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.

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[1] Roque, T., Delettre, J., Hardy, N., Nienow, A.W., Augier, F., Chaabane, F.B., Beal, C. (2021) *The impact of fluid-dynamic stress in stirred tank bioreactors on the synthesis of cellulases by Trichoderma reesei at the intracellular and extracellular levels.* Chemical Engineering Science 232, 116353

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 β^+ 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.

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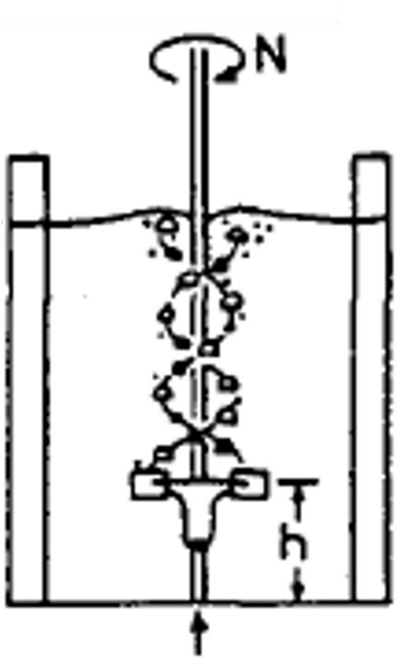
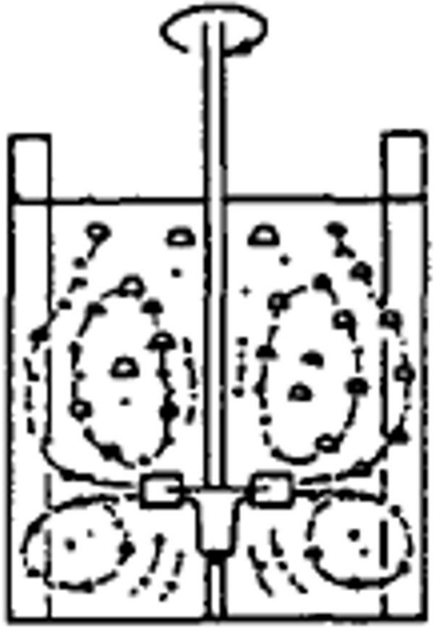
Why PEPT is necessary?





[2, 3]

[2] Nienow, A.W., Warmoeskerken, M.M.C.G., Smith, J.M. and Konno, M. (1985) *Flooding/loading transition and the complete dispersal condition in aerated vessels agitated by a Rushton turbine.* Proceedings of 5th European Mixing Conference, Germany pp. 153-154

[3] Nienow, A.W. (1998) *Hydrodynamics of stirred bioreactors.* Applied Mechanics Reviews 51(1) pp. 3-32

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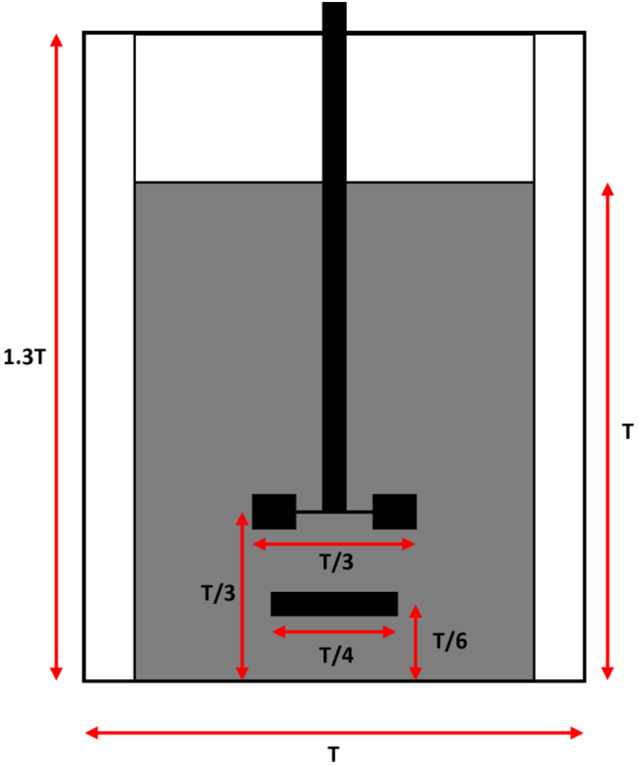
Design of Experiments



VVM	Q_G [L/min]	VSG [cm/s]
0	-	-
1.6	10.053	0.53
3.0	18.885	1.00
5.0	31.416	1.67

- 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.

