Thermal interaction effect on nucleation site distribution in subcooled boiling

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Abstract

An experimental work on subcooled boiling of refrigerant, R134a, to examine nucleation site distributions on both copper and stainless steel heating surfaces was performed. In order to obtain high fidelity active nucleation site density and distribution data, a high-speed digital camera was utilized to record bubble emission images from a view normal to heating surfaces. Statistical analyses on nucleation site data were done and their statistical distributions were obtained. Those experimentally observed nucleation site distributions were compared to the random spatial Poisson distribution. The comparisons showed that, rather than purely random, active nucleation site distributions on boiling surfaces are relatively more uniform. Experimental results also showed that on the copper heating surface, nucleation site distributions are slightly more uniform than on the stainless steel surface. This was concluded as the results of thermal interactions between nucleation sites with different solid thermal conductivities. A two dimensional thermal interaction model was then developed to quantitatively examine the thermal interactions between nucleation sites. The results give a reasonable explanation to the experimental observation on nucleation site distributions.

1. Introduction

Nucleate boiling is a highly nonlinear system, which involves complex interactions between fluids and heating surfaces. As summarized by Shoji [1], those interactions include thermal interactions between bubble and heating surface, thermal interactions between nucleation sites, as well as hydrodynamic interactions between bubble and liquid bulk, and between bubbles. These effects have been experimentally and analytically studied by several researchers in terms of a separate or a combined effect.

Chekanov [2] was the first one to investigate the nucleation site interaction between two artificial sites. Bubble recurrence rates on these two artificial nucleation sites, which were created by two heated copper rods beneath the heating surface, were examined in terms of time interval between two sequent bubble formations. It was found that the time interval has a Gamma distribution and the distribution is determined by the distance between these two sites. The author postulated that the acoustic wave emitted from a growing bubble is the key effect on the bubble formation on an adjacent site, however, not much detail and further explanations were given.

Theoretical analyses and experimental work were conducted by Chai et al. [3] to investigate interactions between bubbles and nucleation sites. In their theoretical analyses, a bubble was idealized as a continuous round instantaneous heat sink. Spatial and temporal surface temperature profiles were then analytically solved. The temperature profiles were found to be greatly impacted by bubble size and thermal properties of the heating surfaces. This effect was then experimentally examined in pool boiling of water on metal plates with various materials and thicknesses. Both analytical and experimental work showed that the thermal conductivity of heating surface plays a critical role during the thermal interaction between two adjacent sites. Chai [4] also proposed a preliminary theoretical frame work using statistical mechanics to describe the nonlinear boiling system.

Judd and Lavdas [5] observed that bubble emission on a nucleation site was capable of either activating or deactivating bubble formation on an adjacent site. As observed in their experiments, a potential nucleation site can be activated from captured vapor as it is previously covered by a bubble formed at an adjacent site. On the contrary, a site can also be deactivated due to thermal and hydrodynamic influence from an adjacent active site. An experimental work was then performed by Calka and Judd [6] to investigate bubbles and nucleation sites interactions in pool boiling. Using a similar method adopted by Chekanov [2], Calka and Judd however obtained a different conclusion compared to Chekanov’s research, with respect to site distance effect on sites interaction. The author believed it is due to the site seeding mechanism, which was published later in [7]. More detailed experimental work and simulations were then provided by Judd and Chopra [8], and Mallozzi et al. [9], respectively.
In recent years, new techniques such as laser and liquid crystal thermography were used in the study of nucleation site interactions. Mosdorf and Shoji [10] investigated the interaction between two artificial laser activated sites. It was found that thermal interaction has an effect to decrease bubble emission frequency, while hydrodynamic interactions tend to increase the frequency. The distance between these two sites was found to be important to the sites interaction. A detailed nonlinear analysis on hydrodynamic aspects of interaction between nucleation sites was done in a later work by Mosdorf and Shoji [11]. A similar laser-activated-nucleation-site method was used by Golobic and Gjerke [12] to study interaction between two, three and four such artificial sites. Phenomenal results, such as frequency of bubbles at those artificially activated sites with different sites arrangement patterns, were given. However, a further quantification of the interaction and mechanism behind were not provided. Kenning and his coworkers [13,14] used liquid crystal thermography to record spatial–temporal temperature on heating surface and to identify site interactions. Both bubble formation and site interaction were able to be identified by interpolate heating surface temperature profile without direct visual observation of bubble formations.

