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Quantifying Air Entrainment at the Gas-Liquid Interface in Stirred Tank Reactors

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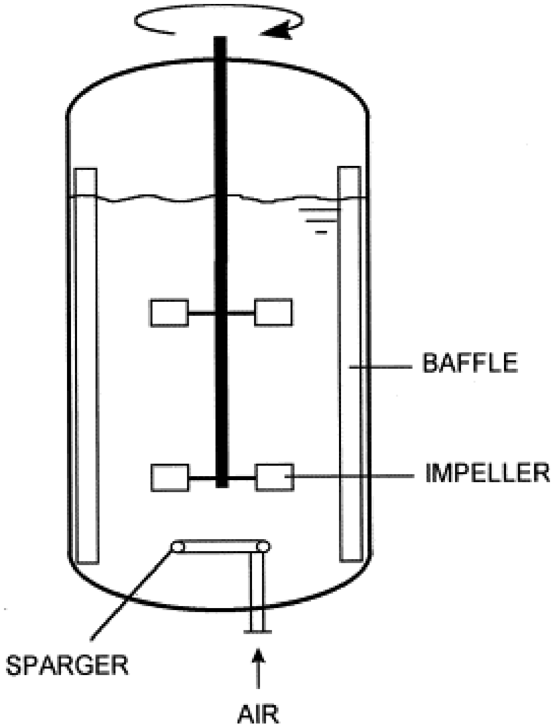
Introduction

- A Stirred Tank Reactor (STR) is a mixing system used in many process industries, including foods, cosmetics, and chemicals.
- Also used in industrial applications, such as: absorption, oxidation, hydrogenation, chlorination, carbonylation, and fermentation.

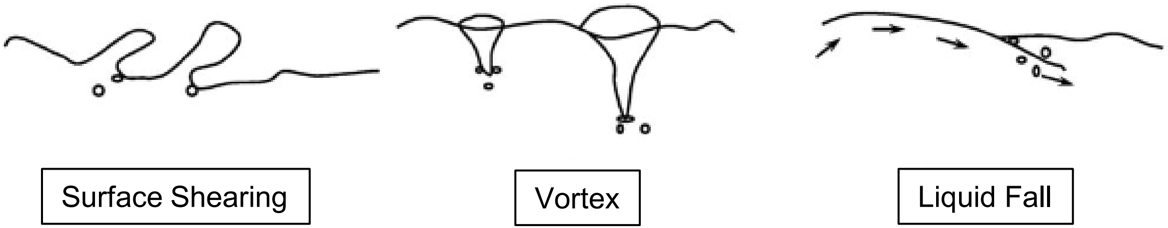
$$Re = \frac{ND^2}{\upsilon}$$

- N: impeller speed
- D: impeller diameter (75.6 mm)
- υ : Kinematic Viscosity (1.0034 mm^2/s)



Air Entrainment Phenomenon

- Air entrainment is a phenomenon that occurs when air is introduced to a system due to the motion of fluids. In general, air entrainment occurs in different applications, such as a drop falling on a liquid surface, open channel flows in hydraulic jumps, and at any air-liquid interface with sufficient shear.