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Design of Experiments

Fluid Properties

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

Operating Conditions

- Experiments performed at:

  $Re = 500$ (flooded)

  $Re \approx 1400$ (dispersed)

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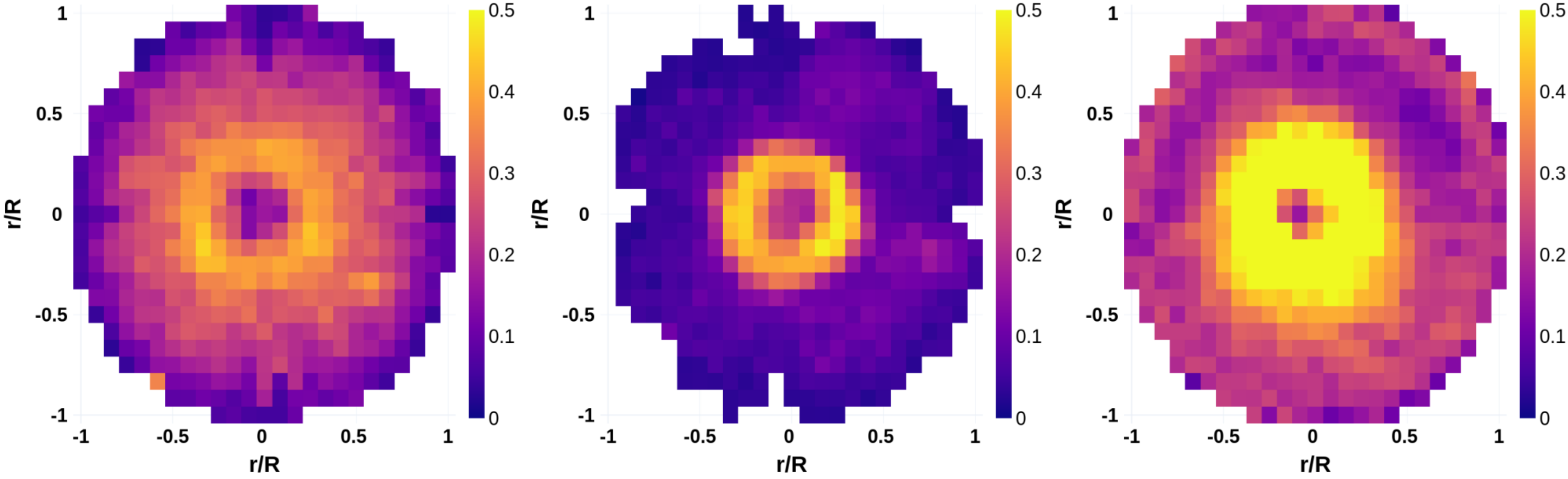
Velocity Scalar Fields – Impeller Slice (XY Plane)

