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CFD Simulation of High Inlet Velocity Air Flow into a Large Tank at Pool Scrubbing Conditions

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Introduction

- ❑ The Fukushima Daiichi nuclear disaster revealed that the fission product retention was less effective than it was previously predicted. Thus, the pool scrubbing phenomenon was brought back on the spotlights again in the nuclear safety community
- ❑ Pool scrubbing is the removal of the airborne fission products in gas bubbles rising in a large body of water, i.e., a water pool
    - BWRs → suppression pools
    - PWRs → steam generators
- ❑ The removal effect (retention capacity) of the radioactive aerosol is quantified by the so-called Decontamination Factor (DF) which is defined as the quotient between the mass injected and the mass escape from the pool
- ❑ the DF is dependent on parameters such as particle size and concentration, bubble size and distribution, submergence, pool depth, pool P/T gas composition, and so on
- ❑ The bubble size and shape play a very crucial role in the retention capacity. Thus, it's important to understand the hydrodynamic behavior of the pool scrubbing phenomenon well through numerical simulations using CFD

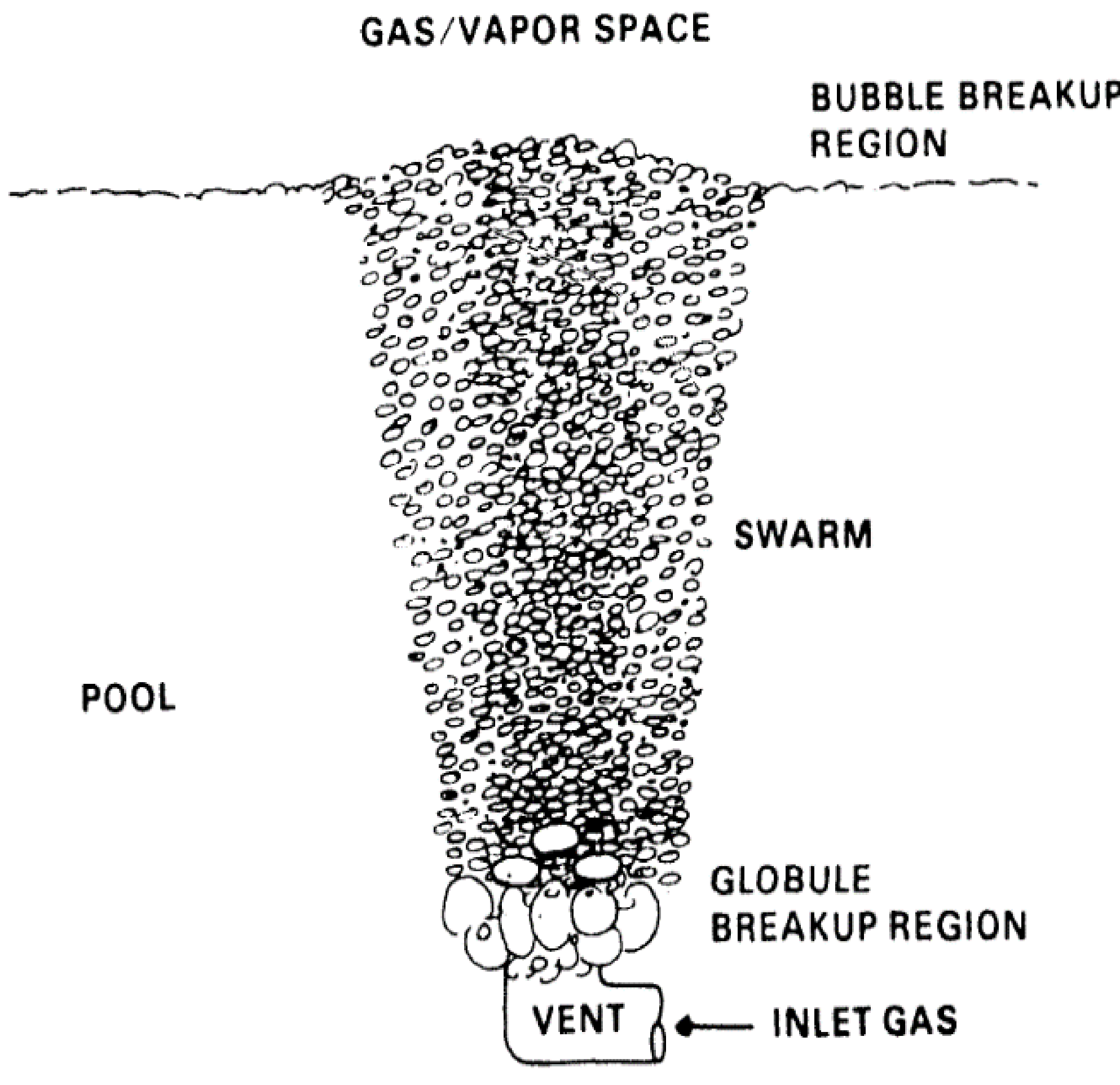

Figure 1. Bubble Behavior During Pool Scrubbing

Owczarski and Burk, 1991

The Experiment and Methodology

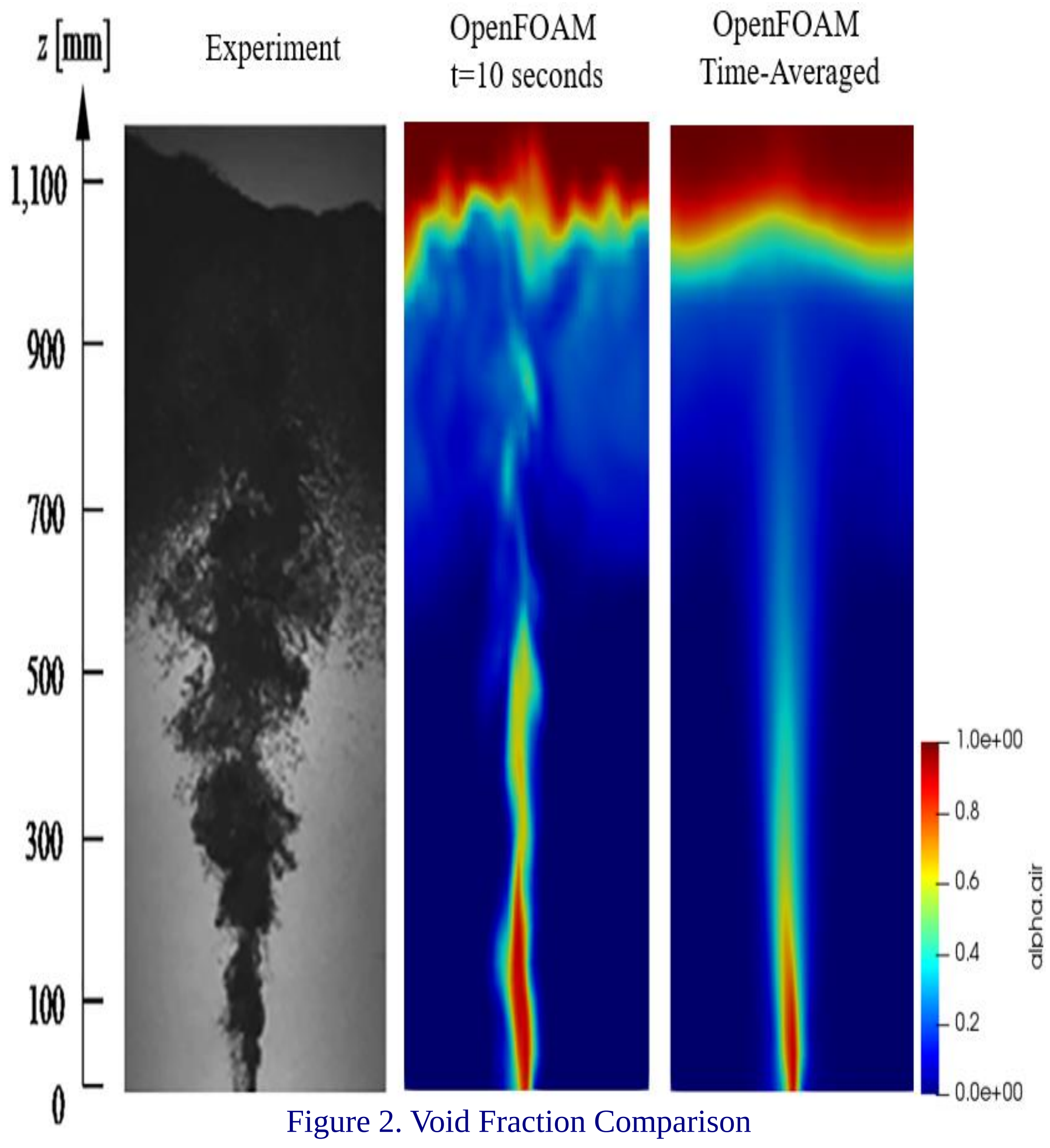

Figure 2. Void Fraction Comparison

