Modeling of Limestone Calcination Using Joule Heating

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Motivation

• Rapid heating of lime stone
  – the recent research interest evaluated by Fall (2011)
  – Savings in energy projected

• Microwave heating of Alumina
  – modeled using COMSOL by Suryanarayana (2011)

• This presentation demonstrates the COMSOL capability to model joule heating of limestone with reaction.
Model details

• Physics used
  – Joule heating
  – Transport of Diluted species

• Geometry
  – 15*15*1 mm limestone particle with entire surface exposed for heating

• Mesh
  – Physics controlled mesh with fine element size

• Time dependant study (0-20 min heating time)
Joule Heating

• Initial condition
  – T=303.15K and V=220 Volts.

• Influx range
  – 500000 (rapid heating) - 500 W/m² (slow heating).

\[ \rho C_p \frac{\partial T}{\partial t} + \rho C_p u_{\text{trans}} \nabla T = \nabla \cdot (k \nabla T) + Q + W_p \]

\[ \nabla \cdot J = Q_j \]

\[ J = \sigma E + \frac{\partial D}{\partial t} + J_e \]

\[ E = -\nabla V \]
Transport of Diluted Species

\[
\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i) = R_i
\]

\[N_i = -D_i \nabla c_i\]

CaCO\textsubscript{3} ==> CaO + CO\textsubscript{2}

- Rate expression: \( R_j = k \cdot C_j \)
- Reaction Rate Constant \( k = A \cdot \exp(-E/RT) \)
  - Frequency factor, \( A = 9.67 \times 10^{24} \text{ hr}^{-1} \)
  - Activation Energy, \( E = 1092.947 \text{ KJ/mol} \)
  - Convective Inward flux = 0.1 mol/m\textsuperscript{2}.s
  - Mass transfer coefficient = 0.0833 m/s
  - CO\textsubscript{2} concentration in bulk phase = 0.002 mol/m\textsuperscript{3}

- Diffusion of CO\textsubscript{2}
  - \( D\text{CO}_2 = 1.39 \times 10^{-8} \text{ m}^2/\text{s} \)
Results (Heating)

<table>
<thead>
<tr>
<th>Inward Flux, W/m²</th>
<th>Time, seconds (to reach 700°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$5 \times 10^5$</td>
<td>1</td>
</tr>
<tr>
<td>$5 \times 10^4$</td>
<td>12</td>
</tr>
<tr>
<td>$5 \times 10^3$</td>
<td>120</td>
</tr>
<tr>
<td>$5 \times 10^2$</td>
<td>1200</td>
</tr>
</tbody>
</table>
Results (CO$_2$ Concentration)

- Uniform concentration of 0.014 mol/m$^3$
Conclusion

• COMSOL capability demonstrated
• Useful to design the experiments
References

- Fall W, S. M. Allan, H. S. Shulman, “Rapid limestone calcination using Microwave Assist Technology”, 35rd International Conference & Exposition on Advanced Ceramics and Composites ICACC-S8-023-2011
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