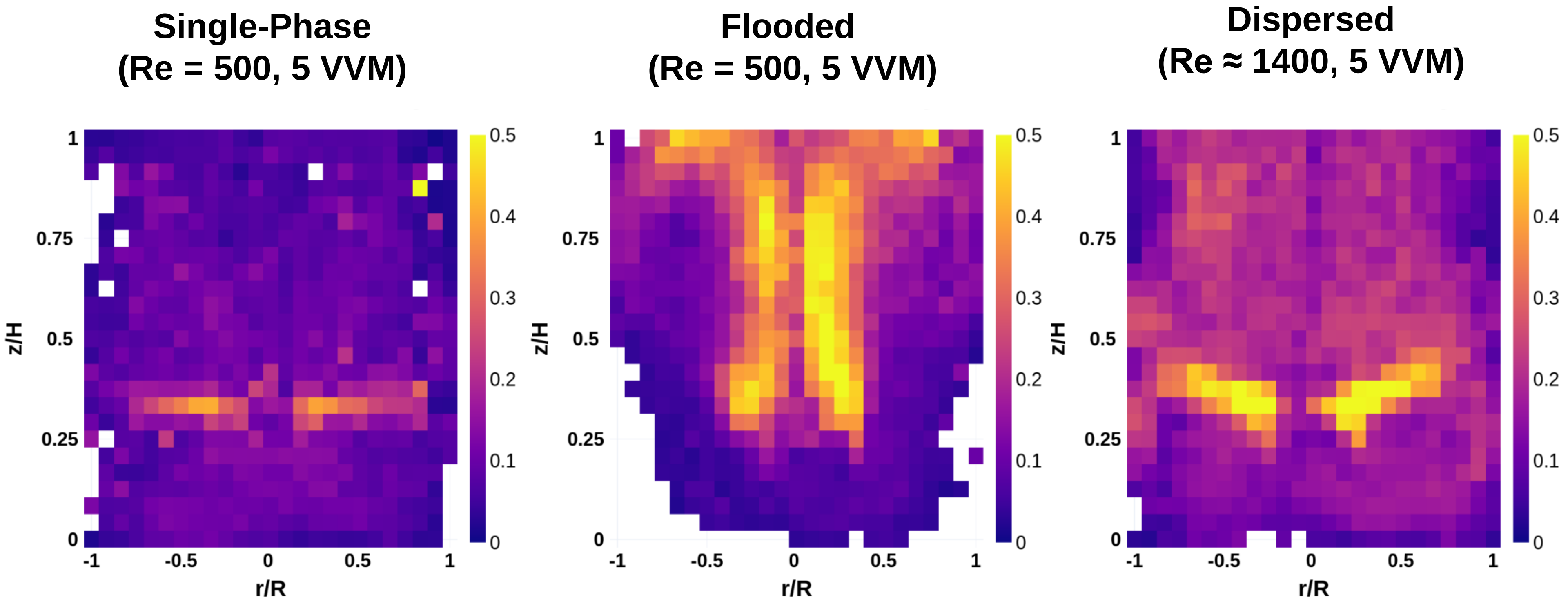
Single-Phase
(Re = 500)

Flooded
(Re = 500, 5 VVM)

Dispersed
(Re ≈ 1400, 5 VVM)

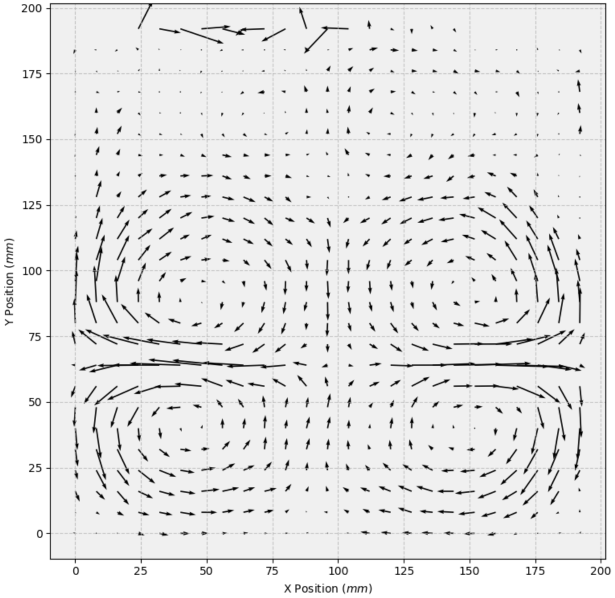


Velocity Scalar Fields Central Slice (XZ Plane)

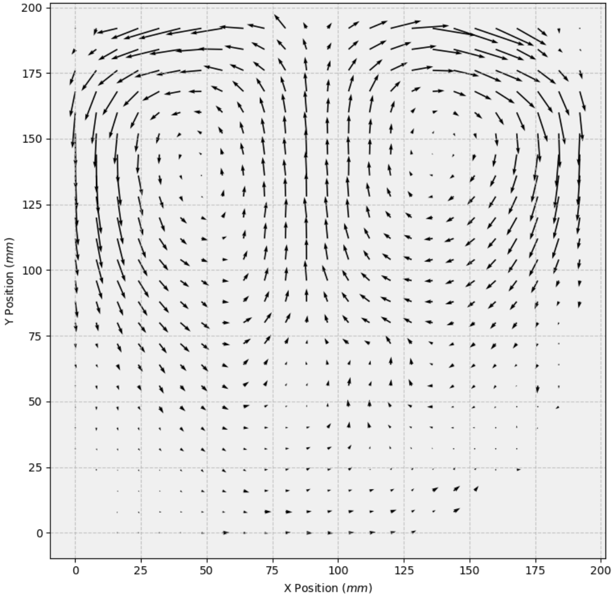


Velocity Vector Fields (XZ Plane)