Site interaction has also been pointed out in other researches in a different aspect. Del Valle and Kenning [15] examined the nucleation site density and its statistical distribution in subcooled flow boiling of water at high heat flux at atmospheric pressure. By counting active nucleation sites in sub-domains, the nucleation sites were found to fit the spatial Poisson distribution [16] very well. However, the experimential observed nearest-neighbor distances did not fall between zero and a certain minimum value, which is suggested to be a result of site interaction.

In this current study, the effort was made to focus on the impact of heating surface thermal conductivity on nucleation site distribution in a statistical point of view. Two heating surfaces made of copper and stainless steel, which have similar wettability to the working fluid while greatly different thermal conductivities, were selected to perform subcooled flow boiling experiments. Experimental results and discussions are provided in later sections.

2. Experimental setup

The experimental facility consists of a refrigerant test loop with an electrically heated test section, as well as other measurement instruments such as thermocouples, pressure transducers, flow meters, etc. A schematic drawing of the flow boiling test loop is shown in Fig. 1. The loop was designed to supply working fluid to the test section at desired inlet pressure, temperature and mass flow rate. A widely used refrigerant, R134a, was chosen as the working fluid for its relatively low critical pressure, saturation temperature and latent heat. A liquid reservoir is utilized to store refrigerant and to stabilize the system pressure. A gear pump, manufactured by Micro-Pump®, is used to provide a variable range of coolant mass flow rates (4 l/min maximum). The electrically heated pre-heater is installed upstream of the test section to adjust the inlet temperature of the test section. Two cooling sub-loops were used to cool the coolant flowing out from the test section in order to avoid system pressure oscillation and potential pump damage. A schematic drawing of the test section is shown in Fig. 2. The copper heating block with a rectangular heating surface, 12.7 mm by 107.95 mm (width by length), is installed in the middle bottom of the straight horizontal rectangular stainless steel flow channel. Three quartz windows were installed around the heating block (i.e., front, back and top) to allow proper lit on the heating surface so that clear bubble images can be taken. The dimensions of the flow channel are 1000 mm by 12.7 mm by 12.7 mm (length by width by height). The heating block is heated

![Fig. 1. Schematic diagram of the flow boiling test apparatus.](image1)

![Fig. 2. Schematic diagram of the test section (cartridge heaters are not shown).](image2)

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### Nomenclatures

- $C_p$: heat capacity
- $h_{ev}$: evaporation heat transfer coefficient
- $H_{fg}$: evaporation latent heat
- $N_a$: number of active nucleation site
- $P$: pressure
- $q^r$: heat flux
- $R_b$: bubble radius
- $r$: position vector
- $s$: nearest-neighbor nucleation site distance
- $T, T_{sat}$: temperature, saturation temperature

### Greek symbols

- $\alpha$: thermal diffusivity, condensation/evaporation coefficient
- $\sigma$: surface tension
by seven cartridge heaters, which provide a controllable heat source at a maximum total power of \( 750 \times 7 = 5250 \) W. Two heating blocks with copper and stainless steel heating surfaces were manufactured and then employed separately to study heating surface thermal conductivity impact on nucleation site distributions. Both heating blocks were made out of pure copper. The one with a copper heating surface did not require special further machining; while for the other one with stainless steel heating surface, a 1 mm thick stainless steel strip was attached onto the copper block using silver solder. To estimate the heating surface temperature and heat flux, eight type-K thermocouples were installed inside the heating block to measure local temperatures beneath the heating surface. A Photron FASTCAM Ultima 1024 high-speed digital camera was used to record the bubble emission images. The camera can acquire images at a rate up to 12,000 frames per second (fps) using an intensive back-lit source, with various magnifications controlled by a set of micro lenses. A camera speed of 2000–4000 fps was generally used for bubble emission images recording in the current experiment.

