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Ice growth and air/water interface motion of water droplets impinged on a horizontal cooling surface

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The formation of ice layer by water droplets on surfaces causes many troubles, such as poor visibility through the windshields of aircraft, trains and automobiles; the breaking of power transmission lines; a deterioration of the aerodynamic performance of aircraft wings. Thus, many studies have been carried out. However, the details of heat transfer during the freezing have not yet been clarified. We have carried out experiments and numerical simulation to elucidate the detailed mechanism of droplet freezing. In this report, we have focused on time changes in the freezing fronts and air-water interfaces for impinged water droplets on a horizontal cooling surface. In this research, we carried out two-dimensional numerical simulation on the droplets. The time advancements of the air-water interfaces and ice-water interfaces for the droplets were predicted using Phase-field methods. The ice area was expressed with an immersed boundary method. The velocity fields of air and water were predicted by solving the Navier-Stokes equations. The temperature field in the whole domain was predicted by solving the energy equation. The surface tension force and the properties of ice, water and air at around 0 degrees were adopted. The temperatures of air and the cooling surfaces and the droplet impact velocity were varied. The Reynolds number and Weber number of the droplets were in the range of 35 - 129 and 1.6 - 22, respectively.

The computational results showed that the height of the impinged droplets on the symmetrical axis started to oscillate as a result of the impact of the collision of droplets with the surfaces in all the cases that we investigated. The oscillations converged rapidly in all impinged water droplets that froze on the cooling surface. This is due to the fact that ice layer, developed along the cooling surface, reached the air-water interface of the droplet on the cooling surface and that the contact area of the droplet was fixed. The ice layer was downward convex during the growth of the layer. This is partly because the water temperature in the central part of droplets was slightly high as a result of the convection and conduction of the latent heat, and partly because the water temperature near the air-water interface was slightly low as a result of low temperature of the air near the cooling surface. When we also took account of the homogeneous ice nucleation, we introduced many ice nuclei into the sub-zero degree region inside the droplets. These nuclei melted by the latent except for the region adjacent to the air-water interface. The predicted oscillation frequency of the air-water interface during the freezing was much lower than the measured frequency, while the maximum amplitude and convergence time of the oscillation were reasonably predicted. This discrepancy was due to the difference in the freedom of oscillation in the two-dimensional computation and the three-dimensional measurements. Thus, our computational results were consistent and reasonable.

Significance statement

We have focused on time changes in the freezing fronts and air-water interfaces for impinged water droplets on a horizontal cooling surface. Our computational results show that our simulation is reasonable.

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