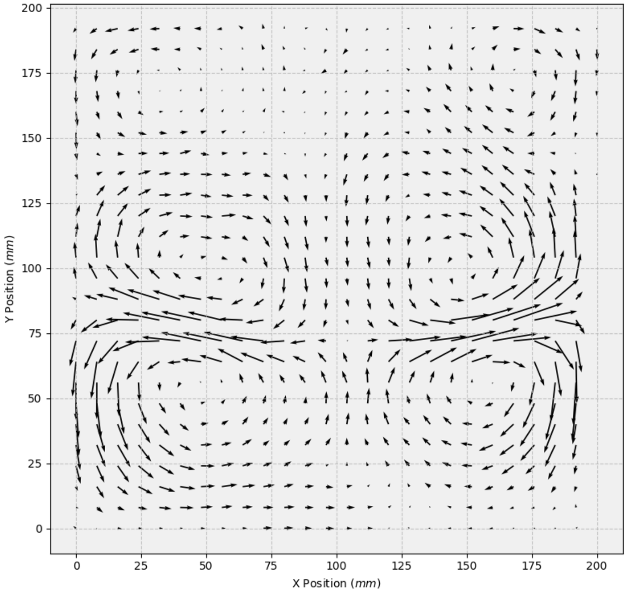
Single-Phase (Re = 500)



Flooded (Re = 500, 5 VVM)



Dispersed (Re ≈ 1400, 5 VVM)



