Experimental Investigation of Air-Water Bubbly Flow Characteristics under Motion Conditions Using Synchronized Wire-Mesh Sensor and High-Speed Camera

Jaehyun Kim, Hyukjae Ko, Hyoung Kyu Cho*

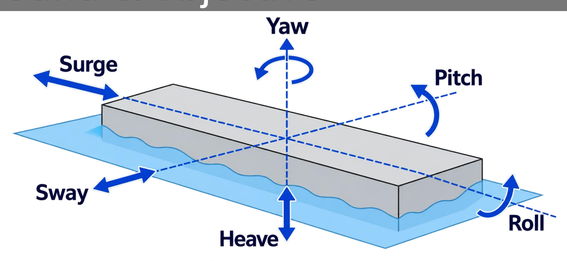
Department of Nuclear Engineering, Seoul National University
**Corresponding author: chohk@snu.ac.kr*

Introduction

Research background & objective



FNPP (BANDI by KEPCO)



Ocean motions

❖ Thermal-hydraulic phenomena under ocean conditions

- Need to consider motion effects in thermal-hydraulic analysis

❖ Two-phase flow visualization under motion conditions

- Direct observation and evaluation of motion effects on two phase flow
- High-temporal resolution measurement using a wire-mesh sensor (WMS)

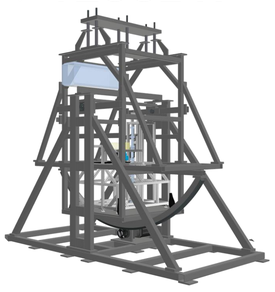
❖ Synchronized WMS–HSC measurements

- Cross-validation of postprocessed WMS data

Experimental methods

Experimental setup

❖ YEOUL-R

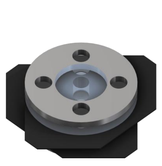


- Air–water two-phase flow loop at atmospheric pressure
- 13 mm I.D. acrylic test section (L/D 66)

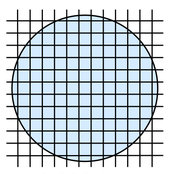
Liquid superficial velocity, j_f	0.63 m/s
Gas superficial velocity, j_g	0.022, 0.053 m/s
Static inclination	0°, 15°, 30°, 45°
Rolling amplitude / period	30°, 45° / 6, 12 s

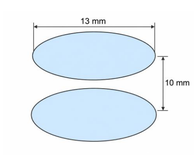
❖ Wire-mesh sensor (WMS)

- High temporal and spatial resolution
- Double sensor for velocity estimation



12 × 12 electrodes, 8,000 fps

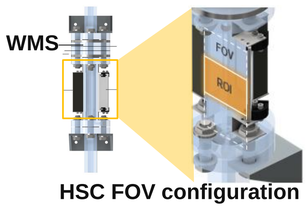




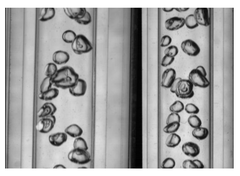
Double-stacked sensor

❖ High-speed camera (HSC)

- 600 fps, 1,024 × 720 pixels
- Simultaneous direct and mirror views



HSC FOV configuration



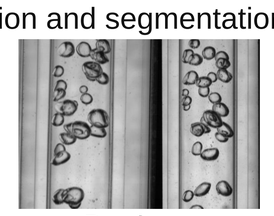
Direct view Mirror view

- Hardware-triggered WMS–HSC synchronization on a common time base

HSC image processing

❖ Bubble detection[1,2]

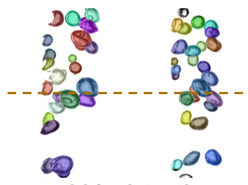
- Detection and segmentation of individual bubbles in direct and mirror views



Raw frame



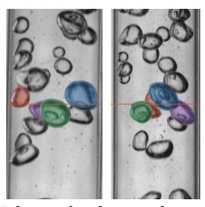
Contrast enhancement



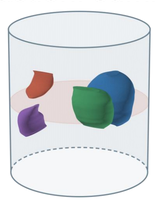
Bubble detection

❖ Void fraction estimation

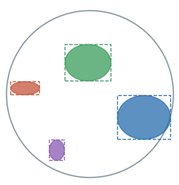
- Bubble cross-sections are obtained by 3D carving of direct and mirror views
- Cross-sectional void fraction: summed bubble areas / pipe cross-sectional area



