

Project Title: Evaluation of Surface Wettability as a Parameter in Preferential Separation of Multi-Component Dissolved Gas Systems and Bubble Points of Pure Liquids

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Narrative Progress Report:

Separation of dissolved gases- and phase transition of vapors- from liquids are of primary importance to a wide range of natural and industrial processes such as boiling, cloud formation, food and beverages production, biological, environmental, nuclear, pharmaceutical, electrochemical, and petroleum production and refining. The dissolved gas separation and nucleate boiling phenomena, which include bubble nucleation, growth, and detachment steps, significantly influence various stages of the industrial processes, and the associated production strategies and equipment design criteria. In almost all real-world scenarios, nucleation, which is the first step in the dissolved gas separation and nucleate boiling, occurs on the surface of the container or solid particles in the bulk of the liquid due to the lower energy requirement compared to the gas/vapor bubble nucleation within the bulk of the liquid. Therefore, it is very critical to understand the influence of interfacial properties of solid-liquid-gas/vapor systems on dissolved gas separation and nucleate boiling at a fundamental level.

The proposed work involves three objectives: 1. To study the effect of wettability on the bubble measurements of single component and two component systems; 2. To study the effect of wettability on gas bubble incipitation pressure from oil in the presence and absence of water film present on the solid surface; and 3. To test the influence and sensitivity of surface wetting and topology on preferential gas liberation from a multi-component dissolved gas systems.

For the above objectives, we have developed pressure/vacuum-driven and temperature-driven nucleation experimental facilities and their operating procedures, and experimental protocols to prepare various degrees of wetting and non-wetting glass surfaces using silanes and siloxanes. The wettability alteration methods were presented at 256th ACS National Meeting, Boston, MA (Sushobhan Pradhan, Prem K. Bikkina (2018) Preparation and Quantification of Various Degrees of Hydrophobic Glass Surfaces). We have conducted bubble nucleation experiments for one-component (water, decane) and two-component systems (water-CO₂, water-N₂, water-CH₄, decane-CO₂). A profound dependency of incipitation pressure for bubble nucleation on wettability was observed.

The photomicrograph shown in Figure 1 illustrates the influence of wettability on CO₂ bubble nucleation from its supersaturated aqueous solution. The figure shows preferential CO₂ bubble nucleation on a hydrophobic glass bead in a hydrophilic glass vial containing the supersaturated aqueous solution prepared by reducing the system pressure from 6000 mbar to atmospheric pressure. The incipitation pressure for bubble nucleation was observed at 5700 mbar.

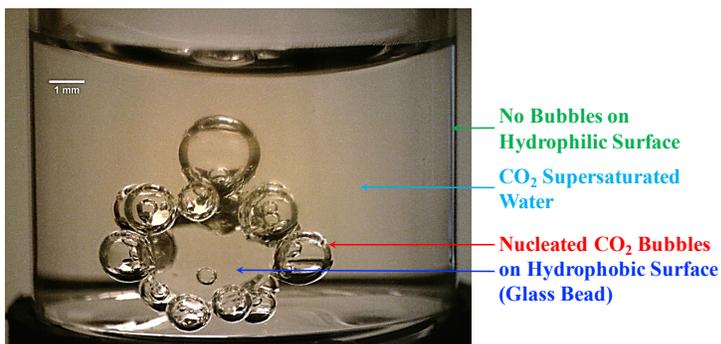


Fig. 1: A microscopic image showing CO₂ bubble nucleation on a hydrophobic surface in supersaturated water in a hydrophilic vial

The photomicrograph shown in Figure 2 illustrates vigorous vapor bubble nucleation on a hydrophobic rod immersed in water at the saturation temperature. The water was in a hydrophilic vial that was

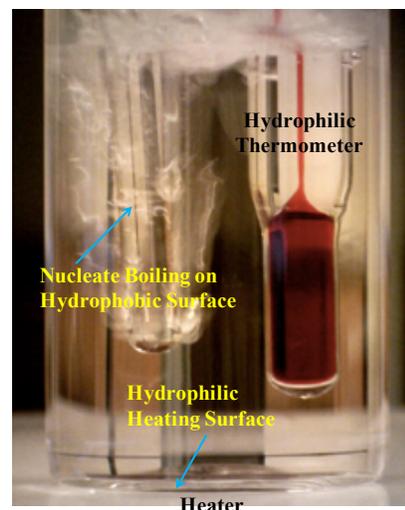


Fig. 2: A microscopic image showing vigorous vapor bubble nucleation on a hydrophobic surface immersed in saturated water in a hydrophilic vial

being heated from below using a heater. It can be noticed that no vapor bubbles were formed on the hottest hydrophilic heating surface (i.e., at the bottom inner surface of the vial), or on the hydrophilic thermometer.

The experimental findings are reported in a peer-reviewed journal article (Sushobhan Pradhan, Ruaa Jasim Qader, Bhishma Raj Sedai, Prem K. Bikkina (2019), Influence of Wettability on Pressure-Driven Bubble Nucleation: A Potential Method for Dissolved Gas Separation, *Separation and Purification Technology*, 217: 31-39.), and a peer-reviewed conference proceeding (Prem Bikkina, Sushobhan Pradhan, A Potential Solution for Boiling Crisis, *18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-18)*, American Nuclear Society, Portland, OR, 2019). The findings were also presented at two invited talks by the PI at the Department of Chemical Engineering, Kansas State University, Manhattan, KS (2018), and the Nuclear Engineering Division, Argonne National Laboratory, Lemont, IL (2019).

The PI's research group participated in the *National Lab Day* and *GrandParent University* events conducted at Oklahoma State University, in May 2019. The wettability alteration procedures developed as a part of this research were useful to prepare teaching aids to demonstrate concepts of surface tension, wettability & capillary pressure, and their various daily life and industrial applications.

Impact on the PI's career. This grant provided him the opportunity to continue his research on bubble nucleation. The results obtained were helpful to submit multiple proposals for industrial and government funding, including his NSF CAREER proposal. He was able to publish a peer-reviewed journal article and a peer-reviewed conference paper. He also had the opportunity to deliver two invite talks on the research findings. Hence, he is deeply indebted to the support from the ACS PRF grant for providing the opportunity to establish a highly visible research program on bubble nucleation, and to train and work with excellent graduate and undergraduate researchers.

Impact on Students. One graduate researcher, Sushobhan Pradhan, and two undergraduate researchers, Landen Keffer and Alissa Meek, have been supported by this grant. Sushobhan was the first and second author in the peer-reviewed publications mentioned above. He also had opportunities to present the research findings at 256th ACS National Meeting, and 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-18). The graduate and undergraduate students were trained on various state-of-the-art surface science concepts such as wettability alteration & quantification, and quantification of surface roughness using AFM, pressure-, vacuum-, and temperature-driven bubble nucleation. Sushobhan Pradhan was awarded *Distinguished Graduate Fellowship* and *Robert L. Robinson Jr. Endowed Fellowship* for both of which the credentials he earned through this project were helpful.