### 3. Results and discussion

Bubble emission images in a view normal to the heating surface were obtained using the high-speed digital camera mounted above the test section, through a quartz window installed on the top side of the flow channel. Lights were provided from above through the same quartz window. The reason a normal-to-the-surface view rather than a side view was chosen was to acquire more accurate nucleation sites measurements. Bubbles at different depths would produce overlapped bubble images if a side view was used. In this case, it would be difficult to identify bubbles from each other and two-dimensional bubble distribution information would be lost. In addition, due to the very small depth of field of the high-speed digital camera, bubbles not sitting on the camera's focal length are generally blur in images. The heat fluxes examined in this experiment, however, were limited in a relatively small region, ~20% of the critical heat flux. The reason is that, for higher heat fluxes clear bubble images are difficult to obtain as bubbles in the bulk flow starts to distort the image due to light reflections. Digital images of bubble emissions on the heating surface were recorded at a frequency of 2000 fps, for a time period of several seconds in general. Normally, for each experimental condition, a set of several thousands of images were obtained for data analyses. These images were then loaded into a computer code implemented by Visual C++\(^0\), so that they can be displayed frame by frame either automatically or manually. Active nucleation sites are identified at positions where bubbles are continuously released. Due to presence of sliding bubbles, automatic image processing to identify active nucleation sites was difficult. However, all active nucleation sites were able to be visually identified, marked, and their coordinates automatically recorded. Measurement errors mainly came from nucleation sites not always being activated. Due to random characteristics of boiling, not all nucleation sites are constantly activated. It has been observed that some sites can be randomly activated or deactivated due to interactions with nearby bubbles or bubbles sliding from upstream. At high heat fluxes the error is estimated to be relatively large since nucleation sites are more crowded and this activation/deactivation process occurs more frequently. The measurement error was estimated to be around 10% by counting the sites that were not constantly activated for higher heat fluxes, while for low heat fluxes the error was relatively low at around 2% since bubble emissions are more stable and less interactions was found between bubbles. Fig. 3(a) shows a typical bubbles image from a bubble image set obtained for R134a in boiling on the copper surface. Locations of active nucleation sites identified from this set of images are shown in Fig. 3(b).

In this experimental investigation, bubble emission images were taken at different system conditions. Experimental parameters explored in the experiments are listed in Table 1. Fig. 4 shows a typical nucleation sites distribution on the copper heating surface. As shown in this figure, the observed area is divided into 16 identical sub-domains (4 by 4) so that the statistical probability density of site distribution can be estimated. The statistical probability density can be simply calculated as a fractional ratio of number of sub-domains having \( N_a \) nucleation sites to the total number of sub-domains,

\[
P(N_a) = \frac{N(0, N_a)}{N_{\text{total}}} \tag{1}
\]

where \( N(0, N_a) \) is number of sub-domains having \( N_a \) nucleation sites, and \( N_{\text{total}} \) is total number of sub-domains. The estimated discrete probability densities are also compared with the discrete spatial Poisson distribution proposed by Gaertner [16],

\[
P(N_a) = \frac{e^{-\bar{N}_a} (\bar{N}_a)^{N_a}}{(N_a)!} \tag{2}
\]

where \( \bar{N}_a \) is the mean value of nucleation sites number in a sub-domain.

![Fig. 3](image-url) (a) A typical bubble image from a set of bubble images at high camera frame speed to identify active nucleation sites locations. Experimental conditions: 606 kPa, \( \Delta T_{\text{ev}} = 9.23 \) °C. Image taken conditions: 1000 fps, 1/2000 s of shutter time. Other information: 256 by 256 pixels of image size, frame number, 13,616, real time, 13.616 s (left) and (b) nucleation sites, shown as green squares, identified from the same bubble image set (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
general trend indicates a difference between the observed nucleation site distribution and the spatial Poisson distribution. To investigate more details, the distribution of the distance between two nearest adjacent nucleation sites, generally referred as 'nearest-neighbor distance', are examined. This nearest-neighbor distance is defined as the distance from a nucleation site to its nearest neighbor. For the discrete spatial Poisson distribution, the distribution of the nearest-neighbor distance can be analytically derived as [16],

\[
P(s)ds = 2\pi N_0 s e^{-\pi N_0 s^2} ds
\]

where \(s\) is the nearest-neighbor distance.

Fig. 6 shows the experimentally observed nearest-neighbor distance distributions and their comparisons with the spatial Poisson distribution. It can be found that the experimentally observed distribution do not agree with the spatial Poisson distribution well, especially in the interval between 0 and the mean nearest-neighbor distance. For example, as shown in Fig. 6(a), the probability of the experimentally observed nearest-neighbor distance is much smaller than that given by a corresponding Poisson distribution, in the interval between 0 and 250 \(\mu m\). However, an opposite trend is shown as the nearest-neighbor distance is close to the mean nearest-neighbor distance.