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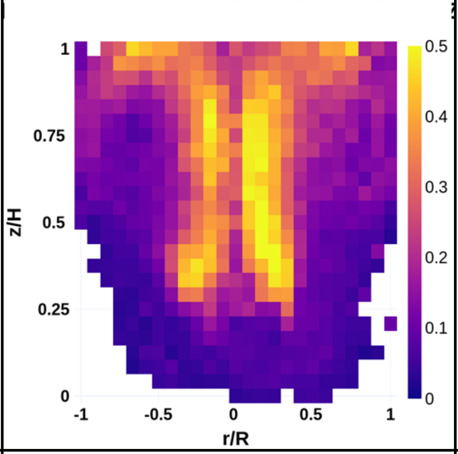
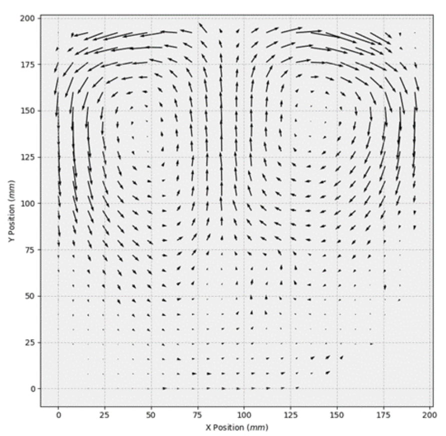
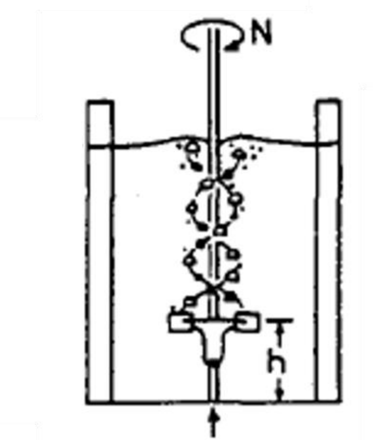
<tr><th>Aeration Regime</th><th colspan="2">PEPT</th><th>Qualitative [2, 3]</th></tr>
<tr><td>Flooding</td><td>
</td><td>
</td><td>
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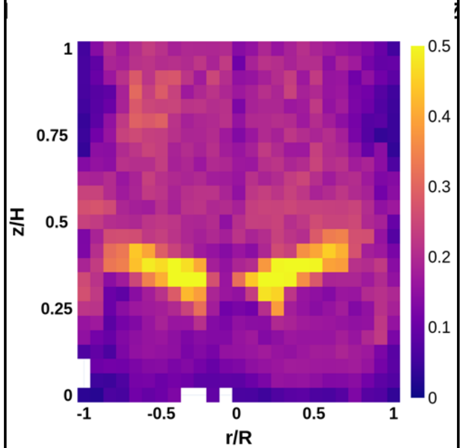
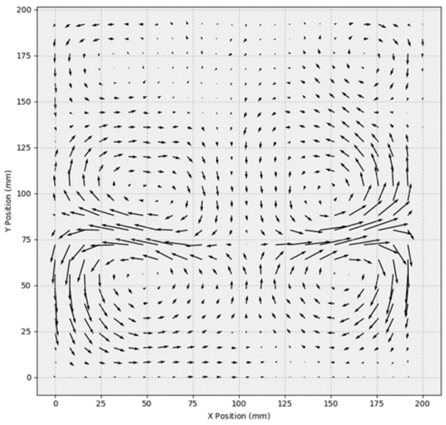
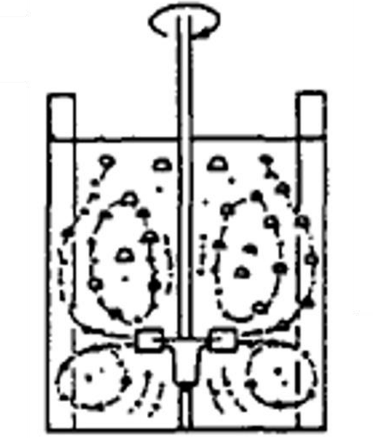
<tr><td>Dispersed</td><td>
</td><td>
</td><td></td></tr>
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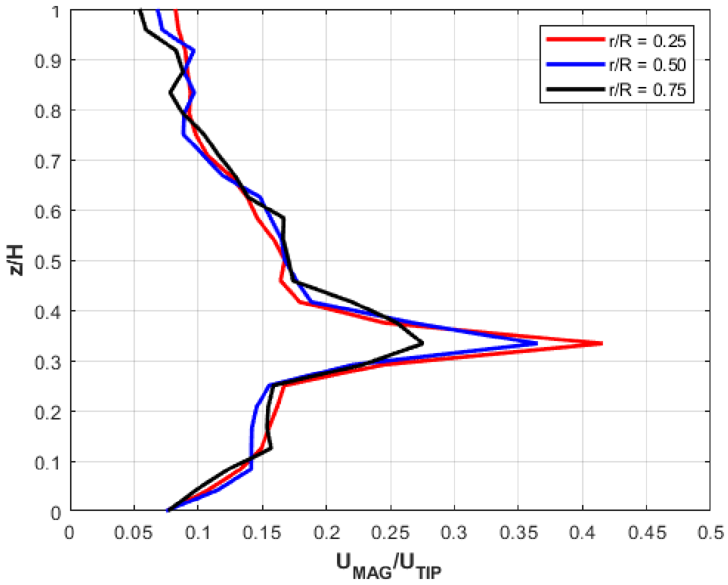
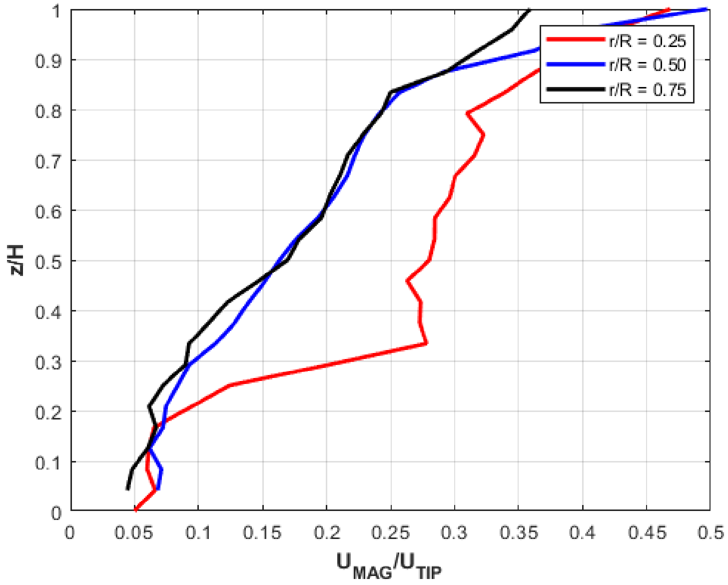
Flooded (Re = 500): Influence of Gas