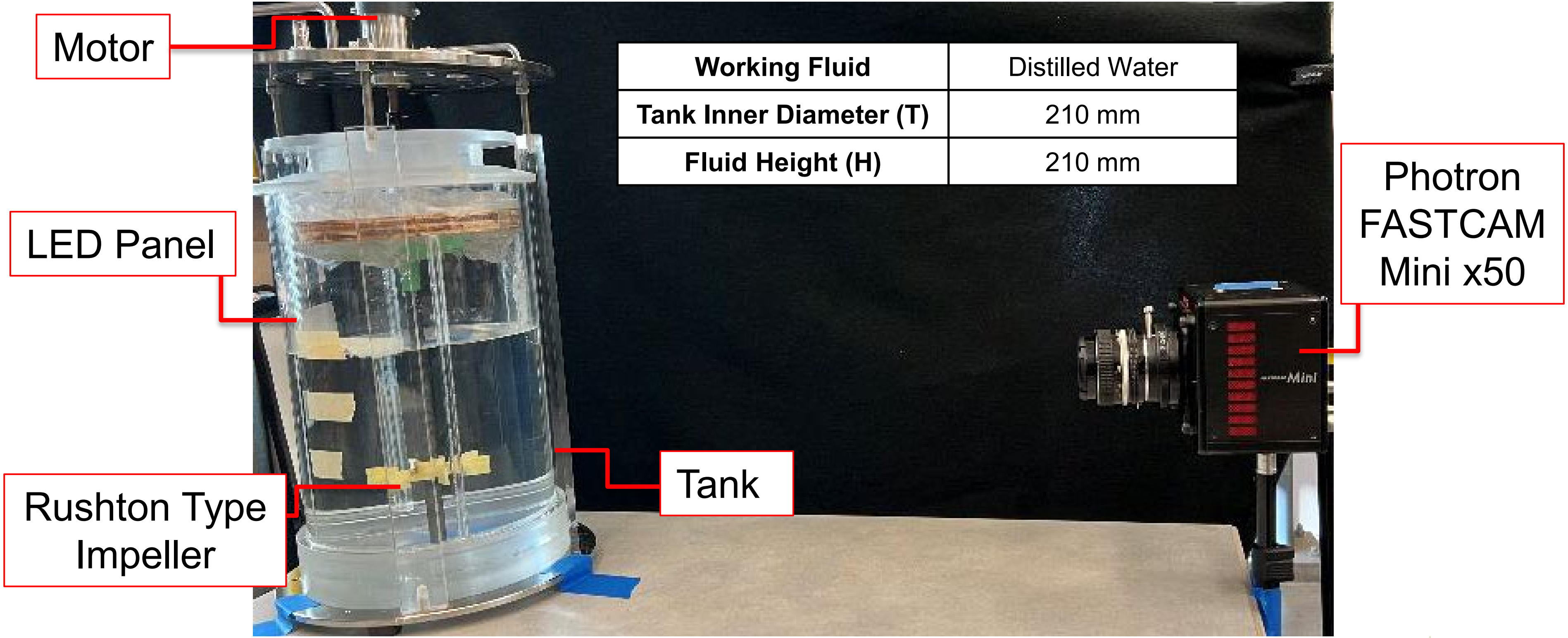


Source: R. G. Mali and A. W. Patwardhan, "Characterization of onset of entrainment in stirred tanks," *Chem. Eng. Res. Des.*, vol. 87, no. 7, pp. 951–961, Jul. 2009, doi: 10.1016/j.cherd.2009.01.010.
Cited in: P. Luo, J. Wu, X. Pan, Y. Zhang, and H. Wu, "Gas-liquid mass transfer behavior in a surface-aerated vessel stirred by a novel long-short blades agitator," AIChE J., vol. 62, no. 4, pp. 1322–1330, Apr. 2016, doi: 10.1002/aic.15104.

Motivation

- Air entrainment is a complex phenomenon that occurs naturally or by operating machines (such as STRs), which could affect the efficiency of a system.
- Under each STR condition, instabilities may cause air entrainment and alter flow regimes.
- This can benefit or disturb industrial processes such as metal pre-treatment and waste treatment. For instance, dispersing solid particles into molten metal as well as having a mixing pattern to some extent.