- ❑ Flow patterns two-phase flow in water pools, large and small-diameter pipes are inherently different from each other. Thus, the concerned flow patterns for two-phase flow in a liquid pool are bubbly and churn-turbulent flows. Y. Abe et. al., 2018 experiment is chosen to be studied
    - The air was injected through a 6 mm inner-diameter nozzle into a rectangular test section (500×500×3000 mm) that was filled up 1100 mm with tap water at room temperature
    - The inlet superficial velocity (J_g) is around 150 m/s which is quite high compared to similar experiments in the literature
- ❑ The multiphaseEulerFoam solver, which is a solver for a system of any number of compressible fluid phases with a common pressure but otherwise separate properties, was selected to simulate the experiment in OPEN source Field Operation And Manipulation (OpenFOAM) version 8 with pure hexahedron meshes in Salome
- ❑ To obtain a stable swarm in high-velocity airflow cases the drag force with swarm correction, virtual mass force, transversal lift force, and the turbulent dispersion force were found to be the most important ones among interfacial forces
- ❑ All simulations were performed for 10 seconds in parallel on distributed processors using Message Passing Interface (MPI) standard. In total, 16 processors were used and the decomposition was performed using the decomposeParDict
- ❑ The void fraction comparison shows similar results, especially in the swarm area as shown in Figure 2. However, the swarm radius toward the upstream does not seem to be gradually increasing as it is shown in the experiment

The Results and Future Work