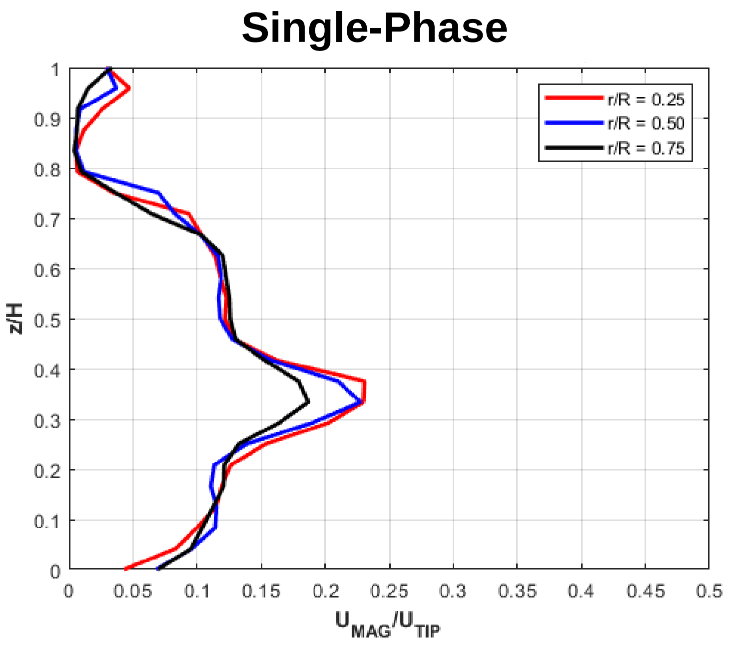
Single-Phase

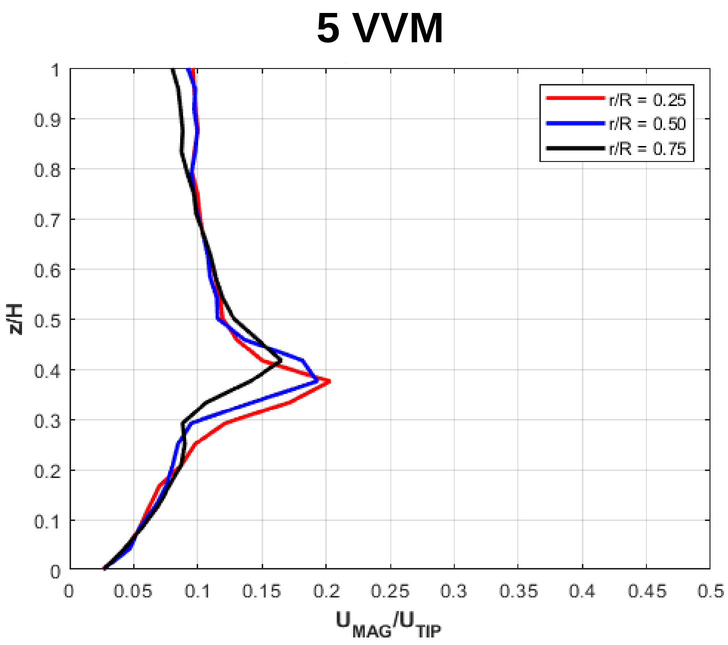


5 VVM

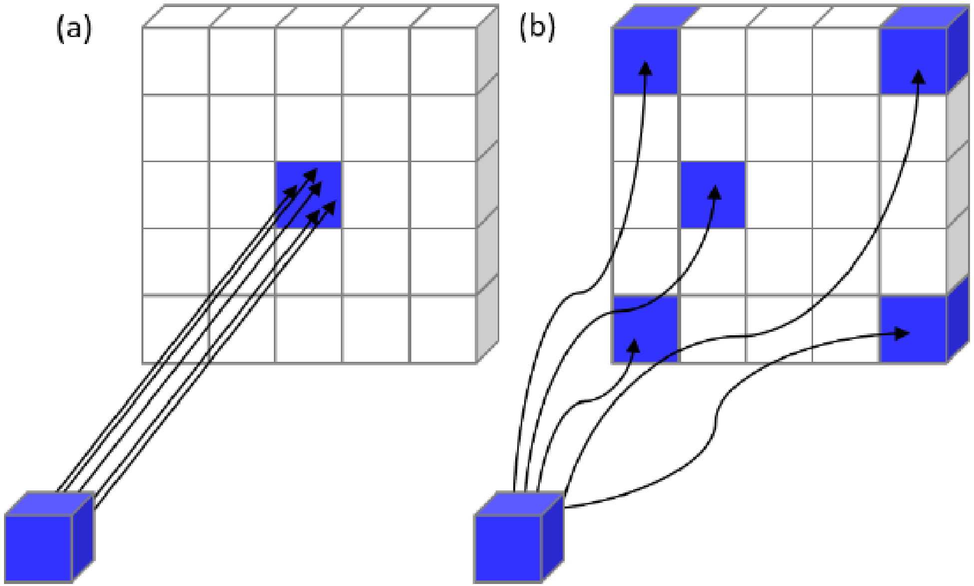


Dispersed (Re ≈ 1400): Influence of Gas





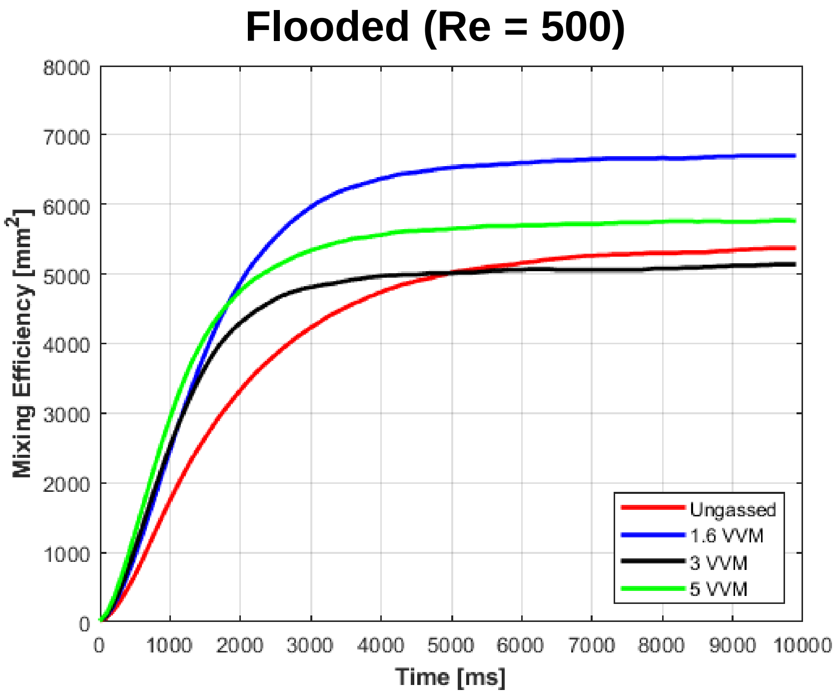
