SOLPART Project

Solar reactors for particle processing: The solar rotary kiln

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Overview

• The solar rotary kiln concept
• Detailed design
• Construction
• Some trials and errors
• Experiments
• Conclusions and Outlook
How we introduce concentrated solar energy to the particles?
Solar calcination reactors – Overview

Indirect concept – Double cylinder
Reactor design
Solar reactor modeling – Thermal model

Empty reactor
Heat sink on back
Conduction through insulation
Convection and radiation outside
Incident flux Gaussian distribution
Case 1: Improving inner insulation

Conduction losses = 35 %

\[ T_{\text{out}} = 150^\circ\text{C} \]

Improved insulation:

Conduction losses = 26 %

\[ T_{\text{out}} = 120^\circ\text{C} \]
Case 2: Improving axial contact of the ceramic ring

Conduction losses = 35 %

\[ T_{\text{out}} = 150^\circ C \]

Improved insulation and contact:

Conduction losses = 12 %

\[ T_{\text{out}} = 60^\circ C \]

Thermal performances are satisfying
Mixing analysis
Influence of lifters
Image analysis
20 pixels (ca. 280 µm)
Image analysis

Pixel with tracer neighbours

Image number

S > 0 %
S > 10 %
Optimal lifters shape:
1 mm x 10 mm bars
12 optimal number
Reactor manufacture
Crucible and holding
Housing
Frame
**Insulation**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>$d_i$</td>
<td>0.25</td>
<td>m</td>
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<td>$\lambda_1$</td>
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<td>W/mK</td>
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<td>$\lambda_2$</td>
<td>0.035</td>
<td>W/mK</td>
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<tr>
<td>thick. 1</td>
<td>0.1</td>
<td>m</td>
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<tr>
<td>thick. 2</td>
<td>0.04</td>
<td>m</td>
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<tr>
<td>$L$</td>
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<td>m</td>
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<td>$A_{ext}$</td>
<td>1.17</td>
<td>m²</td>
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<table>
<thead>
<tr>
<th>Symbol</th>
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<tbody>
<tr>
<td>$T_{inside}$</td>
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<td>°C</td>
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<tr>
<td>$T_{end1}$</td>
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<td>°C</td>
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<tr>
<td>$T_{out}$</td>
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<td>°C</td>
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<tr>
<td>$T_{amb}$</td>
<td>20</td>
<td>°C</td>
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Reactor design and construction
Screw feeder
Measuring system
Experiments
Test facilities – Solar Furnace

- Heliostat dimensions: 8.2 m x 7.4 m (= 57 m²)
- Concentrator dimensions: 7.3 x 6.3 m (= 46 m²)
- Available power in chamber: 25 kW (for DNI of 850 W/m²)
Solar simulator

10 Xenon lamps

\[ P_{\text{max}} = 24 \, \text{kW} \]

\[ P_{\text{in aperture}} = 14 \, \text{kW} \]

Flux density = 4.2 MW/m²
Closed configuration

- WINDOW
- LEAF SEALING
- GAS OUTLET
- SEALING
First experimental campaign – Solar furnace

Problem: $T_{out}$ too low
Lessons learnt: No insulation gaps allowed

Problem: high temperature at the chain was reached. Fat of chain at high temperature burns
Thermal tests

![Graph showing thermal tests data with temperature and time on the x-axis and temperature in °C on the y-axis. Different lines represent various measurements (TC 01 °C to TC 06 °C) and power flow. The graph compares temperature changes over time for different conditions.]
Experimental campaign-close configuration

\[ \eta_{th} = \frac{\dot{m} \cdot c_p \cdot \Delta T}{Q_{inc}} \quad \rightarrow \eta \approx 62\% \]
Chemical tests CRM

\[ \text{CaCO}_3(s) \leftrightarrow \text{CaO}(s) + \text{CO}_2(g) \]
Second experimental campaign – Solar simulator, CRM
Open configuration (parallel study to solve the window problem)

Few more problems with feeding system or material blocked inside the hopper
But then we could start chemical tests!!

\[ X = \frac{X_{\text{meas}}}{X_{\text{theor}}} \]

46 %
Final results of chemical tests

\[ X_{chem} = \frac{X_{meas}}{X_{theor}} \]

\[ \eta_{Tot} = \frac{\dot{m} \cdot c_p \cdot \Delta T + \dot{m} \cdot X \cdot \Delta H}{Q_{inc}} \]
Conclusions

- A continuous solar rotary kiln was built and tested

- 17 successful chemical tests with rotary kiln
  - 4-12 kg/h of CRM treated
  - DOC in the range 24-99 %
  - Efficiency above 60% were achieved in thermal tests and between 20-40% in the chemical tests

- Calcination of CaCO$_3$ was successfully shown

Outlook

- The suction unit must be optimized
- Mixing identified as key factor – parallel study
- Window cleaning system is developed
- Scale up
Acknowledgements: EU for financing the Project SOLPART (contract 654663) under the H2020 research and innovation programme

Thanks for your attention
Efficiency calculations

\[ \eta_{Tot} = \frac{\dot{m} \cdot c_p \cdot \Delta T + \dot{m} \cdot X \cdot \Delta H}{Q_{inc}} \]

\[ X_{chem} = \frac{X_{meas}}{X_{theor}} \]
Experimental campaigns
Importance of particle treatment

Many industrial processes treat material in the form of particles

Examples:
- Pharmaceutical industry
- Chemical plants
- Food industry
- Pyrolysis
- Phosphate production
- Cement production ...
Most used commodities worldwide

1) Water
2) Concrete

[Cement Technology Roadmap 2009, WBCSD and IEA, 2009]
Facts about cement

- Main concrete components (Cement + Filler + Water)

Limestone (CaCO₃), Sand (SiO₂), Iron ore (Fe₂O₃), Clay

Cement industry is responsible for 8% of human-made CO₂-emissions

High temperatures necessary in the process:

- > 900 °C for calcination \( \text{(CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2) \)
- > 1300 °C for sintering \( \text{(Formation of 3 CaO·SiO}_2) \)

[Cement Technology Roadmap 2009, WBCSD and IEA, 2009]
Conventional cement plant:

> 900 °C for calcination  
(CaCO₃ → CaO + CO₂)

> 1300 °C for sintering  
(Formation of 3 CaO·SiO₂)
Industrial process

The SOLPART project:

- Fresh raw meal
- Heat recovery
- Pre-heating
- Calcination
- Solar Calcination
- Storage
- Clinker furnace
- Clinker
- Burner
- Burner
Thanks for your attention!

http://www.dlr.de/dlr/jobs/en/desktopdefault.aspx#Promotion/S:77