Simulated Flow Through Structured Packing

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Structured Packing

- Used in distillation, absorption, and stripping
- High efficiency, low pressure drop, and high capacity
Single Phase Simulations

- Experimental Validation
  - Simulation and experimental bed were nearly identical
Comparison to Experimental Data

EXP = 23.944*F^{1.7464}

k-ω = 20.118*F^{1.7307}

k-ε = 20.74*F^{1.7537}

\[ F = \sqrt{v_g \rho_g} \]
Packing Design Simulations

- Periodic boundary with pressure drop imposed
- Periodic boundary
Packing Dimensions

\[ \theta \]

\[ h \]

\[ b \]
\( \alpha = 45^\circ, \quad a_p = 250 \text{ m}^2/\text{m}^3, \quad U_{GS} = 1 \text{ m/s}, \text{ Nitrogen Flow} \)
Multiphase Simulations

- Effect of simulation contact angle, liquid density, surface tension, and liquid viscosity examined on periodic geometry
Contact Angle Definition

Contact Angle = 75°

\[ h_L = 6.5\% \]

0.074 N/m  
\[ a_f = 0.27 \]
L = 39 GPM/ft²

0.037 N/m  
\[ a_f = 0.30 \]
L = 46 GPM/ft²

0.018 N/m  
\[ a_f = 0.35 \]
L = 47 GPM/ft²
Contact Angle $= 30^\circ$

$h_L = 6.0\%$

<table>
<thead>
<tr>
<th>N/m</th>
<th>$a_f$</th>
<th>GPM/ft$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.074</td>
<td>0.48</td>
<td>22</td>
</tr>
<tr>
<td>0.037</td>
<td>0.65</td>
<td>20</td>
</tr>
<tr>
<td>0.018</td>
<td>0.80</td>
<td>21</td>
</tr>
</tbody>
</table>
Contact Angle = 0°

\[ h_L = 6.5\% \]

\begin{align*}
0.074 \text{ N/m} & \quad a_f = 0.80 & \quad \text{L = 19 GPM/ft}^2 \\
0.037 \text{ N/m} & \quad a_f = 0.97 & \quad \text{L = 19 GPM/ft}^2 \\
0.018 \text{ N/m} & \quad a_f = 0.98 & \quad \text{L = 23 GPM/ft}^2
\end{align*}
Impact of Liquid Density

\[ \theta_c = 30^\circ, \ h_L = 6.5\%, \ \sigma = 0.074 \text{ N/m} \]

- \(a_f = 0.281\)
  \(L = 24 \text{ GPM/ft}^2\)
  \(\rho = 500 \text{ kg/m}^3\)

- \(a_f = 0.48\)
  \(L = 23 \text{ GPM/ft}^2\)
  \(\rho = 997 \text{ kg/m}^3\)

- \(a_f = 0.58\)
  \(L = 23 \text{ GPM/ft}^2\)
  \(\rho = 1500 \text{ kg/m}^3\)
Impact of Viscosity

$\theta_c = 30^\circ$, $\sigma = 0.018 \text{ N/m}$, $\rho = 997.561 \text{ kg/m}^3$

$\mu_L = 0.01774 \text{ Pa-s}$
$h_L = 6.7\%$
$a_f = 0.68$
$L = 2.4 \text{ GPM/ft}^2$

$\mu_L = 0.0008871 \text{ Pa-s}$
$h_L = 5.9\%$
$a_f = 0.80$
$L = 20.9 \text{ GPM/ft}^2$
Experimental Validation

- Wetted area measurements performed via absorption of CO₂ into dilute caustic solution
- 10 ft. bed of Mellapak N250.Y
Wetted Area – Experimental Measurements

\[
\frac{a_c}{a_p} = a_f = 1.34 \left( \frac{\rho L}{\sigma} \right)^{1/3} \left( \frac{Q}{L_p} \right)^{4/3} \right]^{0.116}
\]
Multiphase Simulations – CT Geometry

- Calculate fractional wetted area and holdup for indicated element
  - \( a_f = a_w/a_p \)
  - \( h_L \)
  - \( \Delta P_{\text{Irrigated}} \)
X-ray CT / CFD Comparison


0.074 N/m

\[ a_f = 0.85 \]

\[ L = 15 \text{ GPM/ft}^2 \]

0.074 N/m

\[ a_f = 0.89 \]

\[ L = 15 \text{ GPM/ft}^2 \]
$L=20 \text{ GPM/ft}^2$

$\theta_c = 0^\circ, a_f=0.91$

$\theta_c = 30^\circ, a_f=0.67$
Fractional Wetted Area

\[ a_f = 0.718L^{0.080} \]
\[ R^2 = 0.978 \]

\[ a_f = 0.323L^{0.245} \]
\[ R^2 = 1 \]

\[ a_f = 0.609L^{0.1547} \]
\[ R^2 = 1 \]

CFD Sim, \( \theta = 0^\circ \)

CFD Sim, \( \theta = 30^\circ \)

Tsai Model
Fractional Liquid Holdup

Liquid Holdup (%) vs. Liquid Load (GPM/ft²)

- CFD Sim, θ=30°
- CFD Sim, θ=0°
- Experimental
## Irrigated Pressure Drop

<table>
<thead>
<tr>
<th>Contact Angle °</th>
<th>Liquid Load GPM/ft²</th>
<th>F-factor Pa⁰.⁵</th>
<th>CFD Pressure Drop Pa/m</th>
<th>Experimental Pressure Drop Pa/m</th>
<th>Percent Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>0.86</td>
<td>74.7</td>
<td>52.0</td>
<td>43.5%</td>
</tr>
<tr>
<td>0</td>
<td>15</td>
<td>0.77</td>
<td>74.4</td>
<td>52.1</td>
<td>42.7%</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
<td>0.69</td>
<td>73.4</td>
<td>58.8</td>
<td>24.8%</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>0.82</td>
<td>73.1</td>
<td>47.6</td>
<td>53.6%</td>
</tr>
<tr>
<td>30</td>
<td>15</td>
<td>0.73</td>
<td>71.4</td>
<td>46.7</td>
<td>52.8%</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>0.66</td>
<td>73.5</td>
<td>54.1</td>
<td>35.8%</td>
</tr>
</tbody>
</table>
Conclusions

• Single phase simulations can predict trends and pressure drops accurately

• Multiphase simulations require further analysis
  – Experimentally determined static contact angle not appropriate for predicting wetting
  – Liquid holdup and irrigated pressure drop need additional corrections:
    • Damping of the turbulence at the interface
    • Viscosity correction
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Questions?

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