- ❑ The analyses were performed using the constant diameter model in OpenFOAM assuming a 6 mm bubble size with mixtureKEpsilon turbulence model with only using the drag and the virtual mass forces
    - The drag force is unarguably the most important force acting on bubbles which control the rise velocity through the water
    - The virtual mass force is also very important for a stable swarm formation since it is related to the acceleration of the continuous phase relative to the dispersed one
- ❑ The void fraction results reasonably agree with the experiment results as can be seen in the Figure 3. The sharp void fraction profile flattens toward downstream which is the expected behavior in the transition from globule to swarm region at pool scrubbing experiments
- ❑ The gas velocity results given in Figure 4 show a large discrepancy near the exit and the order of the discrepancy gets smaller toward downstream.
    - The inlet velocity of 150 m/s is quite large compared to other pool scrubbing experiments in the literature, so it is harder to evaluate an accurate gas velocity accurately
    - The lift and turbulent dispersion should be activated and the effects of all forces should be carefully investigated
    - A wire mesh sensor was used in the experiment which is not capable of measuring negative velocities
- ❑ To further improve the results, it is intended to improve the turbulence modeling while using the constant diameter model. Once the turbulence modeling is matured and all the necessary phase interaction models are included, the diameter model should be switched to Interfacial Area Transport Equation (IATE) to get a better bubble size distribution

