Investigation of gas flow rates on hydrodynamics in two-phase gas-liquid stirred tanks using Positron Emission Particle Tracking (PEPT)

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Introduction

- IFP Energies Nouvelles use filamentous fungi in the production of biofuels [1].
- Biofuels are essential for the transition between fossil fuels and climate-friendly alternatives.
- Good gas dispersion is required to help with fungal growth and therefore produce homogeneous and high-quality biofuel.
- However, these systems are poorly understood:
  - Quantitative measurements have been limited to low gas flow rates.
  - Qualitative observations have been made on higher gas flow rate systems.
- This work looks to provide quantitative measurements of gas-liquid flows in a Newtonian mixture in flooded and dispersed aeration regimes.

Positron Emission Particle Tracking (PEPT)

- Non-invasive, three-dimensional measurement technique.
- A single 300μm diameter resin particle is radioactively labelled with Fluorine-18 ions.
- Particle undergoes $\beta^+$ decay, emitting gamma rays. Multiple pairs of gamma rays are triangulated to give particle positions, and therefore trajectories.
- Data is collected in a Lagrangian reference frame. By its nature, the data is time averaged.
Why PEPT is necessary?


Design of Experiments

- Varying Vessel Volumes per Minute (VVM), and therefore gas flow rate ($Q_G$), to match industrially relevant superficial gas velocities (VSGs).
- Flow controller has a lower limit of 10 L/min, hence VVM of 1.6 as lowest aerated case.
- Tank diameter ($T$) of 200mm.
- Standard Rushton turbine, with ring sparger below.

<table>
<thead>
<tr>
<th>VVM</th>
<th>$Q_G$ [L/min]</th>
<th>VSG [cm/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.6</td>
<td>10.053</td>
<td>0.53</td>
</tr>
<tr>
<td>3.0</td>
<td>18.885</td>
<td>1.00</td>
</tr>
<tr>
<td>5.0</td>
<td>31.416</td>
<td>1.67</td>
</tr>
</tbody>
</table>
Design of Experiments

Fluid Properties
- Aqueous glycerol solution (70% Glycerol v/v).
- Dynamic viscosity $\nu = 2.81 \times 10^{-5}$ m$^2$s$^{-1}$.
- Density matched to that of the resin particle.

Operating Conditions
- Experiments performed at:
  - $Re = 500$ (flooded)
  - $Re \approx 1400$ (dispersed)
Velocity Scalar Fields – Impeller Slice (XY Plane)

Single-Phase (Re = 500)

Flooded (Re = 500, 5 VVM)

Dispersed (Re ≈ 1400, 5 VVM)
Velocity Scalar Fields Central Slice (XZ Plane)

**Single-Phase**
(Re = 500, 5 VVM)

**Flooded**
(Re = 500, 5 VVM)

**Dispersed**
(Re ≈ 1400, 5 VVM)
Velocity Vector Fields (XZ Plane)

**Single-Phase**
(Re = 500)

**Flooded**
(Re = 500, 5 VVM)

**Dispersed**
(Re ≈ 1400, 5 VVM)
<table>
<thead>
<tr>
<th>Aeration Regime</th>
<th>PEPT</th>
<th>Qualitative [2, 3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td><img src="image1.png" alt="Flooding PEPT" /></td>
<td><img src="image2.png" alt="Flooding Qualitative" /></td>
</tr>
<tr>
<td>Dispersed</td>
<td><img src="image3.png" alt="Dispersed PEPT" /></td>
<td><img src="image4.png" alt="Dispersed Qualitative" /></td>
</tr>
</tbody>
</table>
Flooded ($Re = 500$): Influence of Gas
Dispersed ($Re \approx 1400$): Influence of Gas
Dispersion

Mixing Efficiency over Time

Flooded (Re = 500)

Dispersed (Re ≈ 1400)
Dispersion over Time

Flooded (Re = 500)

Dispersed (Re ≈ 1400)
From qualitative theory to quantitative measurement...

Flooded (5 VVM) Isolated Bubble Column
Conclusions and Future Work

Conclusions:
- Quantitatively observed flooded flow behaviour. Matching previous qualitative observations.
- Interesting phenomena observed with the angle of out jet changing as a function of gas flow rate.
- Noticeable differences in mixing performance between flooded and dispersed aeration regimes.

Future Work:
- Calculate gas hold-up for each of the cases.
- Use PEPT data to produce and validate CFD equivalents.
- How do hydrodynamics change when tank size scales up?
- Perform experiments using the filamentous fungi – do we get similar behaviour?
Thank you for listening! Any questions?