To further quantitatively study the uniformity of nucleation site distributions on both surfaces and the spatial Poisson distribution, the coefficients of variance of nearest-neighbor distance were compared. The coefficient of variance for a data set, which is a measurement of statistical dispersion, is defined as the ratio of its standard deviation to its mean value. For nucleation site distributions on the copper and stainless steel surfaces, the mean nearest-neighbor distance value, standard deviation and the coefficient of variance were calculated statistically. For the spatial Poisson distribution, the mean nearest-neighbor distance value is calculated as,

\[
\bar{s} = \int_{0}^{\infty} s P(s)ds = \frac{1}{\sqrt{4\pi N_0}}
\]

The standard deviation and the coefficient of variance are calculated as,

\[
\sigma_s = \sqrt{\int_{0}^{\infty} (s - \bar{s})^2 P(s)ds} = \sqrt{\frac{4 - \pi}{4\pi N_0}}
\]

Fig. 4. Nucleation sites on the copper surface, pressure at 500 kPa and wall superheat at 10.94 °C. [4 x 4 sub-domains partitioning and [8 x 8 sub-domains partitioning.]

Fig. 5 shows typical probability densities of nucleation sites distributions on both copper and stainless steel surfaces (Eq. (1)), and comparisons to the spatial Poisson distribution (Eq. (2)). The comparisons show that the experimentally observed nucleation site distribution probability densities agree well with the spatial Poisson distribution in general. However, it can be observed that the measured probability density for \(N_a\) close to the average value, \(N_a\), is generally higher than that given by the spatial Poisson distribution. For example, as shown in Fig. 5(a), for the copper heating surface, pressure at 500 kPa and wall superheat at 10.94 °C, the average number of nucleation sites in a sub-domain are 4.8 for the 4 x 4 sub-domain partitioning. The probability from experimental data, \(N_a = 5\) is significantly larger than the value predicted by the spatial Poisson distribution. The same trend is observed for most conditions investigated in the current experiments. This

![Fig. 4](image-url)  
![Fig. 5](image-url)

**Table 1**  
Experimental parameters explored in the experiments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface material</td>
<td>Copper, stainless steel</td>
</tr>
<tr>
<td>Pressure</td>
<td>450–700 kPa</td>
</tr>
<tr>
<td>Wall superheat</td>
<td>7–12 K</td>
</tr>
<tr>
<td>Wall heat flux</td>
<td>(2.19 \times 10^4)–(7.52 \times 10^4) W/m²</td>
</tr>
<tr>
<td>Nucleation site density</td>
<td>(5.64 \times 10^2)–(2.30 \times 10^4) m⁻²</td>
</tr>
</tbody>
</table>
500 kPa, wall superheat at 10.94 °C. These effects have been qualitatively discussed. The thermal interactions can be seen in Fig. 7. Pressure has been found to have very strong effects on bubble size and nucleation site number density [17]. However, for both copper and stainless steel surfaces, pressure does not show a strong influence on the coefficient of variance of nearest-neighbor distance, i.e., the uniformity of nucleation sites distribution. In Fig. 7, this can be seen by looking at how data from different pressures are clustered.

Also, a trend can be seen that for most conditions, the coefficients of variance on both surfaces are smaller than that given by the spatial Poisson distribution. This indicates that the nucleation site density increasing, the average distance between two nearest sites becomes smaller and therefore interactions between sites are stronger.

From Fig. 7, it can also be found that the coefficients of variance of nearest-neighbor distance on the copper surface are generally smaller than that on the stainless steel surface, for different pressures and nucleation site densities. This indicates that the nucleation site distribution on the copper surface is more uniform than that on the stainless steel surface. In our experiments, except the different thermal conductivities of these two materials, all other experimental conditions are keeping the same. This also includes microscopic parameters, such as bubble sizes and contact angles [17]. The difference between these two surfaces can be explained as a result of solid-side thermal interactions: During a bubble growth, local wall temperature near an active site drops dramatically due to liquid evaporation. Consequently, in the bubble influence area due to lateral solid heat conduction, the wall temperature is suppressed to a level which is lower than the required value to activate a potential nucleation site. This influence area is expected to be controlled by the thermal properties of the heating surface. For similar bubbles, i.e., size and contact angle, a material with higher thermal conductivity tends to have a larger influence area in terms of wall temperature suppression. Thus, on the copper surface, the active nucleation sites tend to distribute more uniformly. A detailed numerical model is presented in the next section to quantitatively discuss the thermal interaction effect.