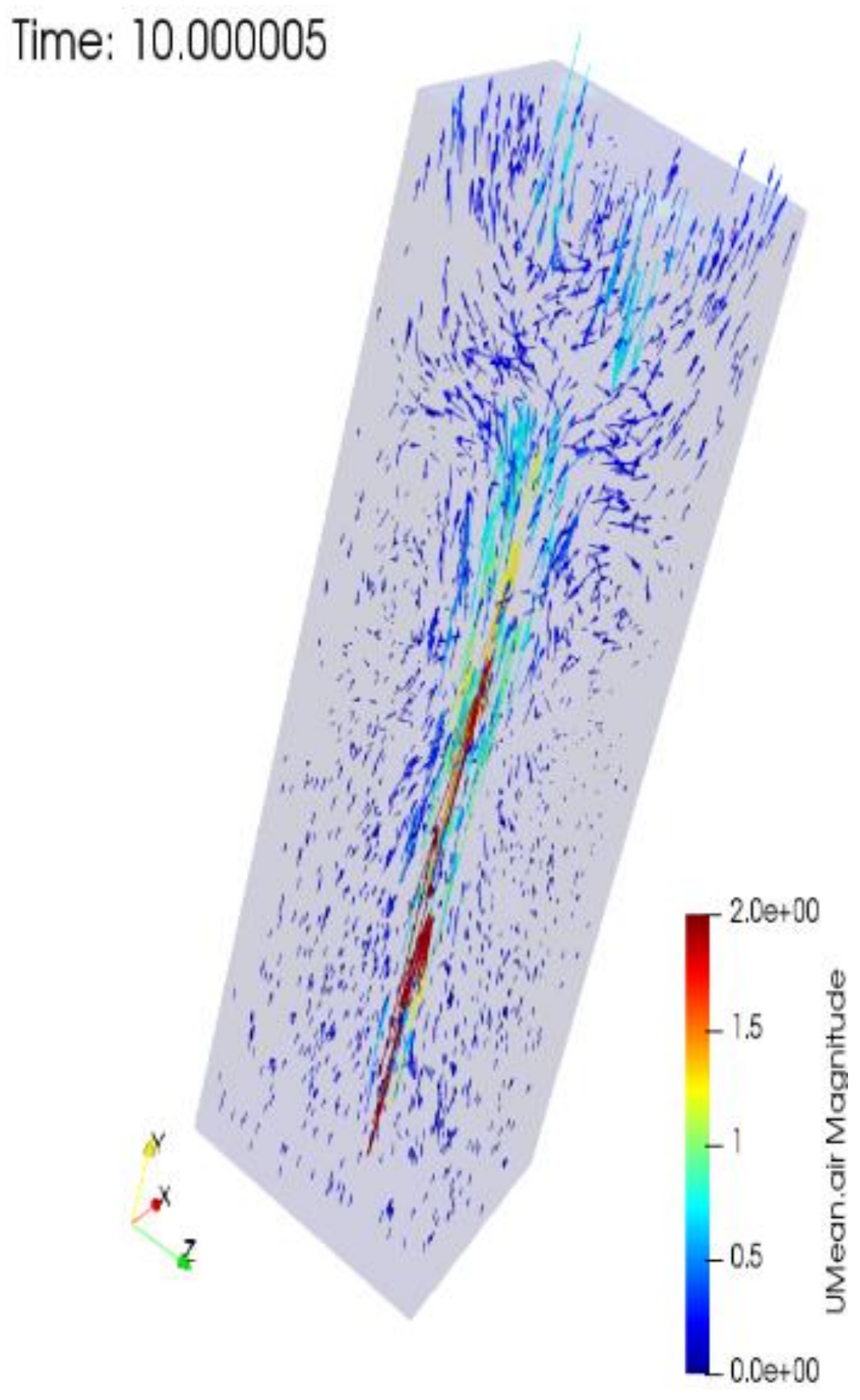

Figure 5. The Vector Plot

