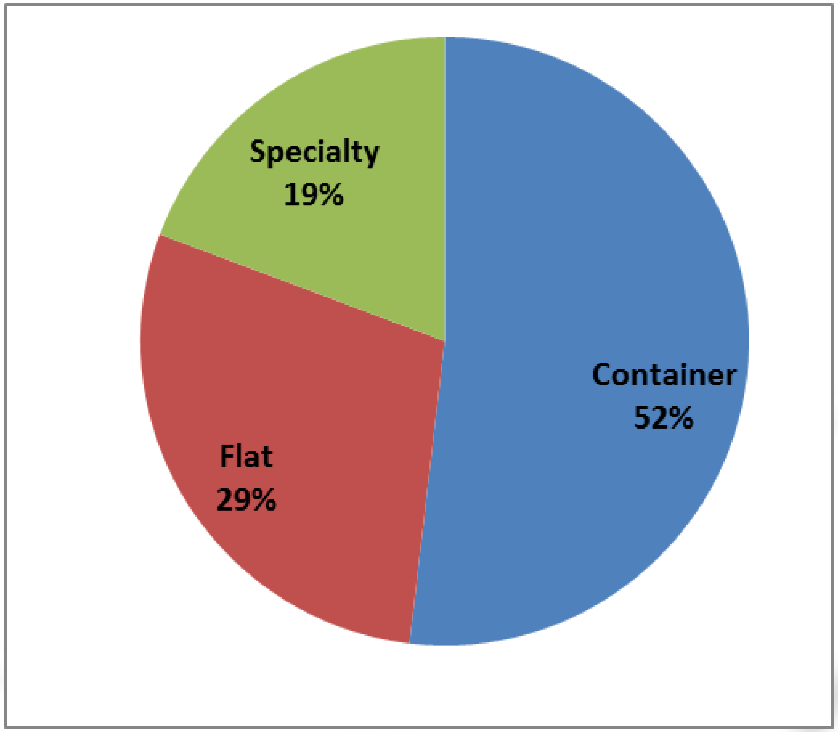
MATERIAUX HAUTE PERFORMANCE

Wordwide leading reference





- Since 2000, 170 000 tons sold
- More than 1 400 furnaces equipped in the world

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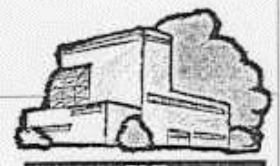
MATERIAUX HAUTE PERFORMANCE

Industrial successes in container industry

11% fuel savings (France)

À L'INITIATIVE DE L'ADEME ET D'INDUSTRIES ET TECHNIQUES

Les trophées des technologies économes et propres



Le 13 octobre, au salon Pollutec, six industriels ont reçu le trophée Technologies économes et propres. Comme s'est plu à le souligner Claude Mandil, directeur général de l'énergie et des matières premières, les lauréats ont mon-

AVEC UN MATÉRIAU ET DES PROCÉDÉS NOUVEAUX

Tourres économise 850 TEP et épure ses fumées de verrerie

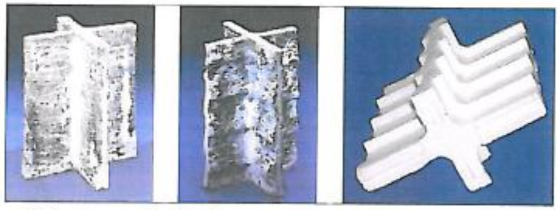
Le verrier-bouteiller a innové … ronnement était à l'ordre du jour ! … donc cherché à réduire les émissions

Improving regenerator efficiency

2% fuel savings (Portugal)

A new solution has been implemented in a large end port furnace for container glass. It led to an increase in efficiency with no other impact on furnace working conditions. By D. Lechevalier*, A. Pinto**, V. Domingues**, O. Citti*, M. Gaubil***

Energy consumption reduction is an increasing concern within the glass industry. Surveys show an important spread of efficiency among many furnaces[1]. Representing up to 20% of the glass production cost, the share of energy is increasing despite glass melting process optimisations. In addition to production cost, energy consumption drives the emission of heavily regulated NO_x and SO_x emissions. As a requirement for industry competitiveness and its environmental



▲ Fig 1. Type 3 (smooth, left) and Type 4 (corrugated, centre) and new Type 8 (right)

New Practice

Final Profile 69

Corrugated cruciform packing in a glass furnace regenerator

Project Objective

To demonstrate the energy benefits of using corrugated cruciform packing in a glass furnace regenerator.

Potential Users

Glass manufacturers operating regenerative tank furnaces.

Investment Cost

£94,370 (1992 prices).

Savings Achieved

41,276 GJ/year, worth £79,880 (1993 prices).

Payback Period

14 months.

Host Organisation

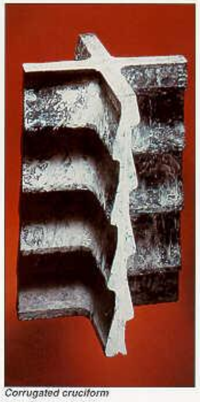
Rockware Glass Ltd
Headlands Lane
Knottingley
West Yorkshire
WF11 0HP

Monitoring Contractor

British Glass
Northumberland Road
Sheffield
S10 2UA
Tel No: 0742 686201
Fax No: 0742 681073
Mr W A Hartley

Equipment Manufacturer

SEPR Ceramics Ltd
Crompton Road
Ilkeston
Derbyshire
DE7 4BG
Tel No: 0602 309555
Fax No: 0602 329789
Mr I Whittaker



Corrugated cruciform

Project Summary

The installation of a new type of regenerator packing has improved both combustion air pre-heat temperatures and the efficiency of fuel use on a furnace at Rockware Glass Ltd's Wheatley factory.

The new packing was one of a number of improvements incorporated during a furnace rebuild. Its corrugated cruciform design increased convective heat-exchange coefficients within the regenerator, increased combustion air temperatures by 118°C and improved regenerator efficiency from 58.6% to 66.9%. The associated reduction in fuel consumption is close to 8%.

Over a one-year period the energy savings attributable to the new regenerator packing totalled 41,276 GJ/year. These were worth £79,880/year to the company at November 1993 prices, giving a payback period of 14 months.

The reduction in fuel consumption helps to lower waste-gas volumes, and measurements showed that emissions concentrations were all below the limits set for 2001 by the Environmental Protection Act.

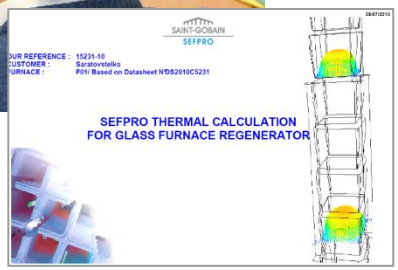
"As a result of the success of this installation, this material has been used on two subsequent rebuilds with similar success."

7.7% fuel savings (UK)

Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

BEST PRACTICE PROGRAMME

SEFPRO Services beyond products:



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

Conclusions

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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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