Dispersion

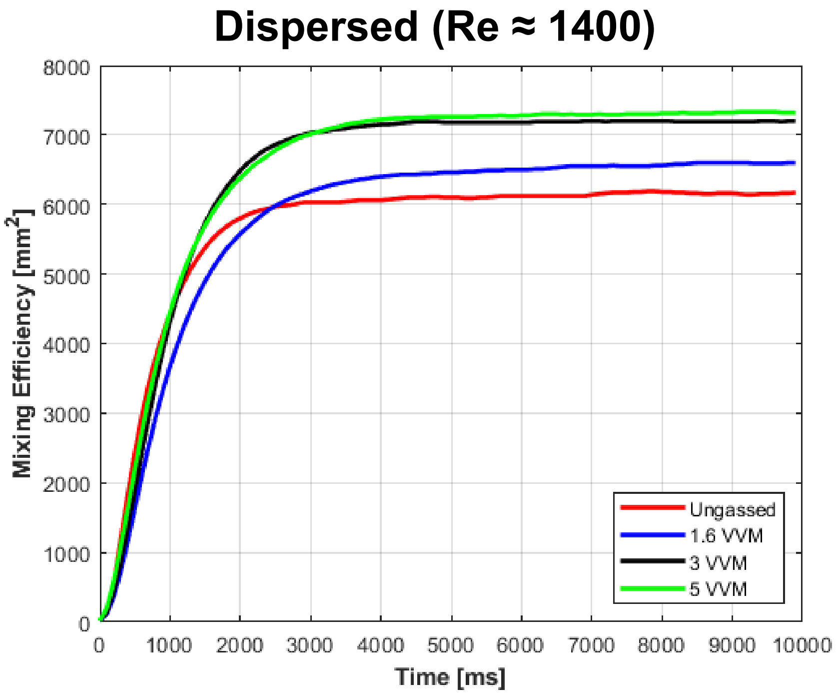


[4]

[4] Windows-Yule, K., Parker, D., Manger, S., Nicusan, A.L., & M.T Herald. (2022). *Positron Emission Particle Tracking: A comprehensive guide*. Institute of Physics Publishing.