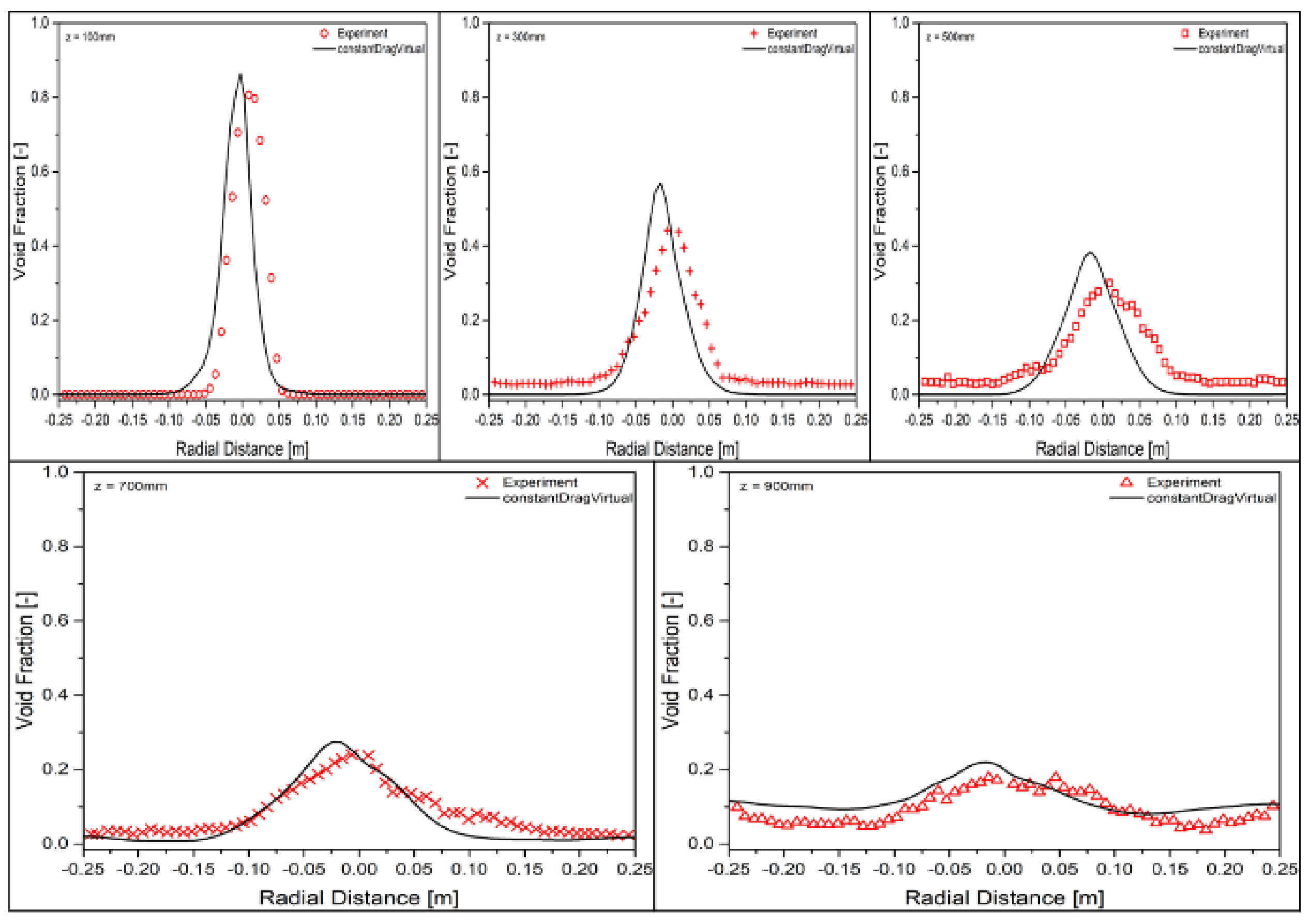

Figure 3. The Void Fraction at each Elevation

