Iowa State University
College of Engineering

Bubble Column Void Fraction and Bubble Size Measurement

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Overview

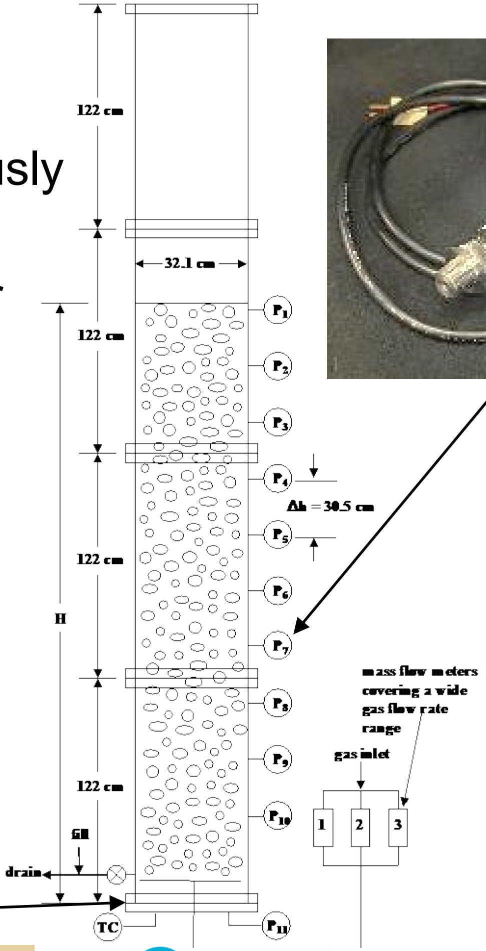
- Motivation
- Experimental setup and details
- Overall void fraction results
- Bubble size measurements
- Future work
- Conclusions

Motivation

- Bubble column bioreactors are often used because of their desirable characteristics
- Scaleup of these bioreactors continues to be a challenge faced in chemical and fermentation industries
- Part of a larger project to validate computational fluid dynamic (CFD) tools to better understand the relationships between bubble column hydrodynamics and fermentation yield

Experimental Setup

- 11 pressure transducers used to simultaneously measure pressure at various locations
- Gas is sparged through 8-arm spider sparger
- Column inner diameter of 32.1cm
- Fluid (water) static height is 10 column diameters or 3.21 meters



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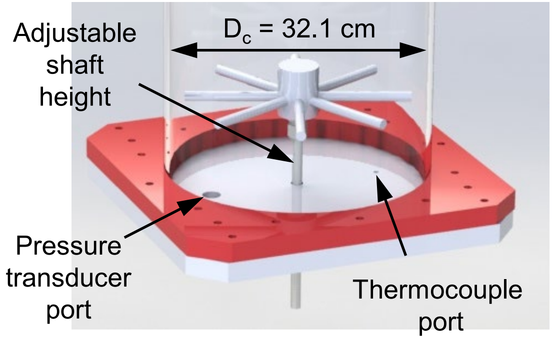
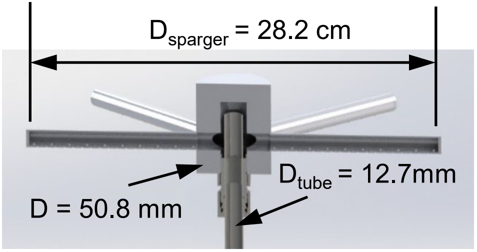
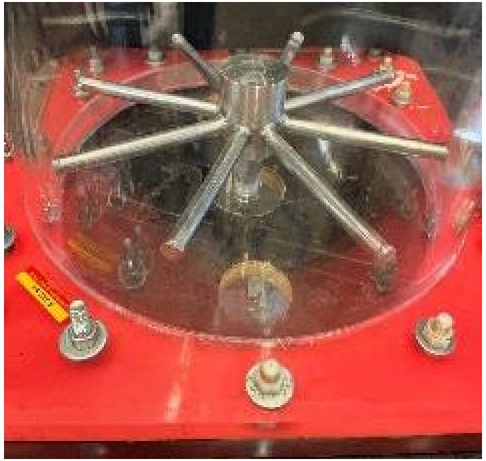
Sparger Details

