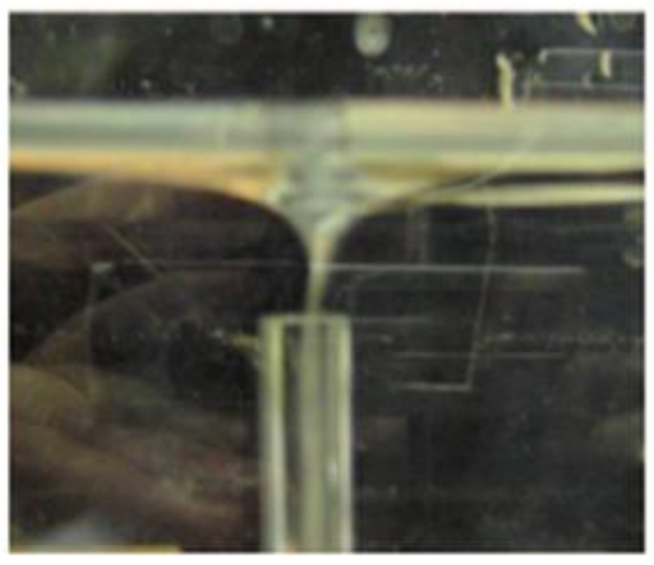
EX24308
Yos Panagaman Sitompul
日本原子力研究開発機構

Gas Entrainment Simulation for Fast Reactors using Two-phase Lattice Boltzmann Method

Introduction



Free-surface vortex induced GE

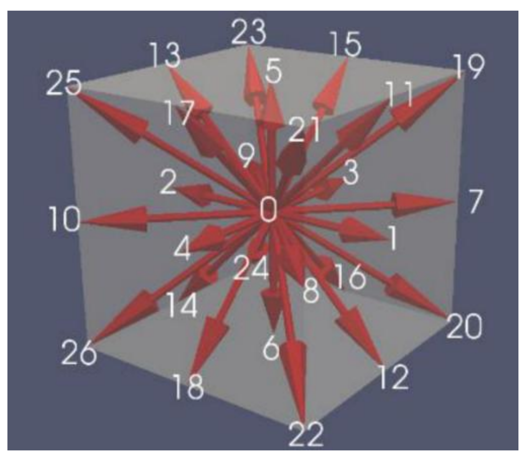
- Gas entrainment (GE) phenomena is crucial in Sodium-cooled Fast Reactors development:
  - ➢ Disturb reactivity and power,
  - ➢ Sensitive to geometry.
- There are limitations of Navier-Stokes based CFD solver in simulating GE in terms of accuracy and efficiency.

Objectives:

Introduce two-phase Lattice Boltzmann Method(LBM) as an alternative for GE simulation:

- ➢ Validate the two-phase LBM for GE simulation
- ➢ Aim for few days calculation

Numerical Methods



We employed LBM:

$$f_\alpha(\mathbf{x}+\mathbf{e}_\alpha\delta t, t+\delta t) = f_\alpha(\mathbf{x},t) - \frac{1}{\tau}\left[f_\alpha - f_\alpha^{eq}\right]_{(\mathbf{x},t)}$$

