Simulation and performance of pulsed pipe flow mixing in non-Newtonian liquid dispersion media

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Aim of this work: Understanding the mixing of liquid dispersions in pulsed flow static mixers.

**Experimental Set-up**

A 50 L mixing tank is equipped with circulation loop: two identical, custom-made static mixers.

Flow in the circulation loop was pulsed (diaphragm pump).

Reference experiments were made using non-pulsing flow (rotor pump).

Mixing power of static mixers were determined based on using pressure drop measurements

\[ P = \Delta pQ \]
Bingham-plastic rheology is modelled for the experimental data:

Apparent viscosity calculated from experimental data is constant 30 mPas at shear rates greater than 20 1/s.

Dispersion density was 1170 kg/m³ determined based on the measurement of light and heavy phases and their weight fractions.
Mixing in pulsed and non-pulsed flow

Mixing samples analyzed based on heavy phase mass fractions of liquid dispersion. Sampling between 10 - 60 minutes.

Mixing performance was calculated based on temporal Coefficient of Variation (CoV):

Experimental result: Non-pulsed flow leads to better mixing

Standard deviation of samples / Average mass fraction of samples
Modelled flow rates: 17 L/min (Non-pulsed) and 28 L/min (Pulsed)
Average shear rate (8v/d) was between 110 – 227 s\(^{-1}\) →
Constant viscosity: 30 mPas
Re: 468 (Non-pulsed flow) and 527 – 995 and Womersley number
\((\sqrt{\omega'} = R(2\pi f)^{\frac{1}{2}})\) was 10.5 (Pulsed flow) → Laminar flow model
Dispersion was treated as a single phase flow in simulations
Non-pulsed flow: steady-state simulation
Pulsed flow: time-dependent solution.
Unstructured grid had 206008 elements
Non-pulsed flow

Velocity magnitude profile of the static mixer. Projection of velocity is at the centreline of the pipe.

<table>
<thead>
<tr>
<th>Measured Non-pulsed flow</th>
<th>Calculated Non-pulsed flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v, \text{ m/s} )</td>
<td>( v, \text{ m/s} )</td>
</tr>
<tr>
<td>( P, \text{ W} )</td>
<td>( P, \text{ W} )</td>
</tr>
<tr>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>1.0±0.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Pulsed flow

Flow velocity (m/s) (left figure) and pressure (Pa) profiles (right figure) in the first static mixer.

<table>
<thead>
<tr>
<th>t (s)</th>
<th>Flow velocity (m/s)</th>
<th>Pressure (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125</td>
<td>v = 0.65±0.2</td>
<td>Δp = 6900±1500</td>
</tr>
<tr>
<td>0.375</td>
<td>v = 0.65±0.2</td>
<td>Δp = 6900±1500</td>
</tr>
<tr>
<td>0.5</td>
<td>v = 0.65±0.2</td>
<td>Δp = 6900±1500</td>
</tr>
</tbody>
</table>

Calculated (average)

<table>
<thead>
<tr>
<th></th>
<th>v, m/s</th>
<th>Δp(total), Pa</th>
<th>P, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noisy measurement (average)</td>
<td>0.65±0.2</td>
<td>6900±1500</td>
<td>3.2±0.7</td>
</tr>
<tr>
<td>Calculated (average)</td>
<td>0.65±0.2</td>
<td>7600</td>
<td>3.5</td>
</tr>
</tbody>
</table>
High pressure variations were observed in measurements. CFD simulations assured high pressure variations at individual pressure meters.
Mixing simulation

- Step function and the diluted chemical species transport equation as a time dependent simulation.
- Previously calculated flow fields were used for the convective transport and diffusive transport was minimized ($D=10^{-9} \text{ m}^2/\text{s}$).
- Spatial CoV was determined from simulation data.
SUMMARY

• Immiscible liquids were mixed in custom made static mixers installed in a circulation loop.

• CFD simulations assured high pressure variations at individual pressure meters in pulsed flow.

• When pulsed flow was used, even the increase in the mixing power did not result in better mixing based on experimental and CFD simulated results.