### 4. Thermal interaction model and numerical simulation

In the previous section, the lateral thermal interaction effect has been qualitatively discussed. The thermal interactions can be quantitatively analyzed in terms of effect of bubble formation on temperature profile of surrounding heating surface. These effects include both transient and quasi-steady effects, which will be discussed in this section.
4.1. Transient effect

In boiling, the formation of a bubble can be idealized as a round continuous surface heat sink during its lifetime. Assuming the heating surface is infinitely large and starts at a constant temperature. The temperature disturbance, \( \theta \), caused by a point heat sink at \( r_0 \), which instantaneously absorbs heat \( Q \), can be represented by [18],

\[
\theta(r, t) = \frac{Q}{4\pi r_0^2 \rho c_p} \exp \left( -\frac{|r - r_0|}{4\pi r_0 t} \right) \tag{7}
\]

The total effect from a bubble can then be derived as,

\[
\theta(r, t) = \int \int q'(r, t) \frac{4}{4(\pi r_0^2 \rho c_p)} \exp \left( -\frac{r - r_0}{4\pi r_0 t} \right) dA r dt \tag{8}
\]

where \( q'(r, t) \) is the instantaneous heat flux on the heating surface covered by the growing bubble. Since this quantity is unknown, Eq. (8) is not readily solvable. However, estimation on the magnitude of temperature disturbance can still be made by using Eq. (7). The heat \( Q \) instantaneously absorbed by a bubble is approximated by latent heat it absorbs, can be calculated as,

\[
Q = \rho V_s h_g \tag{9}
\]

For example, for pressure at 400 kPa and wall superheat at 8 K, a typical vapor bubble has a lifetime of 10 ms and a departure radius at 100 \( \mu \)m. The absorbed heat is calculated to be \( 1.57 \times 10^5 \) J. Using Eq. (7), the surface temperature drops at a site 200 \( \mu \)m (one bubble diameter) away and 1 ms after bubble formation are in the order of magnitude of \( 1 \times 10^{-3} \) K and \( 1 \times 10^{-2} \) K for copper and stainless steel surfaces, respectively. It can be concluded that, for the combination of R134a and copper/stainless steel, the surface temperature disturbance on an adjacent nucleation site caused by a single bubble growth is small and can be neglected. This effect has also been proved by very small bubble waiting times observed during the experiments [17].

4.2. Quasi-steady state effect

As discussed in the previous section, the transient effect of a single bubble formation on thermal interactions is small and may not explain the thermal interactions between nucleation sites. As observed during the experiments, bubbles are continuously generated from a nucleation site and the waiting time between two consequent bubbles are generally very small. In this sense, a quasi-steady analysis is more appropriate to study the bubble formation effect. For purpose of simplicity, the quasi-steady analysis has been simplified as a steady-state problem, which is a reasonable assumption as the waiting time is very small. As shown in Fig. 8, a bubble is modeled as a sphere cap sitting on the heating surface and the thickness of the liquid superheated layer is equal to bubble height. A constant heat flux is supplied from the bottom of the solid heating surface domain, with a thickness of 2.5\( R_b \) and a radius of 5\( R_b \). The solid region domain was chosen to be large enough to minimize the geometry effect on temperature profile within the solid domain [17]. Only heat conduction is in the solid region and heat conduction is dominant in the liquid region (Peclet number is estimated in order of magnitude of 0.01), respectively. Therefore, the heat transfer governing partial differential equation is,

\[
\nabla^2 T(r, z) = 0 \tag{10}
\]

Boundary conditions are,

\[
q_n(r, z) = q_0 \quad \text{at boundary 1} \tag{11}
\]

\[
\frac{\partial T(r, z)}{\partial z} = 0 \quad \text{at boundary 2 and 3} \tag{12}
\]

\[
T(r, z) = T_{sat} \quad \text{at boundary 4} \tag{13}
\]

\[
Q'(r, z) = \frac{2\pi}{2 - \pi} \left( \frac{2}{2\pi R} \right) H_g \left[ \frac{P_l - P_v}{T_f - T_{sat}} \right] \quad \text{at boundary 5 and 6} \tag{14}
\]

