



## Liquid-liquid phase separation heat transfer in advanced micro structure

Wei Xing<sup>a,\*</sup>, Joel Plawsky<sup>b</sup>, Corey Woodcock<sup>b</sup>, Xiangfei Yu<sup>a</sup>, Amos Ullmann<sup>c</sup>,  
Neima Brauner<sup>c</sup>, Yoav Peles<sup>d</sup>

<sup>a</sup> Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY 12180, USA

<sup>b</sup> Howard P. Isermann Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY 12180, USA

<sup>c</sup> School of Mechanical Engineering, Faculty of Engineering, Tel-Aviv University, Tel-Aviv, Israel

<sup>d</sup> Department of Mechanical and Aerospace Engineering, University of Central Florida, 12760 Pegasus Blvd, Orlando, FL 32816, USA

### ARTICLE INFO

#### Article history:

Received 2 June 2018

Received in revised form 15 August 2018

Accepted 20 August 2018

#### Keywords:

Liquid-liquid phase separation

Piranha Pin Fin

Heat transfer enhancement

Micro channel

### ABSTRACT

An experimental heat transfer study using triethylamine (TEA)-water solution as a coolant in a Piranha Pin Fin (PPF) structure is reported here. The triethylamine-water solution undergoes phase separation when heated to a temperature over 18.2 °C at a TEA mass fraction of 32.1% (i.e., critical composition). This separation process was proven to enhance heat transfer in the plain channel geometry. With the aid of the PPF structure, the TEA-water solution was able to dissipate a heat flux of up to 500 W/cm<sup>2</sup> at a mass flux of 600 kg/m<sup>2</sup>s and to keep the surface temperature below 80 °C. The phase separation of a TEA-water mixture in the PPF structure yields about 1.8 times greater heat transfer coefficient compared to a corresponding homogeneous mixture flow. Flow boiling was achieved during experiments when the heat flux exceeded 600 W/cm<sup>2</sup>. The effects of different configurations of PPF were also studied, and it is shown that the PPF configuration with fewer and smaller fins provides the best performance enhancement over water flow at the same mass flux. Two flow conditions, channel flow and extraction flow, were examined. The TEA-rich phase was extracted during the extraction flow experiment and the remaining water-rich phase results in favorable thermal transport performance. A string-shaped flow pattern is observed due to both shear force and the flow disturbance provided by the PPFs. The system exhibits reduced pressure drop as the fluid viscosities decrease after phase separation.

© 2018 Elsevier Ltd. All rights reserved.

## 1. Introduction

The increasing power density of miniaturized equipment highlights the urgent need for advanced cooling technologies to ensure safe operation and to pursue superior performance. The development of advanced electronic devices with their high degree of system integration leaves little room for deploying a cooling apparatus. Micro channel based heat sinks stand out as a feasible cooling solution due to their superior heat transfer performance [1,2]. Various heat transfer enhancement techniques have been developed and applied to further boost the cooling performance of micro channels [3]. These techniques include using extended surfaces to increase the heat transfer area, generating flow disturbances to enhance mixing, and introducing liquid/vapor phase change [4–13]. Flow boiling is an effective enhancement technique due to the large latent heat of vaporization and two-phase flow mixing effects. However, the dry-out condition, also known as

the critical heat flux (CHF), occurs in flow boiling systems when a vapor blanket covers the heated solid surface and significantly hinders the thermal transport process from the heated surface to the fluid. Consequently, the heat transfer performance deteriorates significantly. Additionally, flow instabilities attract major concerns especially in micro scale flow boiling heat exchangers.

In 2014, a new type of enhanced structure at the micro scale, termed the Piranha Pin Fin (PPF) [14–17], was introduced (Fig. 1). The PPF resembles the shape of a piranha where an open mouth is made at the leading edge and a sharp tip is made at the trailing edge. The PPF structure is usually made into an array and embedded into a flow channel. This arrangement enables the incoming flow to exit either through the PPFs' open mouths or the channel outlet (and sometimes both).

It has been shown that integrating PPFs into a micro channel is beneficial for both single-phase and flow boiling heat transfer [15–17]. The PPF structure, by its design, induces flow mixing by disturbing the velocity field and thermal boundary layer. It allows for extra contact between the heated surface and fluid. For single-phase flow, the PPF structure boosts the thermal transport substantially compared to the plain channel structure. Moreover,

\* Corresponding author.

E-mail address: [xingw@rpi.edu](mailto:xingw@rpi.edu) (W. Xing).

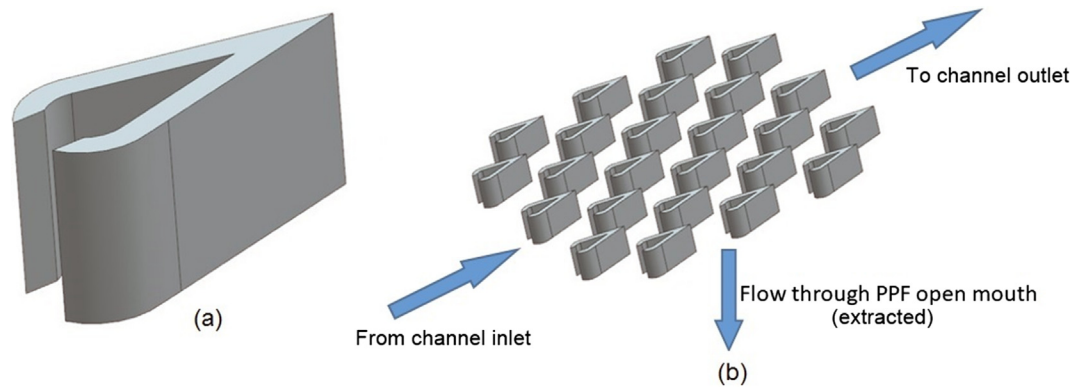


Fig. 1. Illustration of PPF structure. (a) Single PPF. (b) PPF array and flow condition.