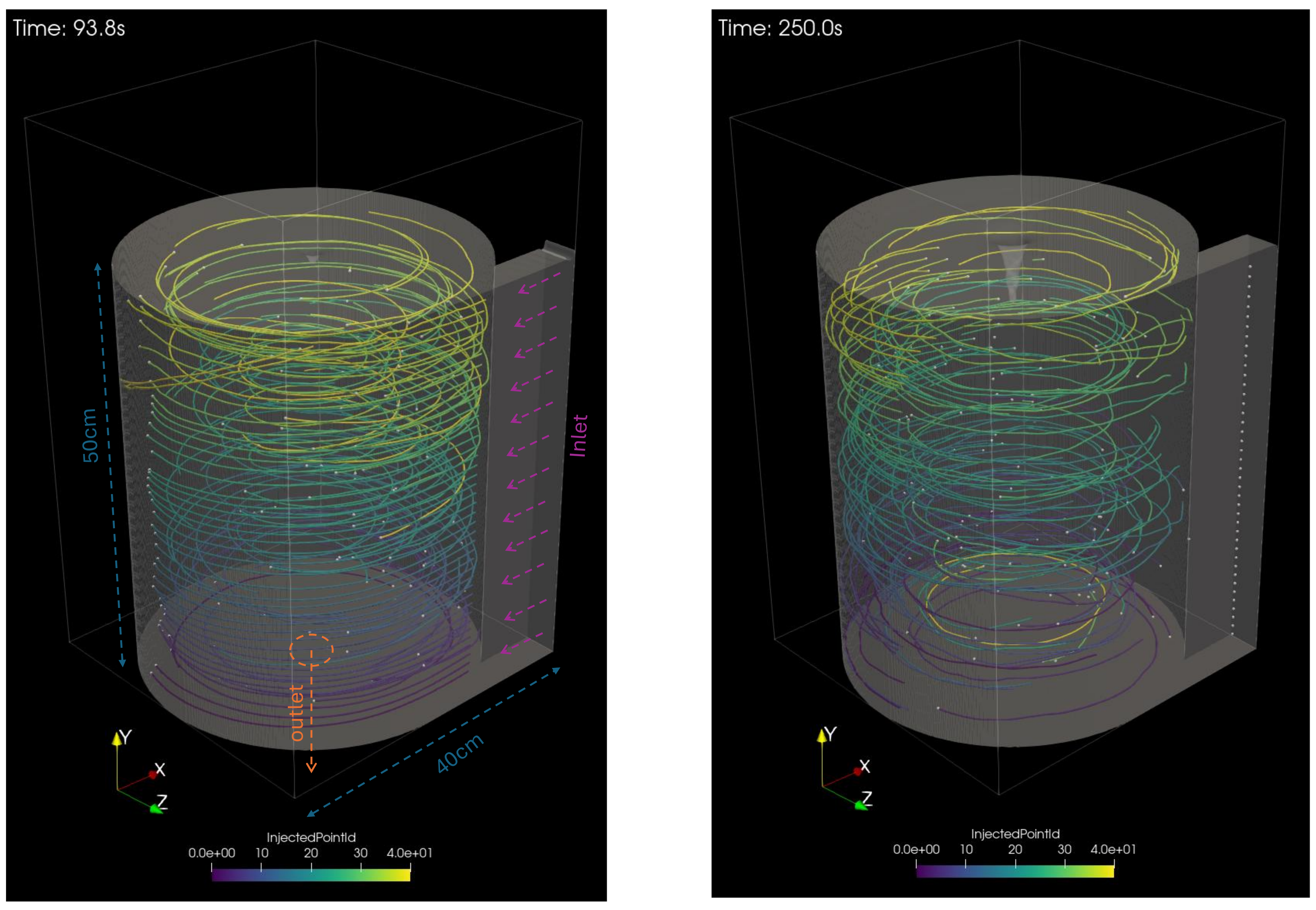
f_α: particle distribution functions (PDFs)
f_α^{eq}: equilibrium PDFs
τ: relaxation time
$\mathbf{x}$: position, t: time, $\mathbf{e}_\alpha$: lattice velocities

- ➢ Velocity based two-phase LBM mode [1]
- ➢ Cumulant collision operator
- ➢ Phase-field LBM for interface tracking
- ➢ CSM-LES model
- ➢ Octree-based Local Mesh Refinement (LMR) [2]

Validation: Flow Profile

We validated our two-phase LBM using Moriya's (1998) experiment (50 L/min flow, 5 cm outlet diameter) [3].