Eq. (14) [19] can be simplified by assuming the liquid phase temperature, \( T_l \), and vapor phase temperature \( T_v \), are both close to the saturation temperature \( T_{sat} \) corresponding to liquid phase pressure \( P_l \). It can be further simplified considering the pressure difference between liquid and vapor phase is due to the bubble curvature, and applying Clausius–Clapeyron relation, Eq. (14) can be finally re-written as,

\[
Q'(r, z) = h_{ev} [T(r, z) - T_{sat} - \Delta T] \tag{15}
\]

where

\[
h_{ev} = \frac{2\pi}{2 - \pi} \left( \frac{M}{2\pi R} \right) \frac{H_g^2}{T_{sat}^2} \frac{1}{v_g} \tag{16}
\]

\[
\Delta T = \frac{2\pi T_{sat}}{R_b} \frac{v_g}{H_g} \tag{17}
\]

In Eqs. (16) and (17), \( \sigma \) is condensation/evaporation coefficient for R134a with a value close to unity [20]; \( M, H_g, T_{sat}, \sigma, v_g \) are molecular weight, latent heat, saturation temperature, surface tension, and specific volume different between vapor and liquid of R134a, respectively; \( R \) is the universal gas constant.

A case calculation was performed under a typical condition explored in our experiment, with pressure at 400 kPa, wall heat flux at \( 2 \times 10^4 \) W/m\(^2\), bulk velocity at 0.1 m/s. Bubble departure radii on both copper and stainless steel surfaces were measured at around 100 \( \mu \)m under these conditions. Contact angles between

Fig. 8. Schematic diagram of the thermal interaction model.

Fig. 9. Temperature distributions in liquid (R134a) and solid (stainless steel) regions. \( P = 400 \text{ kPa}, T_{sat} = 282.08 \text{ K}, q' = 2 \times 10^7 \text{ W/m}^2, R_b = 100 \text{ \( \mu \)m}. \)
bubble and surface were measured to be 40°. Numerical solutions were obtained for liquid and solid temperature distributions in the domain, using a computer code with finite volume method (FVM). Results of calculated temperature distributions in liquid (R134a) and solid (stainless steel) regions are shown in Fig. 9. Wall super-heat profiles on both copper and stainless steel heating surfaces are shown in Fig. 10. Calculations were also performed on two additional materials, nickel (k = 109 W/m K) and carbon steel (k = 54 W/m K). Wall superheat profiles for these two additional materials are also shown in Fig. 10 for comparison purpose. Fig. 10 shows that surface temperatures beneath the bubble are suppressed and close to the fluid saturation temperature due to high evaporation heat transfer coefficient. However, different surface temperature distortion levels caused by the presence of a bubble are observed for materials with different thermal conductivities. It shows that, with identical wall heat fluxes, bubble sizes, and contact angles, the overall surface temperature on higher thermal conductivity heating surface is smaller than heating surfaces with lower thermal conductivity. This is explained as the result of better lateral heat conduction towards the bubble-covered area on a higher thermal conductivity surface. The larger surface temperature distortion level on the copper surface also indicates that a bubble on the copper surface also has a larger influential area in terms of suppression of an adjacent nucleation site. Thus, even if active nucleation site densities are the same, the statistical distribution of nearest-neighbor distance of nucleation site and therefore the distribution of active nucleation site tends to be more uniform on surfaces with higher thermal conductivities.

This paper was aiming at the effect of thermal conductivity on nucleation site thermal interactions. Results show that high heating surface thermal conductivity leads to a lower overall surface temperature as well as a more uniform nucleation site distribution. However, it has to be noted that the thermal interaction is only one mechanism among those interaction mechanisms between bubble and nucleation site. To fully understand the chaotic behavior of boiling, we suggest that all interaction effects have to be considered.

5. Conclusions

An experimental work on subcooled boiling with R134a to examine nucleation site distributions on both copper and stainless steel heating surfaces has been performed. Bubble emission images were obtained from a view normal to the heating surface by using a high-speed digital camera. All active nucleation sites could be identified so that the sites distribution could be statistically estimated. Those experimentally observed nucleation site distributions were compared to the random spatial Poisson distribution. The comparisons showed that, rather than purely random, the active nucleation site distributions are relatively more uniform, which can be explained as results of nucleation site interactions. The experimental results also showed that on the copper heating surface, the nucleation site distribution is slightly more uniform than that on the stainless steel surface. The difference was concluded as the results of thermal interactions between nucleation sites with different solid thermal conductivities. A two dimensional thermal interaction model was then developed to quantitatively analyze the heating surface temperature difference. The model results give a reasonable explanation to the experimental observation on nucleation site distribution.

References