- 8-arm spider sparger
- 26 1-mm holes in each arm arranged in 2 rows of 13 holes, with a 30º offset between rows
- Holes facing downward offset ±15º of bottom dead center
- Total open area ratio: 0.20%
- Height from bubble column base (h) is set at h = 31 mm but is adjustable (31 < h < 254 mm)





Sparger Section View

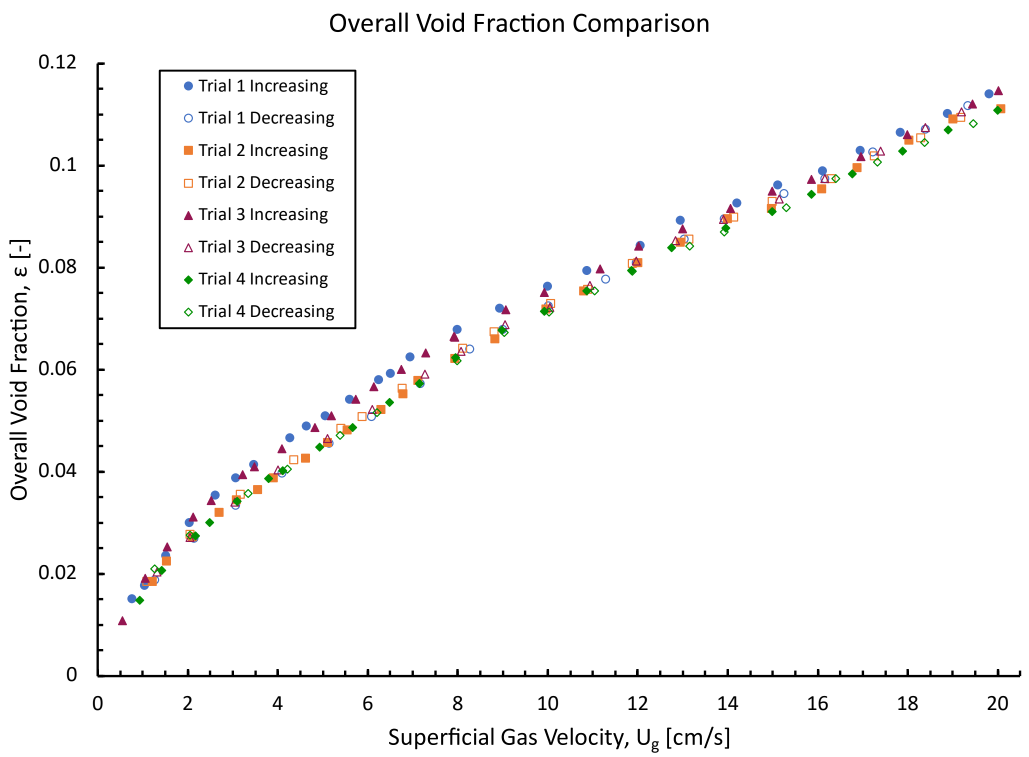


Overall Void Fraction

- Void fraction (also called volumetric gas fraction or gas holdup) determined by:

$$\varepsilon = 1 - \frac{\Delta P}{\Delta P_0}$$

  - ε = void fraction between any two pressure transducers
  - ΔP = average pressure drop between two pressure transducers when there is gas flow
  - ΔP_0 = average pressure drop between two pressure transducers without gas flow