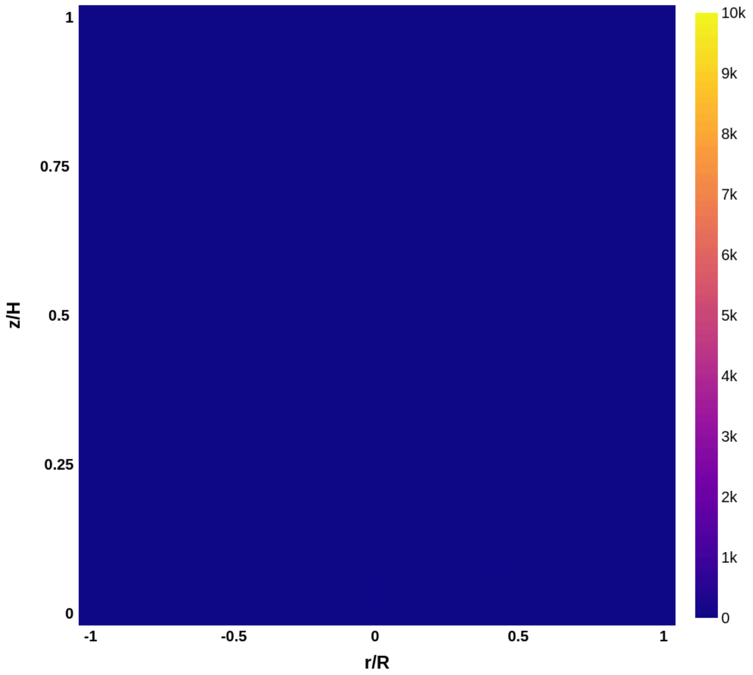
Mixing Efficiency over Time



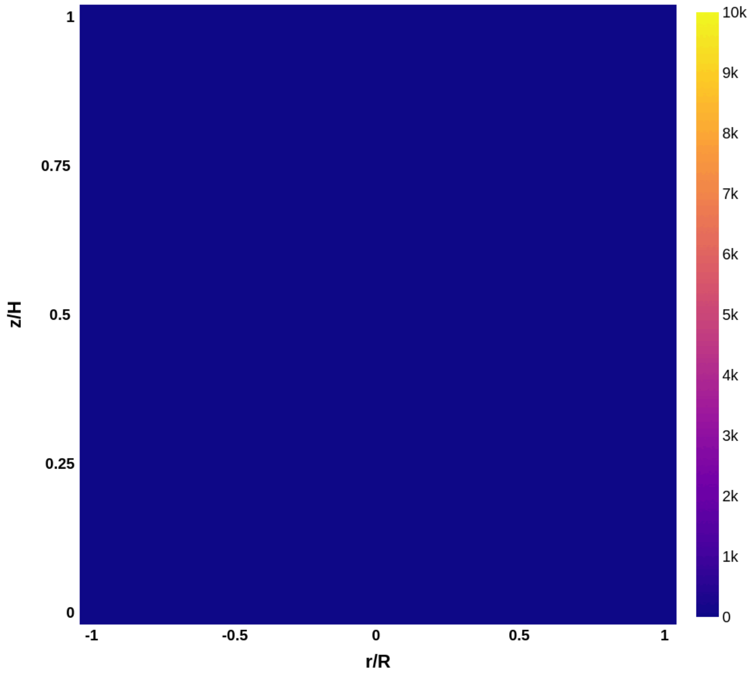


Dispersion over Time

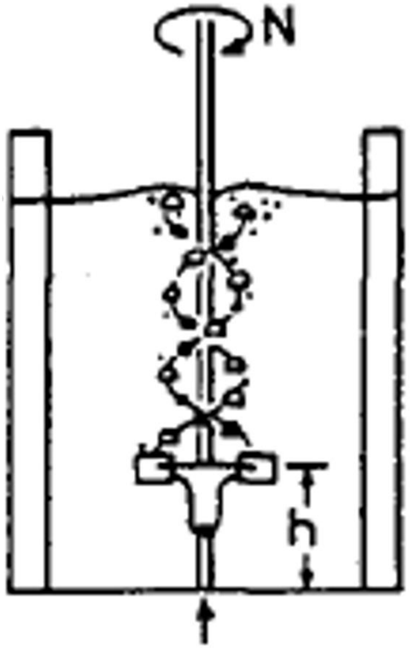
Flooded (Re = 500)



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?

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Thank you for listening! Any questions?