Secondary Flow of Liquid-liquid Two-Phase Fluids in a Pipe Bend

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Introduction

- The world is progressively requiring more energy, mainly from the oil company
- Erosion is a phenomena that costs millions of dollars to companies
- Highest erosion rate is most commonly found in bends
- Better understanding of flow behavior would help in the future to minimize erosion
Approach to a solution

- Physical Model

- Reynolds Number: 100,000 and 10,000

- Phases:
  - Continuous Phase
  - Dispersed Phase

- Fluids:
  - Water with 20% or 0% of NaCl
  - Oil

- Volume fraction:
  - 80% Oil – 20% Brine or Water
  - 20% Oil – 80% Brine or Water
Approach to a solution

• Numerical Model

\[\rho \left( \frac{\partial u}{\partial t} + u \cdot \nabla u \right) = -\nabla p + \nabla \cdot \left( \mu (\nabla u + (\nabla u)^T) - \frac{2}{3} \mu \nabla \cdot u I \right) + F\]

• 2 sets of Navier-Stokes equations

• Continuity Equation

\[\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0\]

• Transport Equation

\[\nabla \cdot (\phi_d u_d + \phi_c u_c) = 0\]

Normal mesh results had 7% difference when compared to finer

Wall lift-off values were lower than 20 (viscous units)
Results

Reynolds 100,000

- Vortical Structures follow same behavior as a one phase fluid
- 2 perfectly defined Dean vortices through the whole bend
### Results

Reynolds 100,000

<table>
<thead>
<tr>
<th>Curvature Ratio</th>
<th>Volume Fraction</th>
<th>Vorticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45°</td>
<td>End</td>
</tr>
<tr>
<td>20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td></td>
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</tr>
</tbody>
</table>

\[ \alpha_c \alpha \frac{u^2}{r} \]
Results

Reynolds 10,000

- Slightly diagonal volume fraction stratification
- Strong gravity seems to diminish the vortical structures
Results

Reynolds 10,000

<table>
<thead>
<tr>
<th>Curvature Ratio</th>
<th>Volume Fraction</th>
<th>45° - Oil</th>
<th>45° - Water</th>
<th>End - Oil</th>
<th>End - Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20%</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>6.5</td>
<td>80%</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>10</td>
<td>20%</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>10</td>
<td>80%</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- Gravity does not affect strongly at the end of the bend
- Some vortical structures appear to be close to the center of pipe
Reynolds 10,000

- Gravity does not affect strongly at the end of the bend
Results

Reynolds 10,000
Conclusions

- The flow behavior is strongly related to gravitational and centrifugal force ratio
- Secondary flow appears, in the form of vortical structures
- Salt concentration plays little or no role on the fluid behavior
- Future work is planned to undergo a study of a gravitational-to-centrifugal ratio of 1 and behavior of two-phase Laminar flow in pipe bends
Thank You!