Experimental Setup

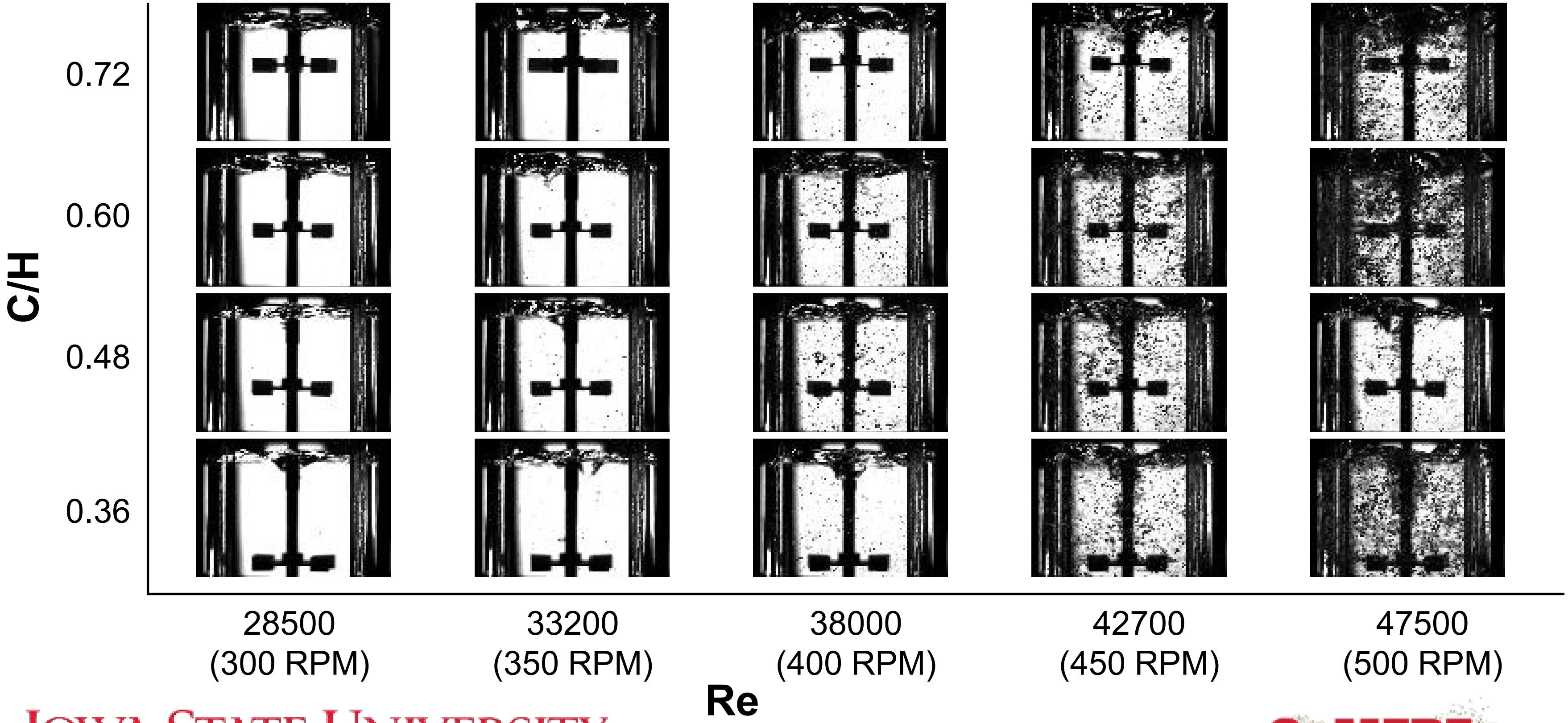


Observational Results

At Re = 42700 (450 RPM)