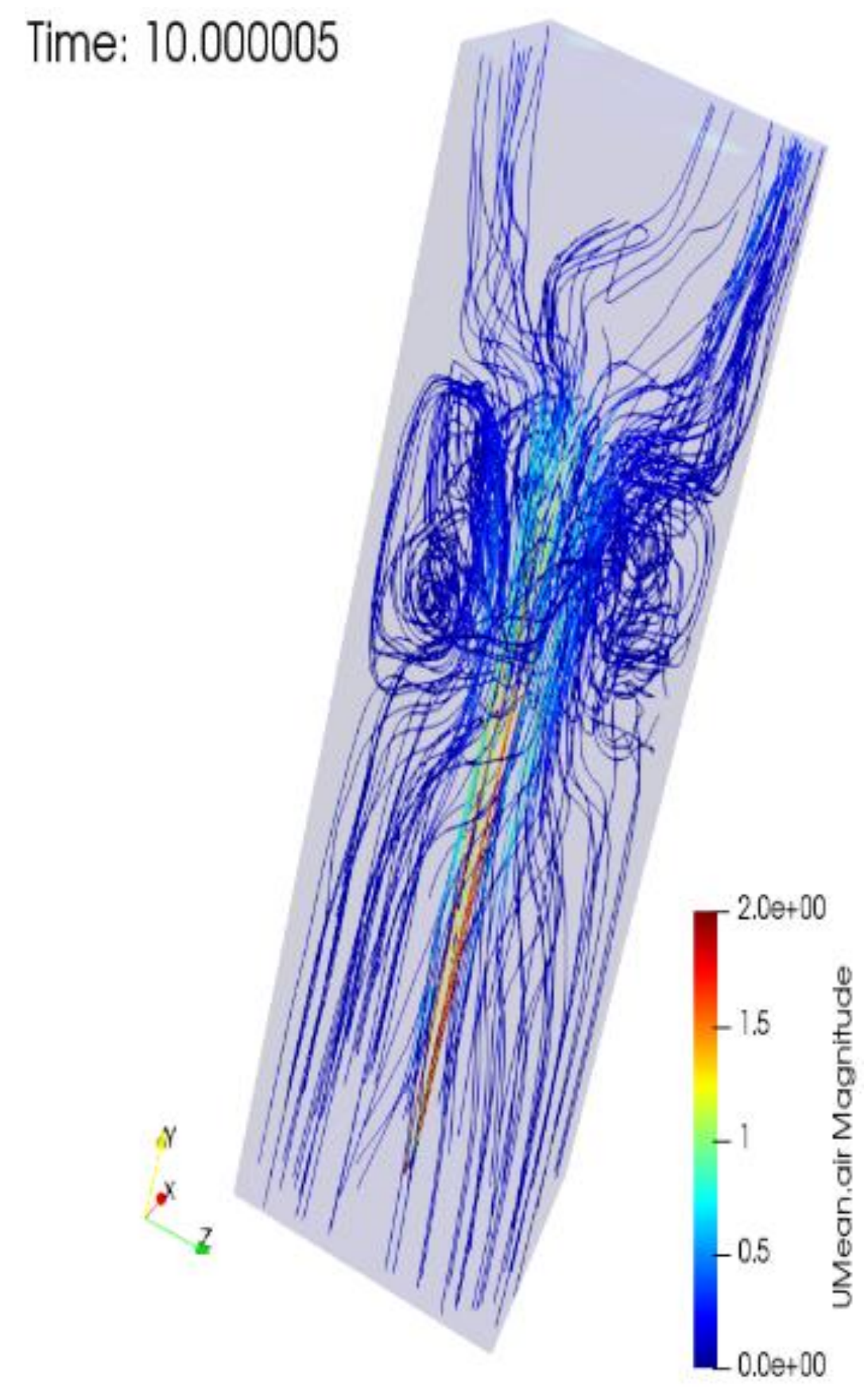

Figure 6. The Streamlines