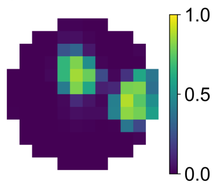
Direct / mirror views



3D carving



Mid-plane sections

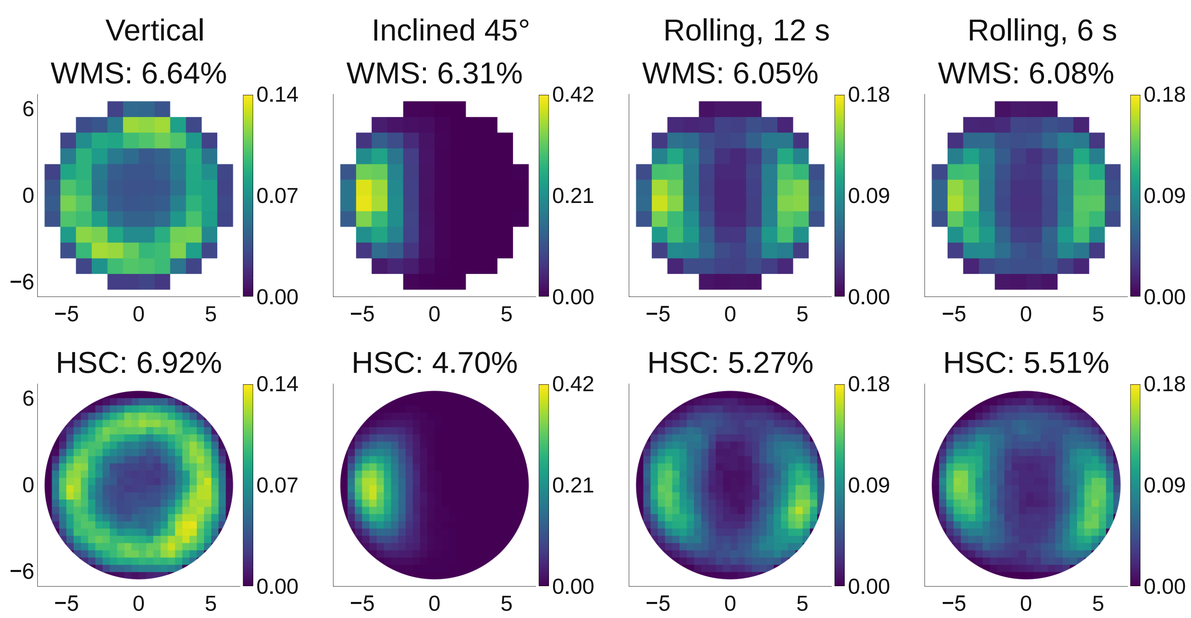


WMS local void fraction

Results and discussion

Results of void fraction estimation

❖ WMS–HSC void fraction comparison



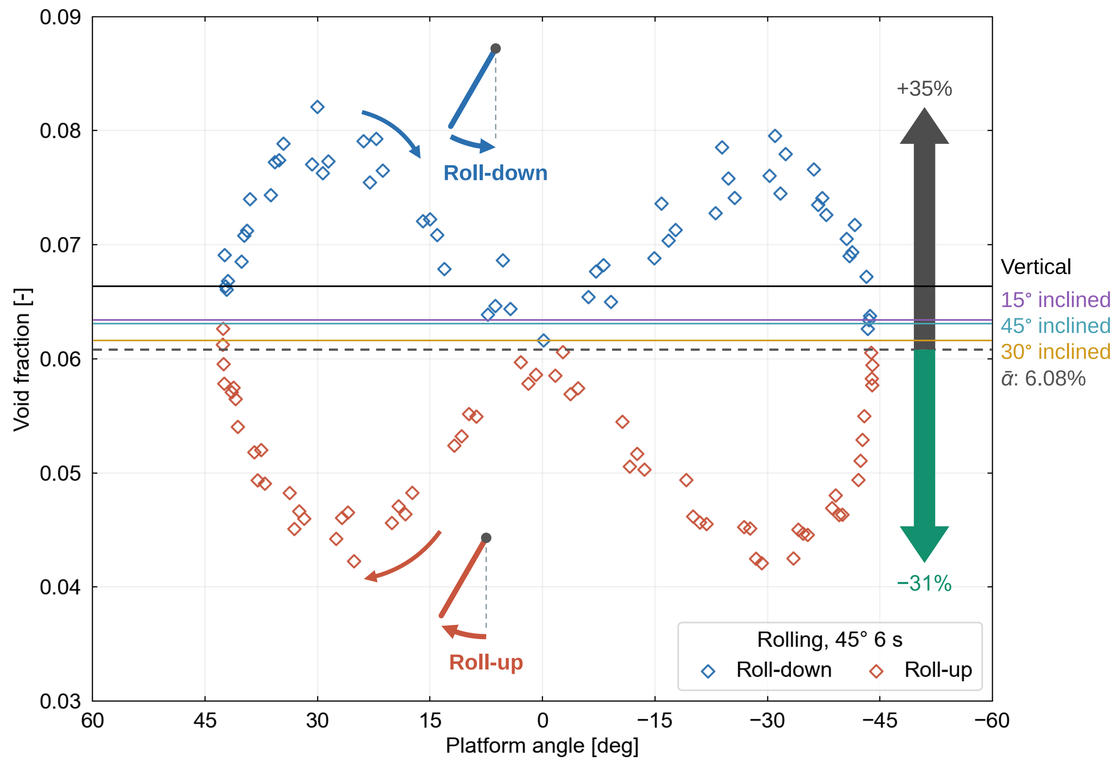
- Similar trends in WMS and HSC void fraction distributions