C/H = 0.72 C/H = 0.60 C/H = 0.48 C/H = 0.36

Observational Results



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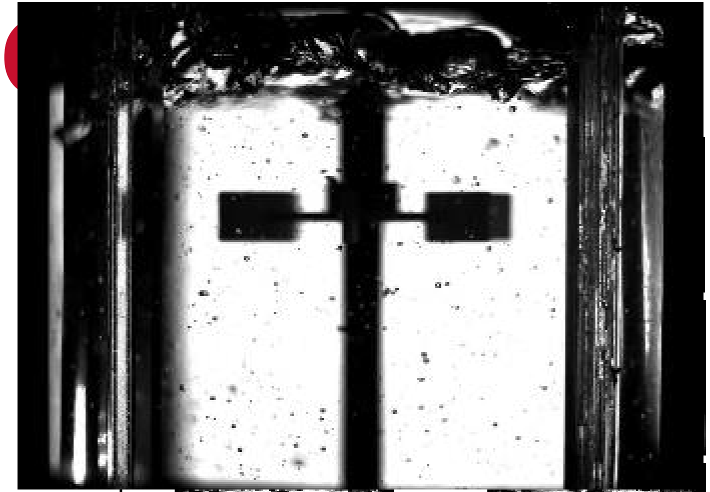
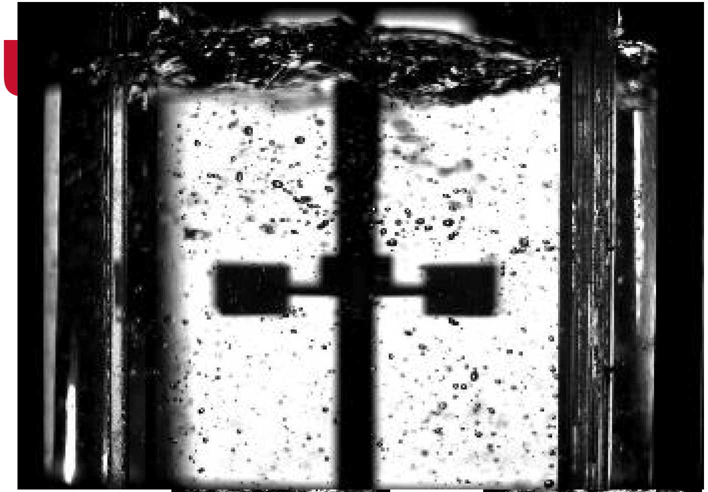
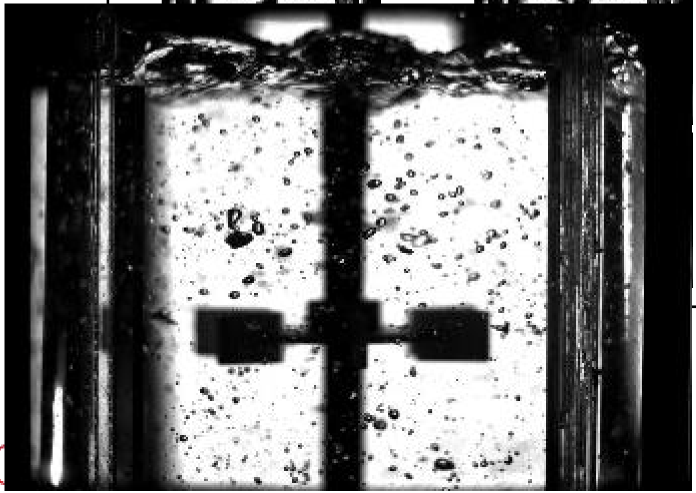
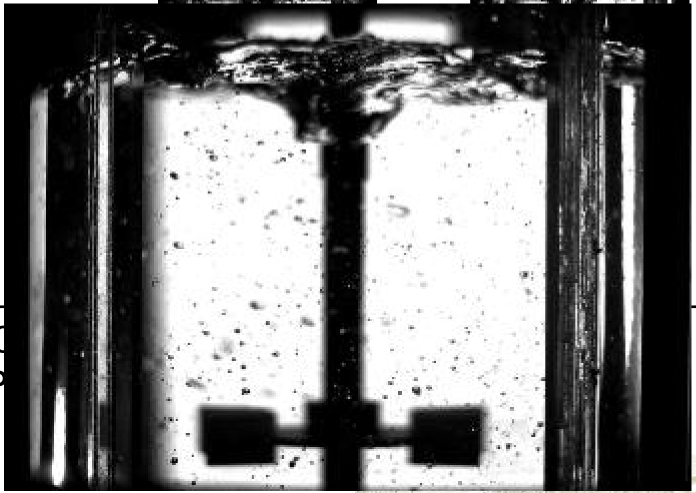




