Poster presentation | Poster session

Poster Session

Thu. Jul 18, 2024 4:30 PM - 6:30 PM Room P

[PO-11] Numerical Simulation of Gas-Liquid Two-Phase Flow with Phase Change for Engineering Applications

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Numerical Simulation of Gas-Liquid Two-Phase Flow with Phase Change for Engineering Applications

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Background

GAPS(General Anti-particle Spectrometer)[(1)]

- Antiparticles in cosmic rays will be investigated to indirectly search for dark matter.
- Silicon detectors will be used to identify the antiparticles.
- The detectors must be cooled to below -40°C to achieve the required energy resolution.

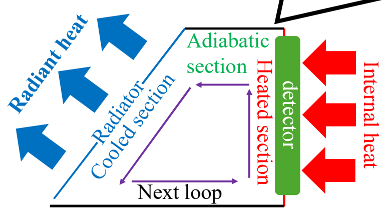
⇒GAPS utilizes a custom-developed heat pipe system to realize the cooling.

The GAPS Heat Pipe System

- Detectors' heat is transported in metal tubes using both latent and sensible heat.
- It is difficult to visualize physical quantities of the flow inside the metal tube.

⇒Computational Fluid Dynamics (CFD) is expected to visualize the flow.

The detector is cooled by a large radiator panel and 36-loop multi-loop heat pipes.



Conceptual diagram of the GAPS heat pipe[(2)]

GAPS prototype[(3)]

Goal : Analysis and elucidation of GAPS heat pipe behavior
⇒Understand the heat transport mechanism, optimize the heat-pipe design, and enhance the cooling performance.

Clarification of the detailed phenomenon of phase change in the main operating mechanism of heat pipes.

This study confirmed the validity of our 3D phase-change model using its basic simulation.

Numerical Method

Governing equations

Continuity equation

$$\nabla \cdot \boldsymbol{U} = \left(\frac{1}{\rho_v} - \frac{1}{\rho_l}\right)\dot{m}$$

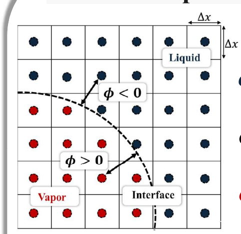
Incompressible Navier-Stokes equation

$$\frac{\partial \boldsymbol{U}}{\partial t} + (\boldsymbol{U}\cdot\nabla)\boldsymbol{U} = -\frac{1}{\rho}\nabla p + \frac{1}{\rho}\nabla\cdot\{\mu(\nabla \boldsymbol{U} + (\nabla \boldsymbol{U})^T)\} + \boldsymbol{F} + \boldsymbol{g}$$

Energy equation

$$\rho C_p\left(\frac{\partial T}{\partial t} + \boldsymbol{U}\cdot\nabla T\right) = k\nabla\cdot\nabla T$$

Interface capturing method



Level set method

$\boldsymbol{\phi} < 0$: Liquid

$\boldsymbol{\phi} = 0$: Interface

$\boldsymbol{\phi} > 0$: Vapor

Advection equation of the interface

$$\frac{\partial \phi}{\partial t} + \left(\boldsymbol{U} + \frac{\dot{M}}{\rho_v}\boldsymbol{n}\right)\cdot\nabla\phi = 0$$

Governing equations for the mass transfer rate

The mass transfer rate

$$\dot{M} = \frac{k_l \nabla T_l \cdot \boldsymbol{n}}{L}$$

The mass transfer rate per unit volume

$$\dot{m} = \frac{\dot{M} S_{int}}{V_{cell}}$$

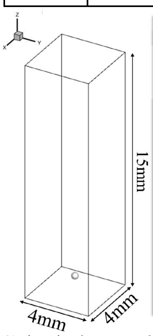
- The heat flux on the gas phase side is not taken into account because it is considered to be small.
- The area S_{int} is calculated with reference to the Marching Cube algorithm.

An equally spaced Cartesian grid is used.

Preliminary Results

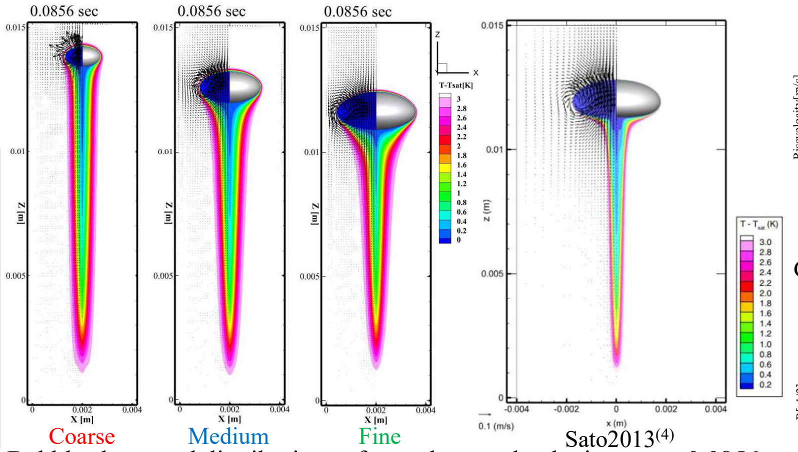
Grid resolution

	Grid size[μm]	Number of grids
Coarse	40	101×101×376
Medium	20	201×201×751
Fine	10	401×401×1501

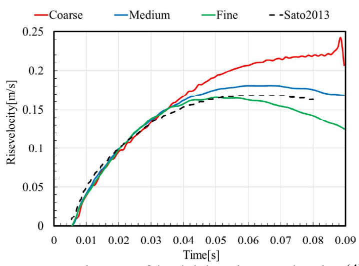


Calculation region

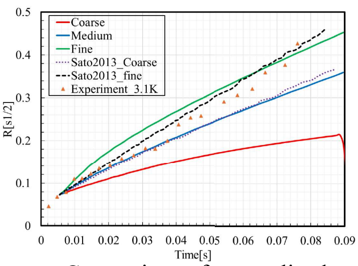
- The working fluid is ethanol.
- The initial radius of the bubble is 210 μm.
- The initial position of the bubble is 1mm from the bottom.
- The initial pressure was given for both the internal and Laplace pressures.
- The domain was shortened from Sato2013 to reduce computational cost.



Bubble shape and distributions of superheat and velocity at t = 0.0856 s (Superheat$[T - T_{sat}]$: 3.1K)



Comparison of bubble rise velocity[(4)]



Comparison of normalized bubble radius[(4)]

- All three results show similar superheat distribution and similar bubble shape, although some dependence on the grid size can be seen.
- Both rise velocity and radius of the bubble are consistent with a previous study, Sato2013.

The analytical results fairly reproduce the experiments, affirming that our model represent actual phenomenon properly.

Conclusion & Next Steps

Conclusion

- Our 3D simulation shows good agreement with a previous benchmark study.
- We confirmed that our simulation method well represents the phase change phenomenon.

Next Steps

- Expand the domain to a scale similar to Sato2013(Large-scale analysis)
- Upgrade the code to simulate a flow in a circular tube which consists of heating, adiabatic, and cooling sections.

(1) Fuke, H. et al., JPS Conf Proc, 18, 011003, (2018). (2) Okazaki, S. et al., Applied Thermal Engineering, 141, (2018), 20-28. (3) Institute of Space and Astronautical Science. Topics, Scientific Ballooning B12-01. JAXA. (2012) https://www.isas.jaxa.jp/j/topics/topics/2012/0604.shtml
(4) Sato, Y., Niceno, B., Journal of Computational Physics, 249, (2013), 127-161.

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