Results and discussion

Results of void fraction estimation

❖ Cross-sectional void fraction under rolling conditions

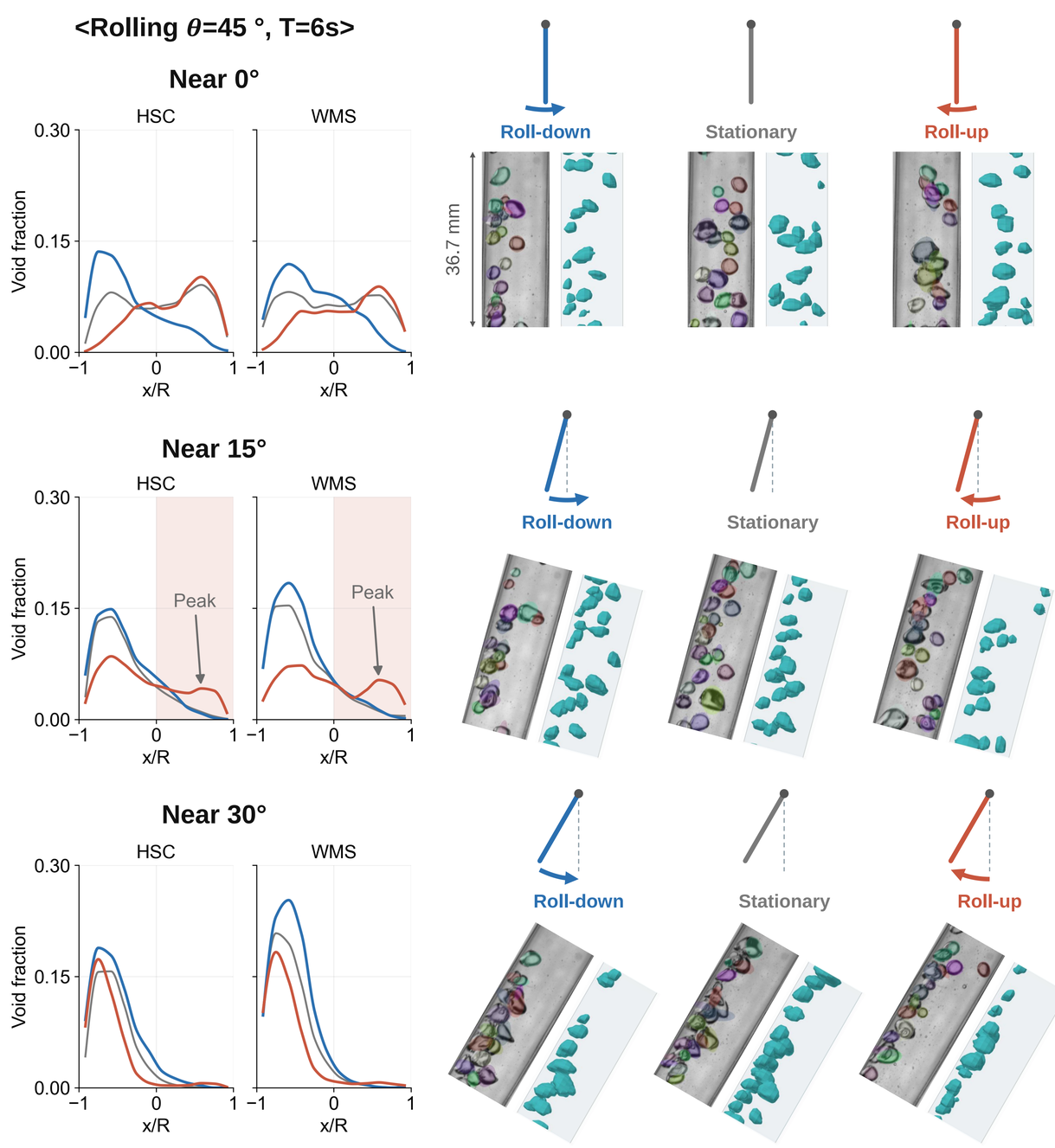
- High void fraction fluctuation compared to stationary conditions
- A delay in void fraction fluctuation is observed



Bubble behavior under stationary and rolling conditions

❖ Radial void fraction distribution

- Buoyancy-driven bubble accumulation at the upper wall is observed
- Delayed bubble shift is observed relative to stationary conditions
  - Roll-up: small peak on the opposite side, similar to the vertical condition
  - Roll-down: higher peak than the inclined condition



Conclusion

❖ Summary

- HSC and WMS agree in time-averaged and phase-resolved distributions
  - Bubble detection and segmentation need to refined for inclined conditions
- A delay in bubble redistribution is observed under rolling conditions
  - Consistent between WMS and HSC

References

1. H. Hessenkemper et al., “3D detection and tracking of deformable bubbles in swarms with the aid of deep learning models”, International Journal of Multiphase Flow, 179, 104932, 2024.
2. C. Stringer et al., “Cellpose: a generalist algorithm for cellular segmentation”, Nature Methods, 18, 100–106, 2021.