C/H

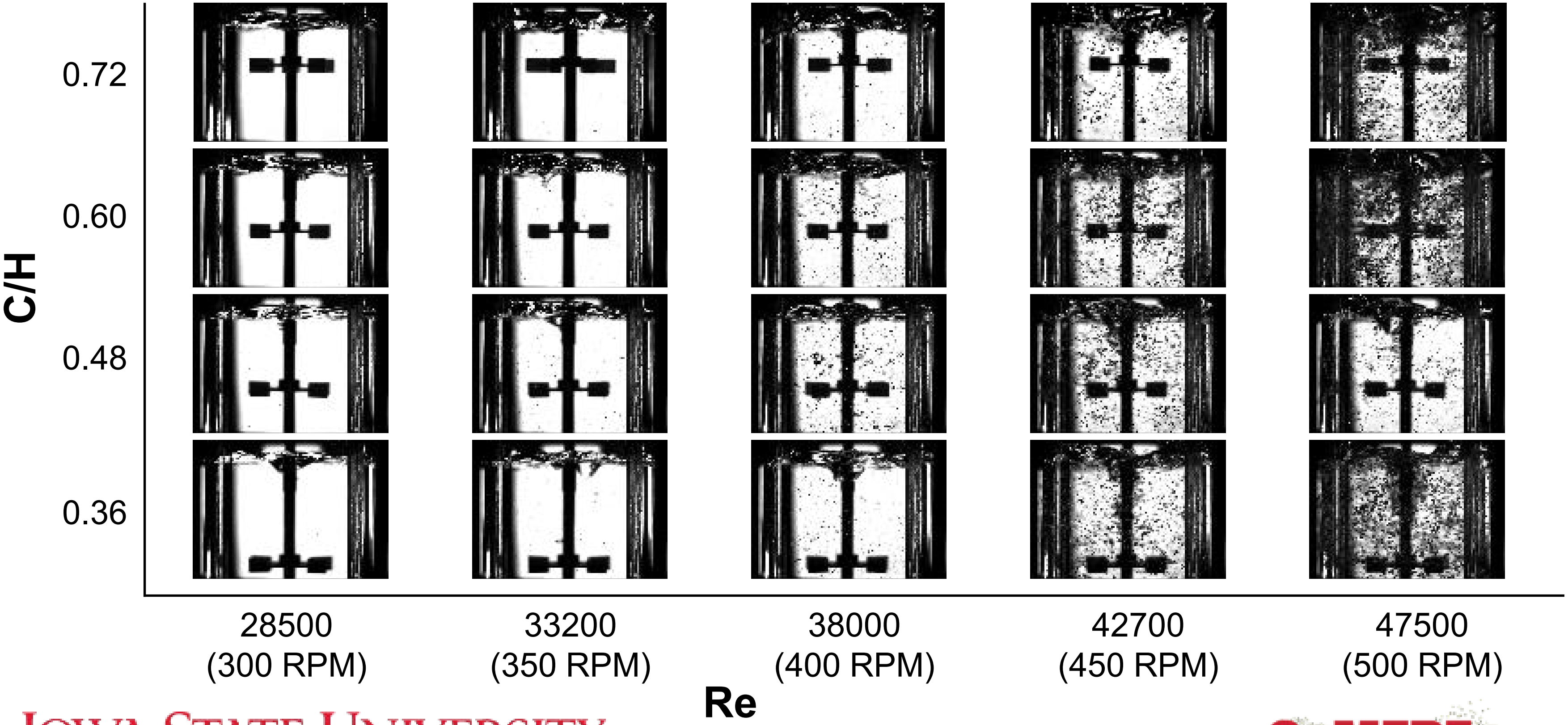




38000
(400 RP

Re

Observational Results



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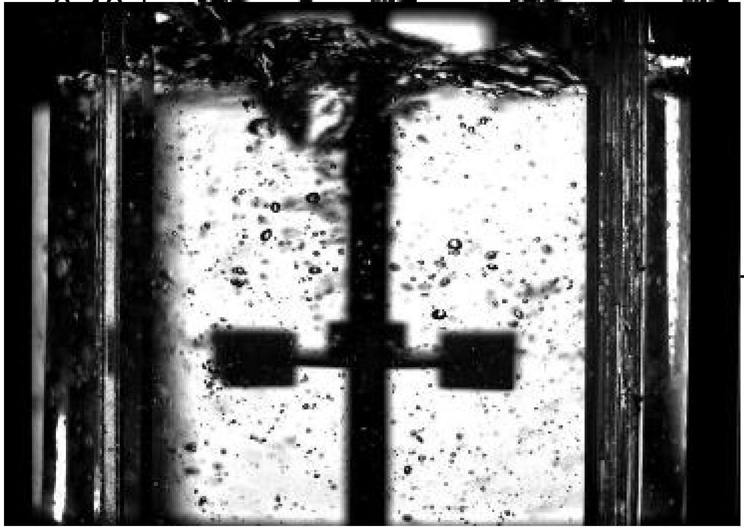
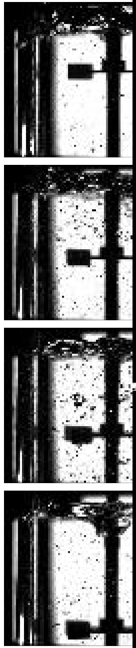
Res



