Snap Freezing Water
Team First Report

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Abstract

The event of snap freezing in supercooled water presents an interesting phenomenon of physics and fluid dynamics, offering a window into the types of phase transitions. This report documents a series of experiments conducted to visualize and analyze the rapid crystallization of ice within supercooled water, a process that remains a subject of fascination within the scientific community, especially to increase efficiency in freezing. Using macro videography, various modes of ice crystal growth were captured, revealing a complex relationship between supercooling temperatures, crystal growth velocities, and the resulting crystal structures. With temperatures closer to freezing producing slow planar dendritic crystallization, and colder temperatures showing 3D crystallization which was also seen to be a bit faster. The study's findings contribute valuable insights into the fundamental principles of phase change kinetics, with potential applications in atmospheric science, cryopreservation, and materials science.

Context and Purpose

The study of fluid dynamics encompasses a vast array of phenomena, with rapid phase transitions being particularly intriguing to the team due to its ubiquitous nature and complex underlying mechanisms. The primary objective of this videography assignment, conducted as part of the MCEN 5151 Flow Visualization course *Team First* assignment, was to capture and analyze the snap freezing of supercooled water. This process, characterized by the sudden formation of ice within a liquid that has been cooled below its freezing point, serves as an excellent subject for visualizing the dynamic behavior of fluids under non-equilibrium or metastable conditions. The purpose of this assignment was not only to observe this captivating phenomenon but also to understand the conditions and variables that influence the formation and growth of ice crystals. I'd also like to thank Haotian Chen and Alexandr Vassilyev for the ideation for this assignment and their continued input for equipment support and videography production.

Flow Apparatus

The experimental setup was carefully designed to replicate the conditions necessary for snap freezing. A series of 330ml water bottles were placed in a freezer, with their temperatures monitored closely to ensure they reached a supercooled state without initiating premature crystallization in the freezer due to being disturbed. Upon trial and error, and further research, the bottles were thinly coated with a mixture of acetone and dishwashing detergent—to mitigate the issue of condensation on the bottle surfaces, which was obscuring the visualization of ice formation[1], [2]. This coating effectively reduced the surface tension of the condensing moisture, allowing it to spread into a transparent film rather than forming droplets that would scatter light and reduce visibility.

Visualization Technique

The visualization technique employed in this study was critical in capturing the transient and delicate process of ice nucleation and growth. A point source of light located at approximately 30cm from the subject, positioned to simulate an infinite distance, provided a consistent and parallel beam, casting sharp shadows and enhancing the visual clarity of the ice crystals. This setup was pivotal in differentiating the subtle changes in the crystal structures and capturing the intricacies of the crystallization process. The supercooled bottles were removed from the freezer and immediately placed at the marked position, then slightly tapped to agitate the water and initiate nucleation for ice formation.

Photographic Technique

The photographic equipment and settings were chosen to ensure the highest fidelity in capturing the snap freezing and ice crystallization process. A Canon EOS 1500D camera equipped with an 18-55mm kit lens and a macro adapter was used to achieve a 1:1 macro magnification, resulting in a 22.2mm wide frame of view. The camera settings were dialed in to balance the depth of field and exposure: a resolution of 1920x1080p provided high-definition video, an aperture of f/3.6 allowed for sufficient light while maintaining a reasonable depth of field, and a frame rate of 25fps ensured smooth motion capture. The challenges of maintaining focus due to the shallow depth of field, preventing condensation, and ensuring successful nucleation required more than 80 attempts, which were helped by keeping multiple bottles to supercool at once to improve frequency of iterations.

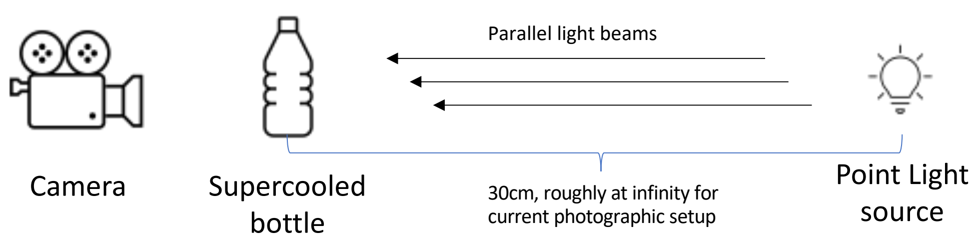

Figure 1 Photographic and Visualization Setup

Fluid Dynamics

The ice crystallization observed during the snap freezing experiments at different temperatures were particularly revealing[3]. The study captured a transition from dendritic, planar ice crystallization to more complex three-dimensional ice formations as the supercooling temperature decreased. The first video clip shows the dendritic, planar ice crystallization while the last clip shows bulk 3D ice crystallization which is classified as Ice I_h and Ice I_{sd} respectively, by Malkin and Murray[4]. The velocity of ice crystal growth was also hypothesized to vary with temperature, the first crystal takes approximately 2.06 seconds to travel vertically a distance of 16.65mm of the frame length. Giving an approximate vertical velocity of 8.28mm/s which gradually increased as seen by one instance showing the velocity of 13.87mm/s (1.2s). Whereas the last clip of the bottle shows 3d ice structure forming at an approximate vertical velocity of 13.36mm/s but at -4deg c. This variation in velocity and crystal structure with temperature provides a deeper understanding of the kinetics of ice formation and the factors that influence the structure of the resulting crystals.

Results and Observations

The experimental observations underscored the sensitivity of ice crystallization to supercooling temperatures. Different temperatures led to distinct crystallization modes, with dendritic structures forming at higher temperatures and three-dimensional crystals at lower temperatures[5]. The presence of additives in the water appeared to change the catalyze the nucleation process, suggesting a potential area for further investigation. It was also observed just after the snap freezing, the temperature of the bottle was approximately 2degrees C which can be accounted by considering the phase change of water turning into ice being exothermic, coupled with heat exchange with the atmosphere. The velocities of crystal growth, calculated from the vertical travel of the ice fronts, provided quantitative data that complemented the qualitative visual observations.
The link to the captured video is here: https://youtu.be/bizW-m3qpT0

Figure 2 Planar dendritic crystallization as seen in bottle supercooled to -2.8°C

Further Work

The findings from this study can pave the way for further research into the relationship between supercooling temperatures, crystallization modes, and the effects of additives on nucleation. Future work could involve a more controlled experimental setup to isolate and analyze these variables more precisely. Additionally, the impact of different types of additives on the speed and morphology of ice formation could be explored, potentially leading to new insights into the control of crystallization processes in various applications.

References

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