for each PPF, the open mouth enables fluid extraction, i.e., part of the fluid exits the channel through the PPFs' mouths. Such a mechanism helps to cool the heated wall by venting cold fluid through the venting holes on the heated substrate. For flow boiling applications, the open mouth enables vaporized fluid to be extracted, and keeps the heated wall wetted to increase the critical heat flux. It has been experimentally demonstrated that the PPF structure is capable of dissipating a heat flux up to  $700 \text{ W/cm}^2$  with flow boiling using HFE-7000 [17].

Phase separation of partially miscible fluid systems is a phase transition process that can potentially augment heat transfer. A partially miscible multi-component liquid system separates into multiple phases that have different compositions. If reducing the system temperature triggers the separation, the system is termed an Upper Critical Solution Temperature (UCST) system. Conversely, a Lower Critical Solution Temperature (LCST) system requires a temperature rise to initiate phase separation. Spinodal decomposition and nucleation are two possible mechanisms triggering the separation process, depending on the system's initial composition. Spinodal decomposition is more intensive than nucleation, and requires no energy barrier to overcome. It is characterized by a bi-continuous and dendritic domain morphology. Nucleation, on the other hand, is featured by localized fluid domain nucleation and growth. During the phase separation process, the sharp concentration gradient at the liquid-liquid interfaces results in a Korteweg force. This interfacial force induces fluid flow to minimize Gibb's free energy. This self-propelled movement of fluid domains acts as a mixing mechanism. Some experimental studies show that phase separation of partially miscible fluid systems can enhance thermal transport for both quiescent and convective systems at both micro and conventional scale. Most of the studies concerning heat transfer enhancement were obtained by using UCST systems, which are relevant for heating applications [18–22]. Only recently heat transfer enhancement obtained by using LCST systems as coolants was experimentally demonstrated in mini and micro scale channels [23–26].

Considering the advantages of the PPF structure and the benefit of phase separation process, we combined the two mechanisms, and investigated the resulting heat transfer and multi-phase flow behavior. Here, we used a triethylamine (TEA)-water mixture, which has an LCST of  $18^\circ\text{C}$ , as a coolant mixture. The mixture was studied with PPF structures of different geometrical configurations and parameters. Channel flow and extraction flow conditions were also examined. Heater temperature, heat transfer coefficient and pressure drop were measured and compared between different experiments. Flow visualization revealed new phase separation morphology and flow patterns.

## 2. Experimental design

### 2.1. TEA-water system

The TEA-water system has an LCST ( $T_{critical}$ ) of  $18.2^\circ\text{C}$  and a critical composition of 32.1% TEA by mass. Its phase diagram was experimentally obtained and a curve-fitting was provided [24,27] (Fig. 2). The solid curve on the phase diagram is called the binodal curve, and it indicates the maximum temperature for the two components to stay miscible at a given concentration. The space above the binodal curve depicts the two-phase region, where the fluid mixture undergoes a phase transition and separates into different phases. The equilibrium compositions of the separated phases can be obtained on the phase diagram by finding the intersections of the final temperature and the binodal curve. It can be seen that, due to the shape of the binodal curve, the compositions of separated phases remain almost identical after the system exceeds  $T_{sat} \approx 40^\circ\text{C}$ . That is, the phase diagram exhibits a saturation behavior of the compositions of the separated phases. When the system is below the binodal curve, the components remain in a mixed, uniform state.

The LCST behavior of the TEA-water system is explained by the system's Gibb's free energy of mixing,  $\Delta g_{mix}$ , which is shown in Eq. (1)

$$\Delta g_{mix} = g_{mixed} - g_{unmixed} = \Delta h_{mix} - T\Delta s_{mix} \quad (1)$$

When the system is cooled below its LCST, hydrogen bonds form between the amine part of TEA and water molecule, and this formation process releases energy. As a result, the enthalpy of

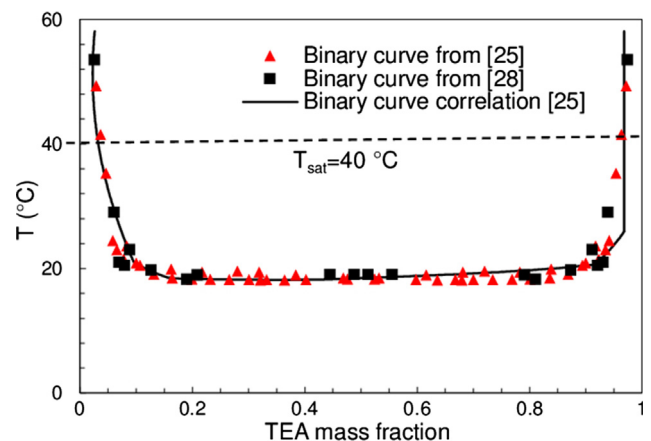


Fig. 2. Phase diagram of TEA-water system.

Download English Version:

<https://daneshyari.com/en/article/10127400>

Download Persian Version:

<https://daneshyari.com/article/10127400>

[Daneshyari.com](https://daneshyari.com)