Numerical and phenomenological modeling of wavy–stratified oil–water flow

Ricardo Pereira de Avila
Advisor: Prof. Dr. Oscar M. H. Rodriguez

November 2013

NETeF (Thermal–fluids Engineering Laboratory) – EESC – USP
Motivation
Multiphase Flow

Natural and industrial processes

Two-phase mixtures:

- gas/liquid-solid;
- gas-liquid;
- liquid-liquid;
Multiphase Flow

Stratified Oil–water Flow

Present in the oil industry:

- in directional wells offshore;
- in pipelines of production and transport (oil and gas);
- way to avoid the formation of emulsions of water in oil in pipelines;

Ensuring the stability of the flow pattern:

- reduce the energy consumption, reduce the operating costs and increase the production;
- separate the phases (production/transport);
Objectives
Objectives

Mathematical modeling 1-D – prevision of parameters:

• Holdup;
• Pressure drop;
• Droplets entrainment;
Objectives

Simulation using numerical code 1-D:

• Interfacial friction factor dependent of the wave amplitude and wave length;

Numerical simulation via CFD (softwares: commercial e opensource):

• Holdup, pressure drop and droplets entrainmenent;
• Comparison with experimental database;
Phenomenological Modeling
Interfacial Friction Factor

Interfacial friction factor (Pereira, 2011; Rodriguez and Baldani, 2012):

\[ f_i = f_k \left( 1 + C_i \frac{\alpha}{D} \right) \]

\[ \frac{\alpha}{D} = 0.06103 + 0.17283 \varepsilon_w \]

Interfacial friction factor proposed:

\[ f_i = f_k \left[ 1 + f_r(\alpha) + g_r(\lambda) \right] \]
Preliminary Results
Computational Support: Configuration

- Processador intel i7 3930k – 12 cores (6/6);
- 32GB RAM memory;
- 1TB of HD memory;
- Ansys CFX 14.0;
- Design Modeler (geometry);
- CFX Meshing (net);
- CFX Pre (setup);
- CFX Solver (solution);
- CFX Post (results);
Preliminary Results

Qualitative Results
Overview of flow – oil (red) and water (blue) and cross sections (XY planes) – 1,500,000 nodes in 1 m of length – $U_{os}=0.03\text{m/s}$ e $U_{ws}=0.15\text{m/s}$ in horizontal (CFX-Post).
Interfacial Wave – Images (Experimental and CFD)

Image of the experimental work obtained by high-speed camera – technique of contrast and color gradient – Pereira (2011).

Image (YZ plane) obtained from the numerical simulation (CFX-Post) – Uos=0.03m/s Uws=0.15m/s in horizontal.
Cross section of the pipe (XY plane) for (a) \( z=0.45 \) m, and (b) \( z=0.64 \) m – oil (red) and water (blue)

\( U_{os}=0.03 \) m/s e \( U_{ws}=0.15 \) m/s (CFX-Post).
Preliminary Results
Numerical Results (Coarse Mesh)
Volume of Control and Pressure Taps (CFD)

Volume of control and points of pressure taps (crosses) – $z=1.5\text{m}$ and $z=1.75\text{m}$ – oil (red) and water (blue) – $U_{os}=0.10\text{m/s}$ e $U_{ws}=0.15\text{m/s}$ in horizontal for 2m of length (CFX-Post).
Pressure versus Time

Graphic of behavior of Pressure versus Time at z=1.5m for the mesh of 200,000 nodes – Uos=0.10m/s and Uws=0.15m/s in horizontal (CFX-Post).
# Oil Volume Fraction (CFD) versus Mesh

Experimental Oil volume fraction: $\varepsilon_o = 0.58$

<table>
<thead>
<tr>
<th>Mesh (nodes)</th>
<th>Oil volume fraction – $\varepsilon_o$</th>
<th>Courant number</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,542</td>
<td>0.669152</td>
<td>0.30</td>
</tr>
<tr>
<td>200,202</td>
<td>0.642921</td>
<td>0.40</td>
</tr>
<tr>
<td>49,916 (20s) e 400,042 (10s)</td>
<td>0.640050</td>
<td>0.53</td>
</tr>
<tr>
<td>49,916 (20s) e 800,418 (10s)</td>
<td>0.641508</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Graphic of Oil volume fraction versus Mesh – Uos=0.10m/s and Uws=0.15m/s in horizontal (CFX–Post).
## Oil Volume Fraction (CFD) versus Mesh: Error

Experimental oil volume fraction: $\varepsilon_o = 0.58$

<table>
<thead>
<tr>
<th>Mesh (nodes)</th>
<th>Oil volume fraction ($\varepsilon_o$)</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>200,202</td>
<td>0.642921</td>
<td>10.85%</td>
</tr>
<tr>
<td>49,916 (20s) e 400,148 (10s)</td>
<td>0.640050</td>
<td>10.35%</td>
</tr>
<tr>
<td>49,916 (20s) e 800,418 (10s)</td>
<td>0.641508</td>
<td>10.60%</td>
</tr>
</tbody>
</table>

Average error: 10.60%
Experimental pressure drop: $-(dp/dz) = 301.3$ [Pa/m]

<table>
<thead>
<tr>
<th>Mesh (nodes)</th>
<th>Pressure drop: $-(dp/dz)$ [Pa/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200,202</td>
<td>764.36</td>
</tr>
<tr>
<td>Error: pressure drop</td>
<td>153.68%</td>
</tr>
</tbody>
</table>
Preliminary Results

Numerical Results
(Fine Mesh)
Pipe Inlet – Image (CFD)

Pipe inlet in Y shaped – oil (red) and water (blue)  
Uos=0.10m/s e Uws=0.15m/s in horizontal after 45s (CFX–Post) – 3,200,000 nodes.
Overview of flow – oil (red) and water (blue) – 3,200,000 nodes – $U_{os}=0.03\text{m/s}$ and $U_{ws}=0.15\text{m/s}$ in horizontal (CFX-Post).
Acknowledgments

- Prof. Dr. Oscar M. H. Rodriguez;
- Prof. Dr. Paulo Seleghim;
- Jonas Ansoni;
- Jorge Nicolau dos Santos;
- colleagues;
Thanks!