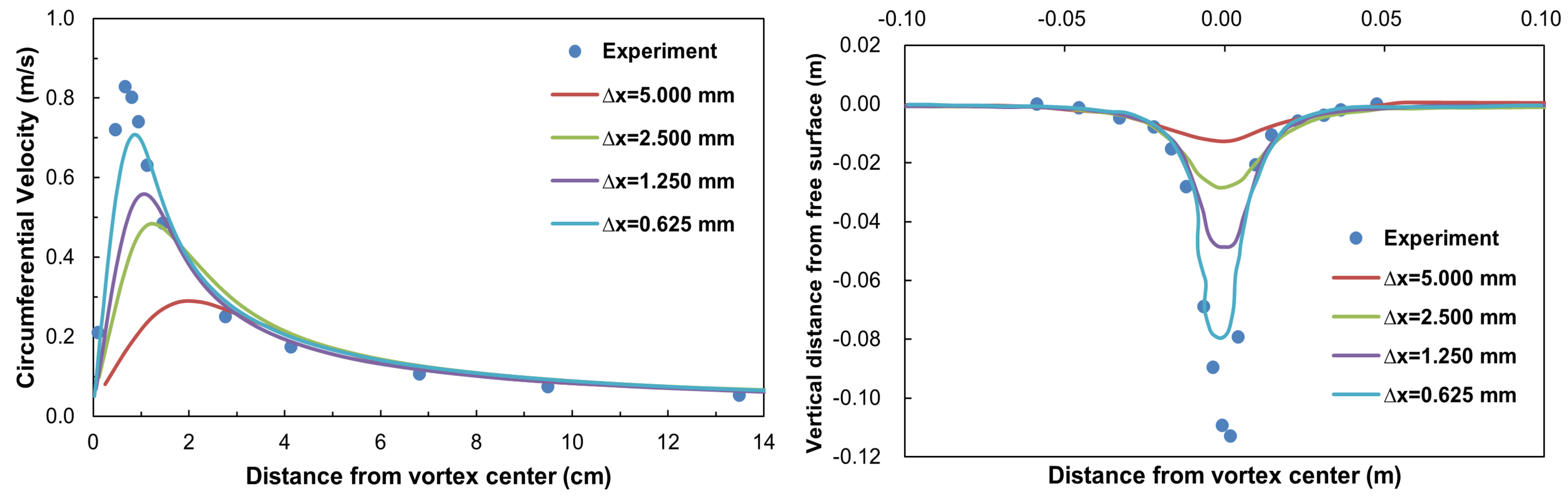
- We reproduced the free-surface vortex and gas entrainment (GE).
- We found that grid spacing < 0.625 mm is crucial for accuracy.



Flow profile shown using ParaView particle tracing. The onset of GE (left), GE length at quasi-steady state (right).

Validation: Flow Statistics

We measure some important flow statistics:

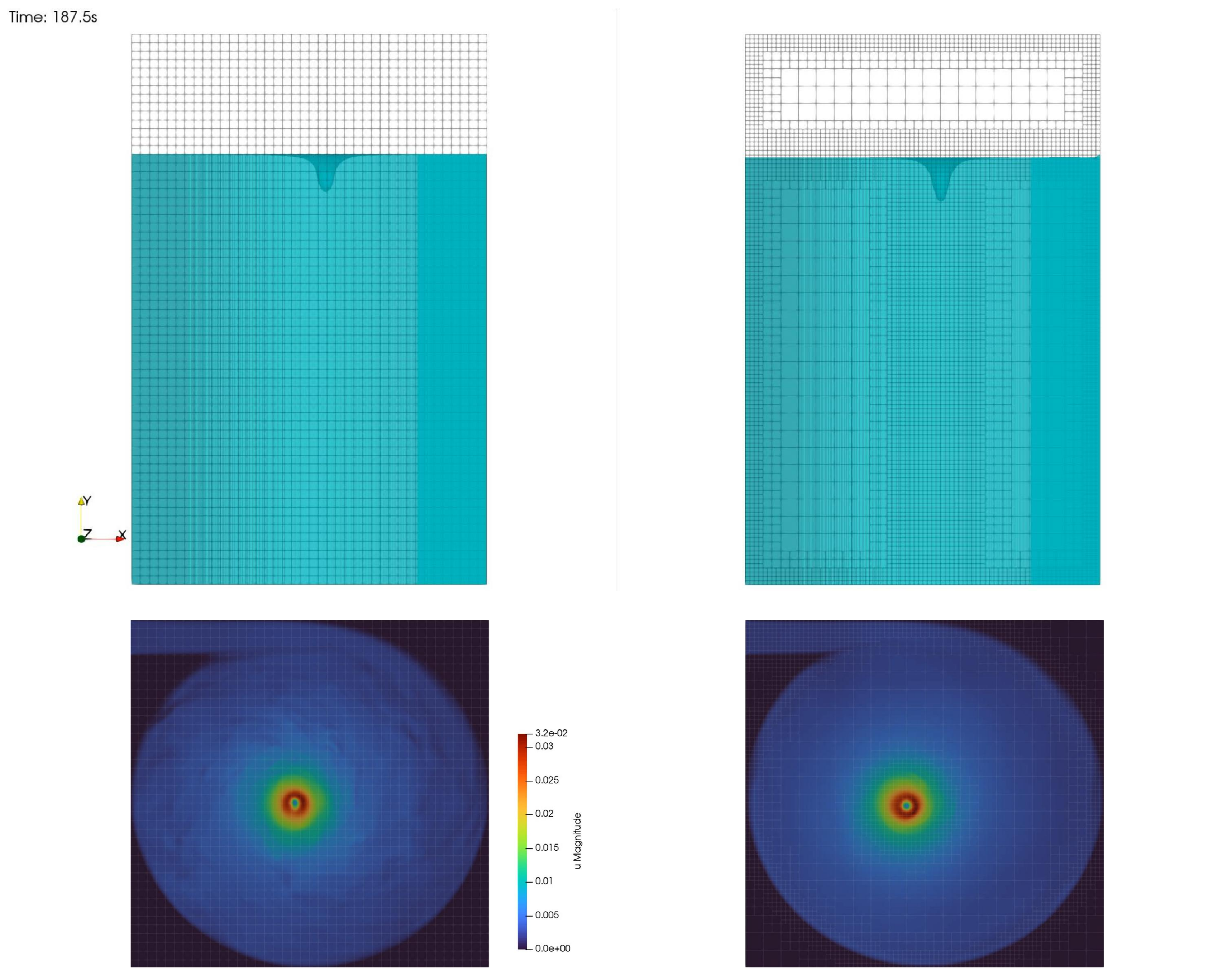


Circumferential profile at 15cm from the bottom (left), GE length(right) obtained using various mesh resolution.

- **Velocity Profile:** Excellent agreement with experimental data
- **GE Depth:** ~8 cm (vs. 11 cm in experiment)
- **Performance (real time: 275s):**
  - ➢ ~1 million cells (80×128×80) → ~50 minutes on a single Wisteria A100 GPU
  - ➢ ~52 million cells (320×512×320) → ~ 33 hours on 8 Wisteria A100 GPUs
  - ➢ ~ 420 million cells (640×1024×640) → ~5 days on 128 SGI8600 V100 GPUs

Local Mesh Refinement Study

We applied a 3-level LMR (320×512×320 case):



GE depth (top), velocity profile at z=Lz/2 (bottom); uniform(left), LMR(right).

- **50% reduction** in total cell count
- **1.5× speedup**, total runtime ~20 hours on 8 Wisteria A100 GPUs
- Results showed strong agreement with the uniform grid in:
  - **Vortex center location**
  - **Axial and circumferential velocity profiles**
  - **Gas entrainment depth**

Conclusions & Outlook

- We validated two-phase LBM with local mesh refinement (LMR)
  - ➢ Good agreement GE depth: **8 cm** (vs. **11.2 cm** in experiment)
  - ➢ Achieved **few days calculation** for real time 275s simulation
- Outlook: We will perform mesh convergence studies with LMR

References

[1] Sitompul, Y. P., & Aoki, T. (2019). *Journal of Computational Physics*, *390*, 93-120.
[2] Watanabe, S., & Aoki, T. *Computer Physics Communications*, *264* (2021):107871.
[3] Moriya, Shoichi. Denryoku Chuo Kenkyusho Hokoku (Technical Report of the Central Research Institute of Electric Power Industry) (1998).

Acknowledgment

This research was conducted using the Tokyo University's WISTERIA and the Japan Atomic Energy Agency's HPE SGI8600 supercomputers.