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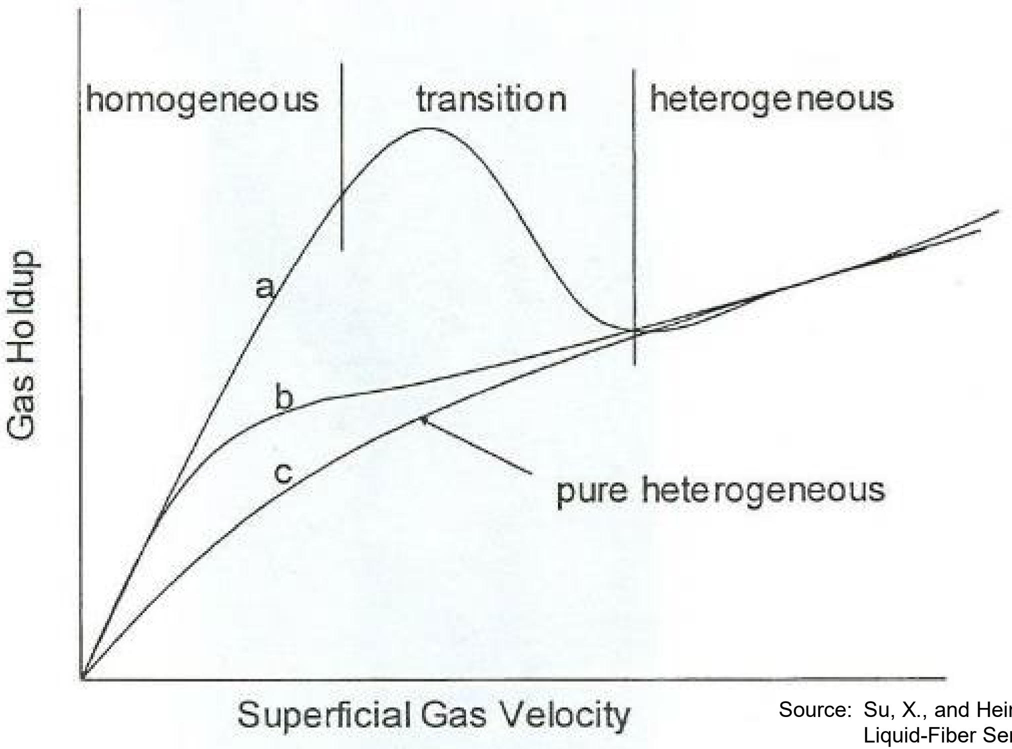
Bubble Column Void Fraction Data



Source:

Source: Su, X., and Heindel, T.J., "Modeling Gas Holdup in Gas-Liquid-Fiber Semibatch Bubble Columns," *Industrial and Engineering Chemistry Research*, 44(24) 9355-9363 (2005).

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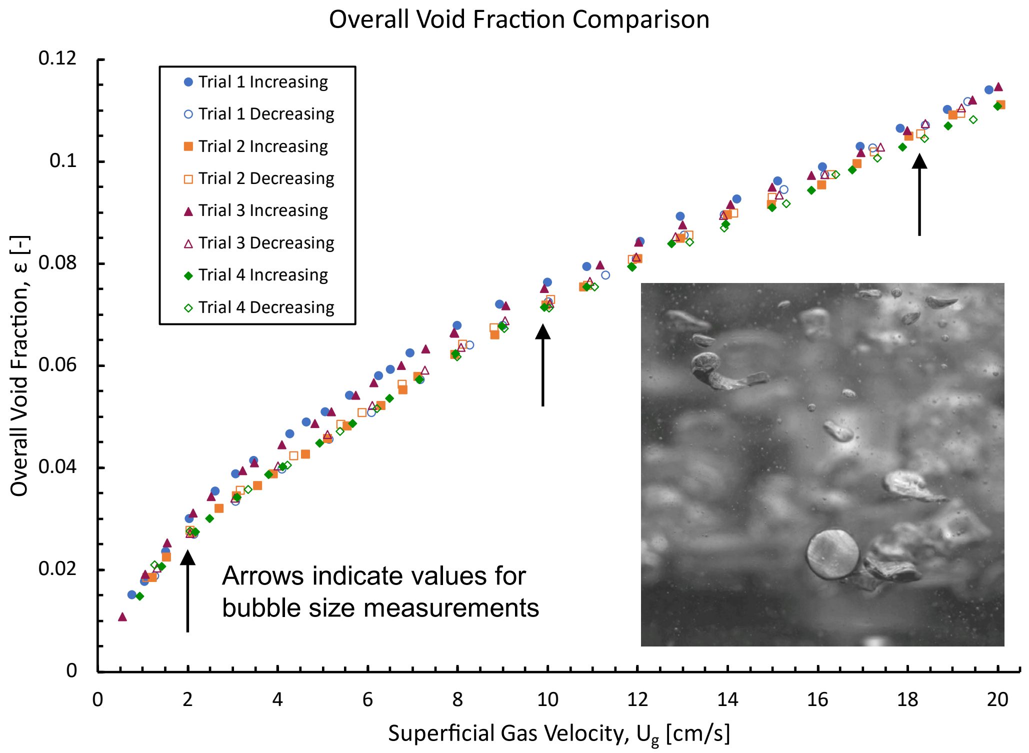
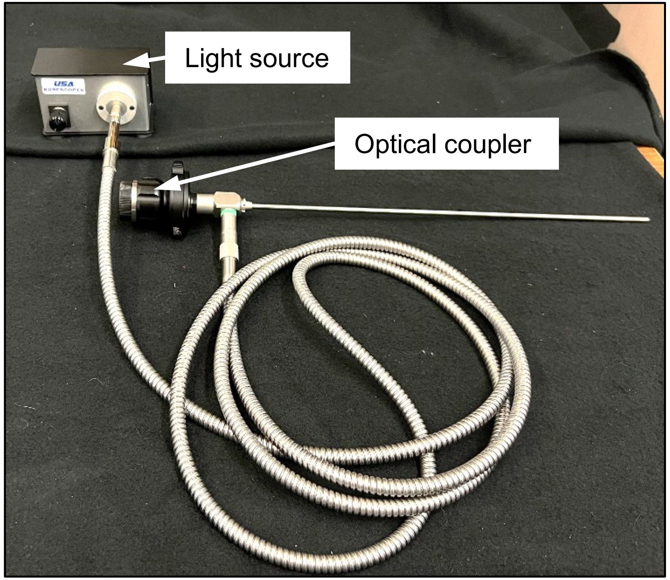
Overall Void Fraction (cont.)

