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A method of concurrent thermographic–photographic visualization of flow boiling in a minichannel

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ABSTRACT

A method is developed to capture the distribution of surface temperature while simultaneously imaging the bubble motions in diabatic flow boiling in a horizontal minichannel. Liquid crystal thermography is used to obtain highly resolved surface temperature measurements on the uniformly heated upper surface of the channel. High-speed images of the flow field are acquired simultaneously and are overlaid with the thermal images. The local surface temperature and heat transfer coefficient can be analyzed with the knowledge of the nucleation site density and location, and bubble motion and size evolution. The horizontal channel is 1.2 mm high $\times$ 23 mm wide $\times$ 357 mm long, and the working fluids are Novec 649 and R-11. Optical access is through a machined glass plate which forms the bottom of the channel. The top surface is an electrically heated 76 μm-thick Hastelloy foil held in place by a water-cooled aluminum and glass frame. The heat loss resulting from this construction is computed using a conduction model in Fluent. The model is driven by temperature measurements on the foil, glass plate and aluminum frame. This model produces a corrected value for the local surface heat flux and enables the computation of the bulk fluid temperature and heat transfer coefficient along the channel. The streamwise evolution of the heat transfer coefficient for single-phase laminar flow is compared to theoretical values for a uniform-flux boundary condition. Examples of the use of the facility for visualizing subcooled two-phase flows are presented. These examples include measurements of the surface temperature distribution around active nucleation sites and the construction of boiling curves for locations along the test surface. Points on the curve can be associated with specific image sequences so that the role of mechanisms such as nucleation and the sliding of confined bubbles may be discerned.

1. Introduction

Mini-channels (those with channel spacing near 1 mm) offer an attractive scale range for technological applications of two-phase cooling. They are small enough to create large heat fluxes, but large enough to remove significant quantities of heat, and they do not present the same degree of fouling and maintenance issues anticipated for applications of true micro-scale channels. For these reasons, industry may adopt two-phase mini-channel cooling systems for its next generation high-flux heat exchangers. For example, some modern nuclear reactor designs call for the coolant to flow through mini-channels in the reactor core.

The dominant heat transfer mechanism in mini-channels is a strong function of flow pattern. A catalog of bubble motions: nucleation initiation, detachment, sliding, lift-off, and merging can have a significant effect on the near-wall temperature profile and thus heat transfer enhancement. Thome [1] presents an excellent review of experimental and theoretical work on boiling in narrow channels. The review done by Bergles et al. [2] gave an insight into boiling in small diameter-channels for work done prior to 2003. Kandlikar [3] listed different ways of using microchannels for high efficiency cooling.

Facilities built to investigate the relationship between the detailed flow physics and the resulting heat transfer rate from the test surface typically do not allow true simultaneous observation of bubble events and surface thermal events. Either full-surface thermography is employed with no flow images or non-concurrent flow imaging, or high-speed flow imaging is possible with traditional single-point thermocouple measurements along the test surface.

For example, Kenning et al. [4] described the use of liquid crystal thermography to investigate the characteristics of boiling heat transfer. Hardenberg et al. [5] used liquid crystal thermography to obtain spatio-temporal data of wall temperature over a period of 30 s. The timing, position, activation, superheat, and radius of the cooled region for nucleation events were deduced without directly observing the particular bubbles that produced these events. Tange et al. [6] used a minichannel apparatus with a 1 mm channel

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