Applications and Improvements of the Two-Cavity Solar Reactor

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Outline

• The two-cavity solar reactor concept
• Applications so far
• Major improvements under study
Two-cavity reactor design (lab version at PSI)

- **Upper cavity**
- **Separation plate**
- **Lower cavity** = reaction chamber
- **Quartz window**
- **Solar Irradiation**
- **Product gas**
- **~1100-1300°C**
- **Packed bed of reactants (shrinking)**
- **Two-cavity solar batch reactor**
Two-cavity reactor: main features

- Sealing towards ambient air by quartz window (water cooled aperture).
- Reduced thermal gradients in reaction chamber due to indirect heating.
- “Efficiency penalty” due to separation plate (increases with operation temperature).
- Demonstrated at close to ambient pressure at temperatures up to about 1400°C.
- Suited for solids and solid-gas reactions.
- Accepts bulk materials.
- Allows for one batch per day operation.
- Best suited for materials which react mainly to gases
  -> otherwise thermal insulation of materials below top layer.
- Requires beam down optical system.
Two-cavity reactor applications of PSI so far

<table>
<thead>
<tr>
<th>Application</th>
<th>Lab scale @ PSI</th>
<th>Pilot scale</th>
<th>Partners</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnO+C (SOLZINC) ((\rightarrow) Zn + CO)</td>
<td>X</td>
<td>300 kW(_{th}) WIS</td>
<td>WIS, Scanarc, CNRS, Zoxy, ETHZ</td>
<td>EU, BBW(CH)</td>
</tr>
<tr>
<td>Waelz Oxide (Zn, Pb, O, Cl,..)</td>
<td>X</td>
<td>-</td>
<td>Montanuniversity Leoben/Austria</td>
<td>BEFESA (Abengoa)</td>
</tr>
<tr>
<td>Gasification of C-Materials (SOLSYN) (C + H(_2)O -&gt; CO + H(_2))</td>
<td>X</td>
<td>150 kW(_{th}) PSA</td>
<td>Holcim, ETHZ</td>
<td>Holcim, CTI</td>
</tr>
</tbody>
</table>

SOLZINC pilot plant has been dismantled

Ownership of SOLSYN pilot has been transferred from PSI to CIEMAT/PSA

Image: SOLSYN pilot plant in operation
Improvements of two-cavity reactors (1)

Up to now:
- Sealing towards ambient by quartz window (water cooled aperture).
- Separation plate loosely lying on reaction chamber walls (not gas tight).
- Separation plate from graphite coated by SiC (expensive, fragile coating).

Goal: Avoidance of quartz window (gas sealing at separation plate)
Requires hot sealing and suitable separation plate materials (gas tight, mechanically stable under thermal stresses, chemically stable in air and product gases up to 1400°C,..).

Status:
Tests on laboratory scale:
modification of lab scale two-cavity reactor
Solar absorber configurations & materials

- C-fiber reinforced SiC

Key material properties:

<table>
<thead>
<tr>
<th></th>
<th>C/SiC</th>
<th>SSiC</th>
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<tbody>
<tr>
<td>Chemical composition</td>
<td>≈ 60 % SiC,</td>
<td>100% SiC</td>
</tr>
<tr>
<td></td>
<td>10 % Si,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 % C</td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2.4</td>
<td>3.15</td>
</tr>
<tr>
<td>T_max in air (°C)</td>
<td>1350</td>
<td>1600</td>
</tr>
<tr>
<td>Thermal conductivity (W m⁻¹ K⁻¹)</td>
<td>20 - 40</td>
<td>125 (20 °C)</td>
</tr>
<tr>
<td>Expansion coefficient (10⁻⁶/K)</td>
<td>1.8 – 3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>50 - 95</td>
<td>400</td>
</tr>
<tr>
<td>Fracture toughness (MPa m₁/²)</td>
<td>23 - 30</td>
<td>4</td>
</tr>
</tbody>
</table>

- Pressureless sintered SiC (SSiC)

C. Wieckert, N. Tzouganatos, A. Steinfeld, SolarPaces 2017
Example: Windowless carbothermal ZnO reduction

Plate from C fiber reinforced SiC (C/SiC)

Concentrated solar energy

Further advantage: No cooling water
Has also been demonstrated for solar steam gasification
C. Wieckert, N. Tzouganatos, A. Steinfeld, SolarPaces 2017

Next logical step: demonstration on pilot scale

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Improvements of two-cavity reactors (2)

**Up to now:** one batch per day operation

- only suited for feedstock (mixes) which react basically to gas with low residual mass (low ash content etc.).
- Specific issues during heat-up for certain applications (e.g. tar formation for solar gasification of certain feedstock)
- slow reactor cooling (without forced cooling pilot reactor too hot for refilling on next morning)

**Goal:** Allow for supply of new feedstock in hot reactor

**Concept:** E.g. ”pushing furnace”

Conceptual design for precommercial solar plant e.g. solar gasification (3MW LHV syngas)

View into commercial pushing furnace

Next logical step: test on laboratory scale (was planned for solar simulator at PSI)
The two-cavity packed bed solar reactor concept is simple and versatile.

It has been demonstrated on pilot scale for different applications.

There is potential for significant further improvements, thereby boosting applicability and economics.

Thank you for your attention!

Questions?

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