- Operating in pure heterogeneous regime due to sparger geometry and bubble coalescence
- Hysteresis is observed with "fresh" water but not after the column is operated for several hours
  - "fresh" water for trials 1 and 3



Bubble Size Image Acquisition

- 30.5 cm borescope inserted into the bubble column with exterior light sources paired with high-speed camera used for image collection
  - Others have used borescopes in homogeneous flows
- Images collected at multiple axial and radial locations paired with pre-selected superficial gas velocities
  - Superficial gas velocities for collection were determined from results and industry collaborator preferences



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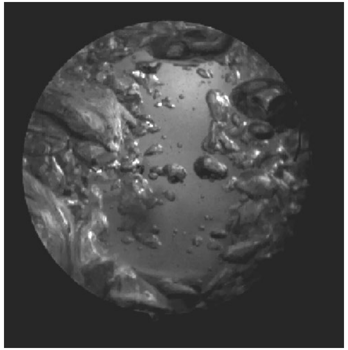
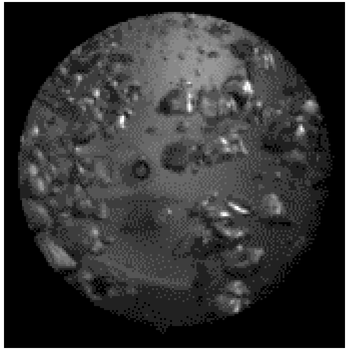
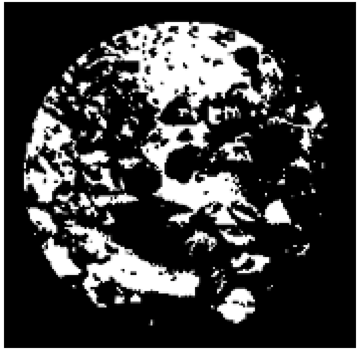
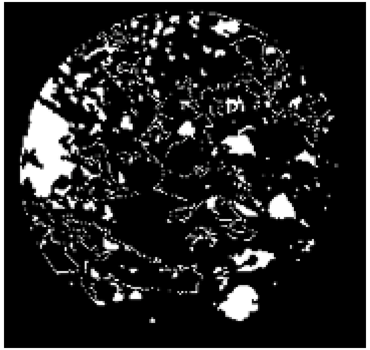
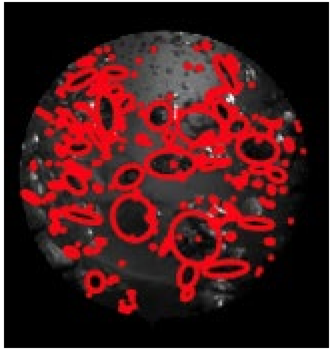
Borescope Image Analysis Challenges


