Modelling Thin Liquid Film Draining of Bubbles on Porous Media in Confined Geometry

By Jared Bahm
Candidate for Master of Science in Mechanical Engineering
Major Professor: Dr. Pence

Abstract

The behavior of the thin liquid film formed between a bubble and hydrophobic membrane is of high interest in applications where separating two-phase mixtures is beneficial. One such application is in-situ vapor extraction heat sinks. In these systems, high heat transfer rates are accomplished by taking advantage of the high energy associated with phase change. However, the generation of vapor may lead to dry-out and subsequent critical temperatures if the vapor bubble is not extracted proficiently. An existing model for single bubble extraction in a confined geometry theoretically predicts the bubble diameter and relevant forces acting on the bubble from inception to extinction. However, the model needed to be supplemented with empirical correlations due to the unknown conditions for bubble rupture and the behavior of the three-phase contact line on the supply and extraction surfaces. In this work, the Stokes-Reynolds-Young-Laplace (SRYL) lubrication model is studied and adapted to the confined geometry of a growing bubble to numerically simulate the thin liquid film draining event at the extraction surface. To the author's knowledge, this is the first implementation of the SRYL lubrication model to the special case of confined bubbles under growth. Experimental data from the existing model is used to qualitatively examine the behavior of the thin liquid film at the extraction surface. It was found that the approach velocity and bubble radius upon reaching the extraction surface was related to the formation of a hydrodynamic dimple in the thin liquid film. The hydrodynamic dimple is characterized by a barrier rim, where the thinnest part of the liquid film is no longer at the apex of the bubble. Larger radii bubbles with lower Laplace pressures are more easily deformed as they approach the extraction surface and exhibit the hydrodynamic dimple at larger liquid film thicknesses. Results show that the minimum liquid film thickness at the predicted time of rupture is relatively consistent, ranging from \( \approx 3.16 \mu m \) to \( \approx 2.72 \mu m \) for confined bubble gap heights ranging from 0.52 mm to 1.90 mm respectively. It is believed this is due to a balance of approach velocity, the degree of bubble deformation and resulting hydrodynamic pressure within the interaction zone of the liquid film. Further, these minimum liquid film thicknesses are outside the bounds of typical long range forces, suggesting other rupture mechanisms may occur in confined geometries. Due to the stochastic nature of liquid film rupture, the rupturing event is not modelled in this study and is suggested as future work.

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School of Mechanical, Industrial and Manufacturing Engineering
Oregon State University