CFD-DEM modeling of fluidized beds with heat production: Influence of the particle size distribution and heat source

Zizi Li
Eindhoven University of Technology; The Netherlands, z.z.li@tue.nl

Martin van Sint Annaland
Eindhoven University of Technology; The Netherlands

Niels G. Deen
Eindhoven University of Technology; The Netherlands

J.A.M. Kuipers
Eindhoven University of Technology; The Netherlands

Follow this and additional works at: http://dc.engconfintl.org/fluidization_xv

Part of the Chemical Engineering Commons

Recommended Citation

This Abstract and Presentation is brought to you for free and open access by the Proceedings at ECI Digital Archives. It has been accepted for inclusion in Fluidization XV by an authorized administrator of ECI Digital Archives. For more information, please contact franco@bepress.com.
CFD-DEM modeling of fluidized beds with heat production: influence of the particle size distribution and heat source

Zizi Li

Supervisors:
Prof. dr. ir. N. G. Deen
Prof. dr. ir. M. van Sint Annaland
Prof. dr. ir. J. A. M. Kuipers
Content

• Project background and objective

• Model introduction

• Simulations and results
  • With mono-dispersed particles
  • With poly-dispersed particles

• Conclusions
The Marcus Hook Plant in Pennsylvania: capable of producing 375,000 tones/year of polypropylene.

Several characteristic length scales in a fluid bed reactor for catalytic olefin polymerization.
Model introduction
Discrete Particle Model (DPM)

Navier-Stokes equations solved in Eulerian cells

Element movement follows from external and contact forces:

\[ m_a \frac{d \mathbf{v}_a}{dt} = \mathbf{F}_d + \mathbf{F}_p + \mathbf{F}_g + \mathbf{F}_c \]

\[ \rho_p V_p C_{p,p} \frac{dT_p}{dt} = -hA_p \left( T_{p,a} - T_g \right) + q_v V_p \]

\[ \frac{\partial}{\partial t} \varepsilon \rho_g \mathbf{u} + \nabla \cdot \varepsilon \rho_g \mathbf{u} \mathbf{u} = -\varepsilon \nabla p - \nabla \cdot \varepsilon \mathbf{\tau}_g - S_p + \varepsilon \rho_g \mathbf{g} \]

\[ C_{p,g} \left[ \frac{\partial (\varepsilon \rho_g T_g)}{\partial t} + (\nabla \cdot \varepsilon \rho_g \mathbf{u} T_g) \right] = -\nabla \cdot \varepsilon \mathbf{q} + Q_p \]
Simulations with mono-dispersed particles

- General understanding of fluidization and energy balance: with mono-dispersed particles
Simulations with mono-dispersed particles

Particle temperature distribution

- Probability distribution function (PDF) of the dimensionless particle temperature.

- Definition:

\[ T_0 = \frac{(T_p - T_{g,0})}{(T_{p,melting} - T_{g,0})} \]

\[ \dot{q} = 6.57 \times 10^7 \text{ J/s/m}^3 \]

\[ \dot{q} = 1.31 \times 10^6 \text{ J/s/m}^3 \]

Simulations with poly-dispersed particles

![Diagram showing the distribution of particle sizes and mass fractions]

**Table. Particle properties**

<table>
<thead>
<tr>
<th></th>
<th>Mean radius (µm)</th>
<th>Standard deviation (µm)</th>
<th>Sauter mean radius (µm)</th>
<th>Mass of the bed (g)</th>
<th>Particle number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>608</td>
<td>0</td>
<td>608</td>
<td>35.6</td>
<td>56,601</td>
</tr>
<tr>
<td>σ1 (narrow)</td>
<td>590</td>
<td>75</td>
<td>608</td>
<td>35.6</td>
<td>59,908</td>
</tr>
<tr>
<td>σ2 (medium)</td>
<td>555</td>
<td>125</td>
<td>608</td>
<td>35.6</td>
<td>66,807</td>
</tr>
<tr>
<td>σ3 (broad)</td>
<td>500</td>
<td>175</td>
<td>608</td>
<td>35.6</td>
<td>80,000</td>
</tr>
</tbody>
</table>
Simulations with poly-dispersed particles
- Particle temperature PDF

Small heat production

Large heat production
Simulations with poly-dispersed particles - Particle temperature PDF

- Particle temperature PDF

- Particle temperature PDF

- Particle temperature PDF

- Particle temperature PDF

\[ \frac{(T_{p,T_g,0})}{(T_{p,T_g,m})} \]

\[ \sigma_1, 5q_v, u_0=2u_{mf} \]

\[ \sigma_3, 5q_v, u_0=3u_{mf} \]

\[ u_0=2u_{mf} \]

\[ u_0=3u_{mf} \]
Simulations with poly-dispersed particles
- Temperature contour

$q_v (W/m^3)$

$Q (W)$

Hot particles
Mechanism of hot spots formation

\[ T_p > 0.80 \]

Hot particles

\[ \sigma 3, 5Q, u_0 = 2u_{mf} \]
Conclusions

• With the same total heat generation and same cooling capacity in the bed, particles with a constant $Q$ show a broader temperature distribution compared to those with a constant volumetric heat production $q_v$.

• The spread in temperature distribution increases as the heat generation is increased.

• The largest difference between the highest and lowest particle temperature in the bed occurs in the case with the broadest PSD and constant heat production per particle (i.e. polymerization). The hot particles that are close to the melting point are those small particles with high catalyst activity.

• They are mostly found in the free board and near the side walls.
Acknowledgment

This research is part of research programs of Dutch Polymer Institute (DPI) as project #751.

Thanks for your attention!