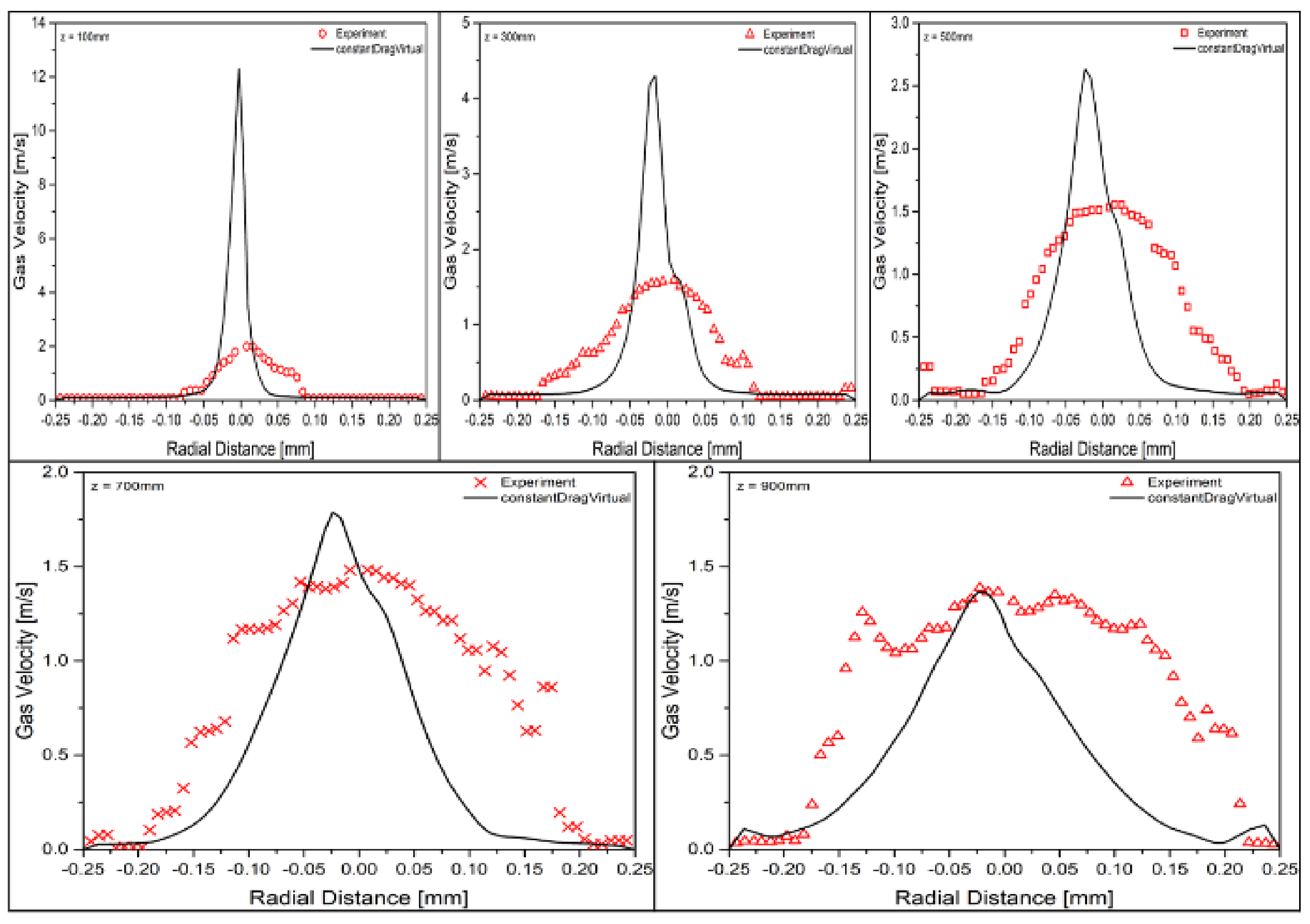

Figure 4. The Gas Velocity at each Elevation