
18 High-Heat-Flux Distributed Capillary Artery Evaporators

Gisuk Hwang, Chanwoo Park, and Massoud Kaviany

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18.1 INTRODUCTION

18.1.1 MOTIVATION AND BACKGROUND

High-heat-flux thermal management systems are in demand for enhancing cooling performances and minimizing degradation for many practical applications such as electronics, nuclear power plants, energy, automotive, and aerospace systems. The phase-change (liquid–vapor, releasing or absorbing heat of evaporation) thermal management systems such as pool boiling and film evaporation systems (single pipe, loop heat pipes [LHPs], vapor chambers, etc.) offer high performances and reliabilities, with no external power consumption and minimal temperature difference. These systems generally consist of three components, namely, an evaporator, liquid–vapor conduits, and a condenser, and transport bottlenecks are liquid, vapor, and heat transport in them. The heat is absorbed at the evaporator, and transported through the vapor conduit, and released at the condenser. The condensate returns the evaporator via gravity (pool boiling) and/or capillarity (heat pipes and vapor chambers). Concentrated heat sources make the evaporator to be the most critical bottleneck, since the condenser surface area is generally sufficiently large.

The optimal design requires continuous liquid (coolant) supply to the evaporator, avoiding dry-out, while minimizing evaporator thermal resistance. It generally employs porous structures, such as grooves and sintered metallic particles, to enhance the capillary pumping capability and minimize the thermal resistance across high thermal conducting metals.

There have been significant advances in the capillary evaporator wick designs to enhance the performance utilizing grooves and uniform and nonuniform-thickness sintered particle wicks (O'Neill et al. 1972; Chi 1976; Polezhaev and Kovalev 1990; Peterson 1994; Faghri 1995; Chang and You 1997a,b; Liter and Kaviany 2001; Hwang et al. 2007, 2010, 2011; Mori and Okuyama 2009). In this chapter, the fundamentals of the liquid and vapor transport in the capillary evaporators are briefly reviewed, and the evolution of the capillary evaporator wick design is discussed regarding the pool boiling (Section 18.2) and film evaporation (Section 18.3) systems. Future capillary evaporator wick design in flow boiling is discussed (Section 18.4), followed by the outlook and conclusions (Section 18.5).

18.1.2 BOILING AND FILM EVAPORATION

Here, boiling and film evaporation mechanisms are briefly reviewed before discussing various wick designs for the enhanced boiling and film evaporation performance. The first part primarily focuses on the liquid–vapor transport above the wick in pool boiling, and the second part discusses about the microscale heat and liquid transport near the thin wick. More detailed background and discussion can be found in the literature (Chi 1976; Collier and Thome 1994; Peterson 1994; Webb and Kim 1994; Faghri 1995; Johnson 1998; Kandlikar 1999, 2001; Kaviany 2002).

Pool boiling employs liquid (coolant) pool to remove heat from the surface of a substrate via phase change (boiling). When the substrate is at a temperature higher than a saturation temperature, the liquid can begin boiling at the solid–liquid interface, and without forced liquid flow, this is called pool boiling. The heat flux q across the interface is released to the heat transfer coefficient through the temperature difference between the solid surface T_s and saturation temperature T_{lg} (superheat, $T_s - T_{lg}$, °C). The generated vapor begins to form bubbles at the surface, which escapes from the solid surface by the phase buoyancy force when those are sufficiently large. As the heat flux (or superheat) increases, the vapor morphology and dynamics evolve, and these are illustrated in Figure 18.1.

As the superheat increases, the nucleate boiling regimes are reached, corresponding to a sharp heat flux increase. At low surface superheats, isolated bubbles are formed at active nucleation sites (isolated-bubbles regime), and at higher superheat, the frequency of the bubble departure increases, and the number of active sites also increases. This is referred to as the combined isolated-bubbles and jets subregime. Next, these neighboring jets coalesce and the vapor-mushroom