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Dynamic surface tension of heat transfer additives suitable for use in steam condensers and absorbers

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ABSTRACT

Additives are often effectively used in enhancing heat transfer by creating a surface tension gradient on the surface of a condensate film to induce Marangoni driven ‘‘drop-wise-like’’ condensation. The objective of the current study is to use the Maximum Bubble Pressure Method (MBPM) to evaluate dynamic behavior of the surface tension of solutions of three different additives (2-ethoxy ethanol, isobutylamine, and 2-ethyl-1-hexanol) of varying concentrations with water. It was shown that the effects of 2-ethoxy ethanol on surface tension was primarily dependent on solute concentration and showed little dependence on time (i.e. surface age of bubble). While both isobutylamine and 2-ethyl-1-hexanol showed strong dependence on both concentration and time, the effects of the later were far more dramatic. The results for all solutions are presented as functions of concentration and time (i.e. surface age of bubble).

Tension superficielle dynamique des additifs favorisant le transfert de chaleur adaptés à l’utilisation dans les condenseurs de vapeur et les absorbeurs

Mots clés : échangeur de chaleur ; absorbeur ; condenseur ; mesure ; tension superficielle ; additif ; transfert de chaleur

1. Introduction

‘‘Interfacial turbulence,’’ alternatively called ‘‘surface convection or Marangoni effect,’’ is recognized as an important mechanism in many interfacial transport processes including absorption and condensation. It is now well understood that that the interfacial turbulence, in general, created by local variations in the surface tension in

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Nomenclature

γ_{LV}	surface tension
A	apparatus constant
ΔP	measured difference in the maximum bubble pressure from the two capilaries
φ	correction factor for asphericity
r	inner radius of the wide capillary
D	density of the solution

two phases, creates the hydrodynamic instability at the interface and leads to convection in adjacent regions and, thus, results in enhanced heat (and/or mass) transfer rate. For example by using selected additives in LiBr absorption chiller systems, the heat transfer can be increased through interfacial turbulence so that an externally-driven forced convection system would no longer be required to overcome diffusion (Kim et al.,1994b, 1995, 1996a,b). Many aspects of heat transfer enhancement using additives have been comprehensively reviewed by Ziegler and Grossman (Ziegler and Grossman, 1996).

As in LiBr absorption systems, interfacial turbulence induced by the introduction of additives has been shown to have effects on the heat transfer increase in the steam condensation process (Utaka and Wang, 2004; Morrison and Deans, 1997; Morrison et al., 1998; Kim et al., 2001; Vemuri et al., 2006). Utaka and Wang (Utaka and Wang, 2004) were able to illustrate the significance of surface subcooling in solutal Marangoni condensation by studying the effect that ethanol vapor concentration had on the condensation heat transfer in a water-ethanol system. With an ethanol vapor mass fraction of 1% under forced convection, they could obtain 2–8 times stronger results in the condensation heat transfer coefficient when compared to the pure water system. Morrison et al. (Morrison and Deans, 1997; Morrison et al., 1998) studied the effect of both ammonia and methylamine as additives to enhance heat transfer. Heat transfer enhancement of up to 2.31 was reported for a 0.2 weight% solution of methylamine in water. Kim et al. (Kim et al., 2001) proposed the necessary considerations to effectively use an additive in the condensation process. Using two selected additives, 2-ethyl-1-hexanol and 2-ethoxy ethanol, the team observed the surface tension gradient and the temperature effect on the condensation heat transfer performance. Vemuri et al. (Vemuri et al., 2006) presented a model for the condensation heat transfer coefficient that considered the actual effects of additives from the measured surfactant data for 2-ethoxy ethanol and 2-ethl-1-hexanol. The model incorporates the theory describing Marangoni convection. The surface tension gradient, as a function of concentration and temperature, is considered as a driving potential.

The general consensus among previous studies on the enhancement of condensation heat transfer via the Marangoni effect is that it is caused by surface tension gradients on the surface. While many studies have been done on the enhancement of condensation heat transfer, the research on surface tension characteristics, including dynamic effects of the additives, is lacking. Additives of various natures such as hydrocarbon alcohols, amine, and ammonia are frequently used in enhancing condensation heat transfer (Utaka and Wang, 2004; Morrison and Deans, 1997; Morrison et al., 1998; Kim et al., 2001; Vemuri et al., 2006; Kim and Janule, 1994). It is unclear how the additives have been chosen for use. The entire mechanism of the condensation heat transfer enhancement under the Marangoni has not been fully explored, due to the lack of detailed, relevant information including the dynamic surface tensions of various solutions. Quantifying the characteristics of the individual additives is crucial in understanding the fundamentals of how condensation heat transfer is being enhanced. Because of this, the scope of this paper is on the experimental measurements of the dynamic surface tensions of various solutions containing additives.

2. Dynamic surface tension measurement

2.1. Apparatus

The Maximum Bubble Pressure Method (MBPM) (ASTM, 2005) was used to measure the dynamic surface tension of solutions of interest. This method consists of 2 capillaries of different sizes submerged in a solution. As gas is fed through the capillaries the maximum pressure bubbles burst at is recorded and used to calculate the surface tension of the solution. By varying the bubble frequency, the dynamic surface tension behavior can be observed. The schematic diagram of the dynamic surface tension measurement apparatus is shown in Fig. 1.

An inert (i.e. Nitrogen) gas is used to make bubbles, with the pressure and volume of the gas controlled by high and low pressure regulators and a needle valve. The gas is then alternately directed either to a narrow syringe or to a wide one in order to generate bubbles using a three-way valve. The bubbler unit is connected to a constant temperature water bath (temperature control range of 0–100 °C) to keep the

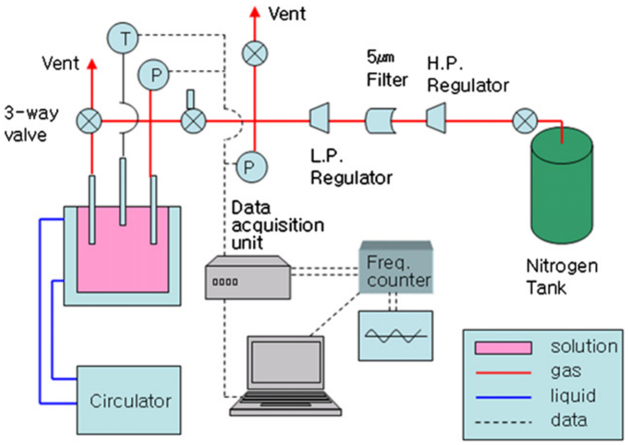

Fig. 1 – Schematic diagram of the dynamic surface tension measurement apparatus.