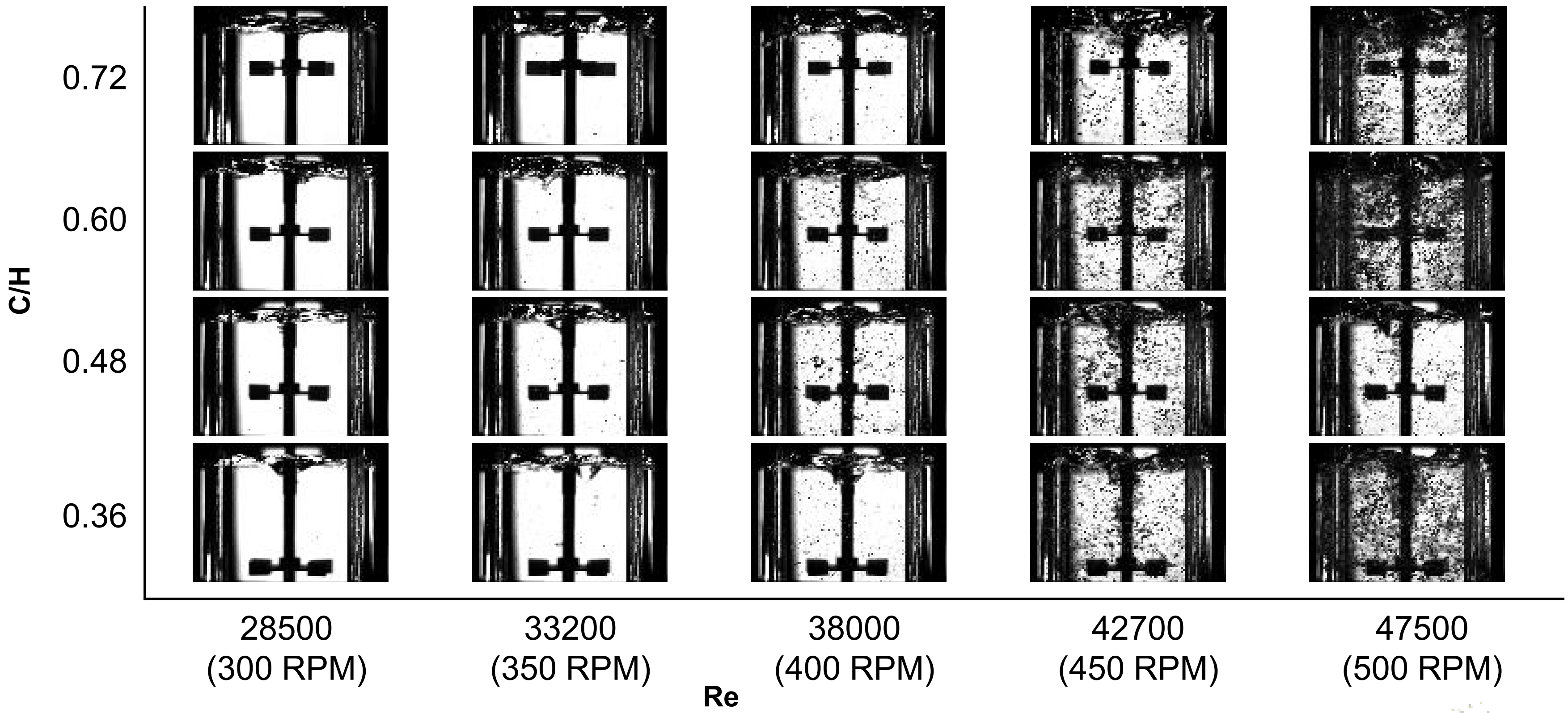


380
(400 R

Re

10

Observational Results



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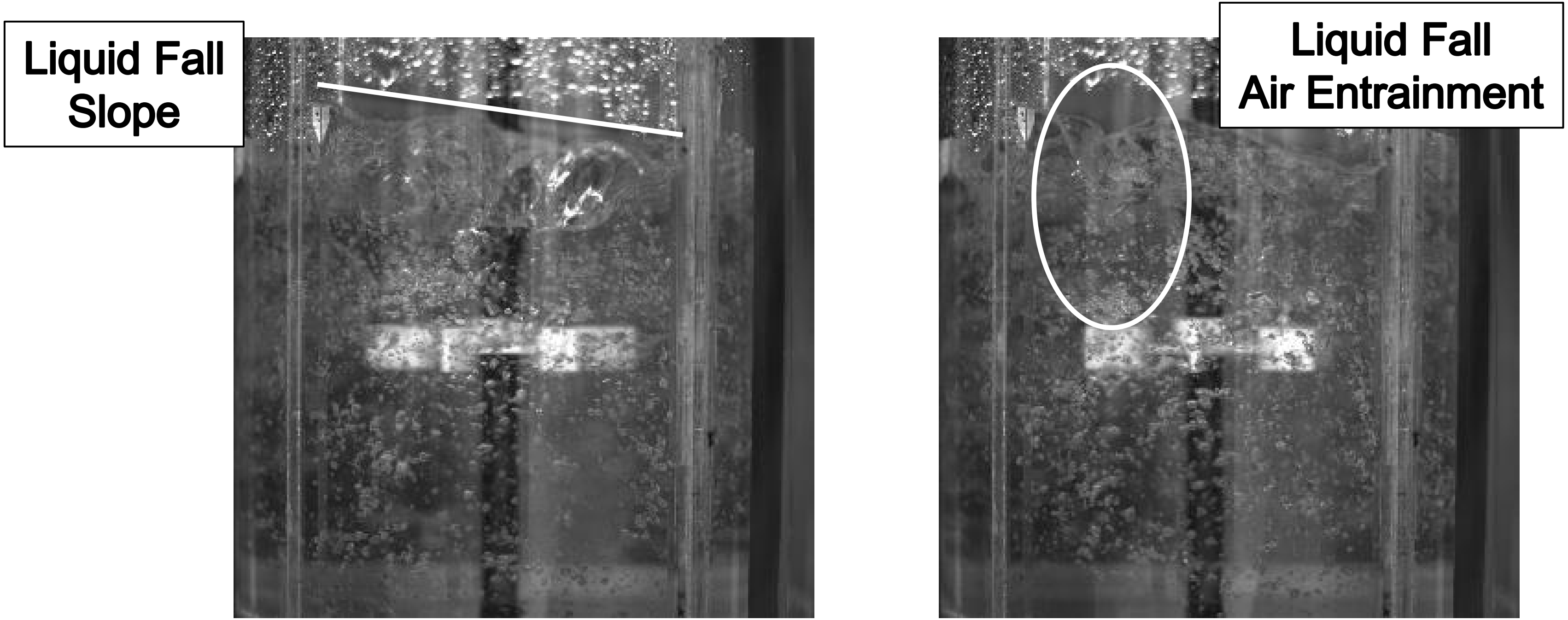
Observational Results

C/H \ Re	28500 (300 RPM)	33200 (350 RPM)	38000 (400 RPM)	42700 (450 RPM)	47500 (500 RPM)
0.72	Almost no air entrainment	Surface Shearing	Surface Shearing	Surface Shearing + Liquid Fall	Surface Shearing + Liquid Fall
0.60	Almost no air entrainment	Surface Shearing + Small Vortex	Surface Shearing + Small Vortex	Surface Shearing + Small Liquid Fall	Surface Shearing + Liquid Fall
0.48	Almost no air entrainment	Surface Shearing + Small Vortex	Surface Shearing + Small Vortex	Surface Shearing + Small Vortex	Surface Shearing + Medium Vortex
0.36	Almost no air entrainment	Surface Shearing + Small Vortex	Surface Shearing + Medium Vortex	Surface Shearing + Medium Vortex	Surface Shearing + Medium Vortex

Observational Results



At C/T = 0.60, Re = 47500 (500 RPM)

Conclusion

- Impeller clearance distance and speed impacts producing different flow conditions.

- The distance between the impeller and the gas-liquid interface controls the gas holdup and the depth of the air entrained in the system.

- Bubble size varies based on air entrainment type.

Future Work

- Use X-ray computed tomography (CT) to quantify gas holdup at different impeller speeds and clearance distances.
- Quantify the depth of air entrained at different clearance distances.
- Use image reconstruction to identify possible flow regimes and air entrainment types as the impeller gets closer to the surface.
- Understand the behavior of the gas-liquid interface.
- Estimate bubble size distribution for each condition.

Thank You for Listening

Questions?