Original Video


Original Still Frame


Binarized Frame

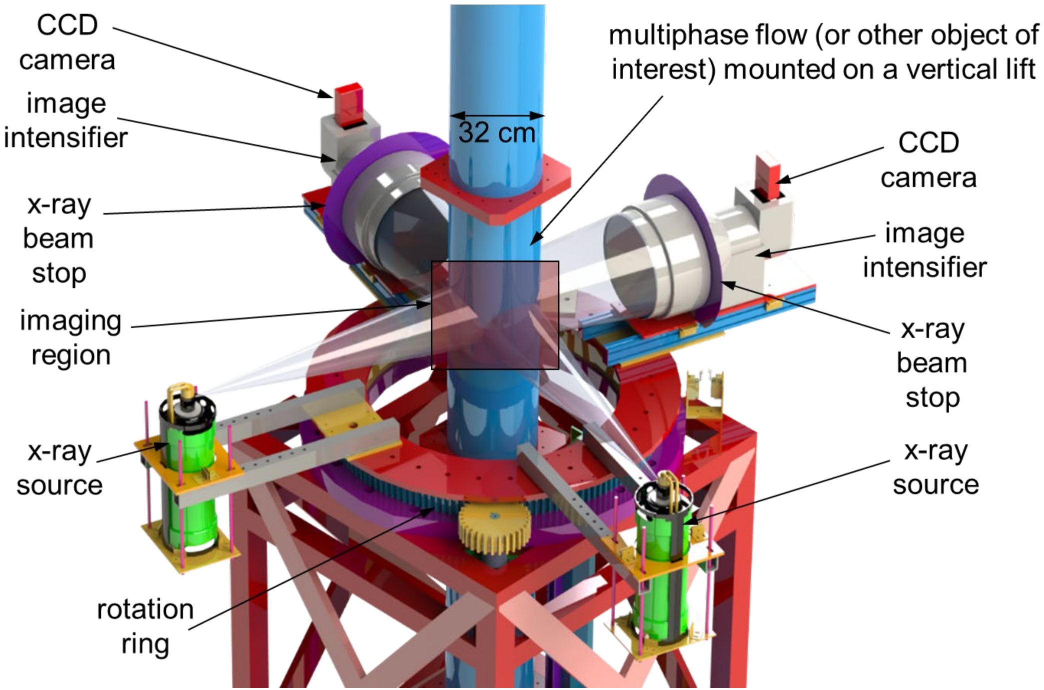

Processed Frame


Verified Frame

- Image information: U_g = 2 cm/s, 60 fps
- In-house image analysis code to determine bubble sizes by detecting bubble edges
- Bubbles that are isolated are easily identified. If there are bubbles ‘stacked’ the code cannot currently identify the edges effectively
  - Solved with lighting to create a broader range of intensities with the images
  - Currently improving process

Next Steps

- Improve image acquisition for bubble size distribution measures
- Use our X-ray flow visualization facility to complete X-ray Computed Tomography (XCT) imaging
  - Provides time-average local void fraction within the imaging region
- Introduce a fermentation broth simulant as the working fluid to conduct overall and local void fraction and bubble size measurements



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Conclusions

- Bubble column bioreactors are used in the fermentation industry but are a challenge for scale-up
- Overall void fraction data provides information across a wide range of superficial gas velocities
- Operating in the pure heterogeneous regime provides challenges for bubble size distribution data collection
- Bubbles are captured with a borescope
  - Addressing imaging challenges

Acknowledgments

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- The input from Cargill and Geno are greatly appreciated.

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