A Detection of Acoustic Emission Signals from the Pool Boiling Condition for Determining Boiling Phenomena

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1. Introduction

For the safety of nuclear power plant, it is essential to identify and predict the nucleate boiling phenomena in a reactor related to the deposition of CRUD in fuel rod [1] and critical heat flux (CHF) which is the loss of cooling ability to fuel rod leading to the severe accident. The conventional detection technologies for the reactor status have a limit to figure out the heat transfer phenomena inside the reactor, and only the correlation of the CHF with a safety factor is known. This conservative approach, however, affords excessive thermal margin, making reactor operations ineffective.

As one of the non-destructive detection technologies, the detection of acoustic emission (AE) signals from the system which is under irreversible elastic changes such as crack formation is a promising method [2,3] for measuring the status of the inaccessible system, the reactor pressure vessel. Using this technology, it is possible to measure in real-time not only the predicted CHF but also the heat transfer information in the reactor system in operation.

There were several feasibility studies to identify and determinate the boiling regime using AE signals in quenching and pool boiling condition [1], [4-10]. Among several studies, Seo and Bang [4] pointed out the relationship of AE signals with boiling phenomena as two things as; 1) a collision and collapse of bubbles showed a higher frequency than bubble growth. 2) the boiling crisis showed unusual frequency peaks and distinctive peaks for each region such that the boiling region can be distinguished by AE signals. And Sinha et al. [6] made an automatic power cutoff system based on AE signals when CHF occurs, it diagnoses the boiling state of the system in real-time and shows the possibility of safety system design automatically. However, a common problem of previous studies is that the AE signal generated from boiling varies from experiment to experiment because the types and locations of AE sensors are different.

To get a more accurate relationship between boiling and AE signals, it is necessary to directly receive the AE signal from the heating surface under pool boiling conditions. Following the previous AE experiment in quenching condition, in this work, the feasibility experiment will be conducted to figure out the relationship of the boiling regime and the CHF with the AE signals from pool boiling condition.

2. Experiments and Results

In this section, the experimental setup for detecting the acoustic emission signals from the pool boiling condition is presented with previous experimental results.

2.1 Experimental Setup

The experimental apparatus is divided into two parts, one is the pool boiling apparatus and one is the AE signal measuring system with data acquisition system (DAS). As shown in Fig.1, Pool boiling apparatus consists of a polycarbonate boiling chamber, four cartridge heaters, condenser, and Infrared (IR) mirror and use DI water as a working fluid, which is for the visualization of the boiling dynamic by high-speed video and temperature distribution in the heated surface by IR thermometry. The heater consists of SiO_2/Si, indium tin oxide (ITO), Au and is heated by direct Joule heating. The pool boiling experiment will be performed by adjusting the heat flux and will be considered CHF when the IR temperature data shows a sharp rise.
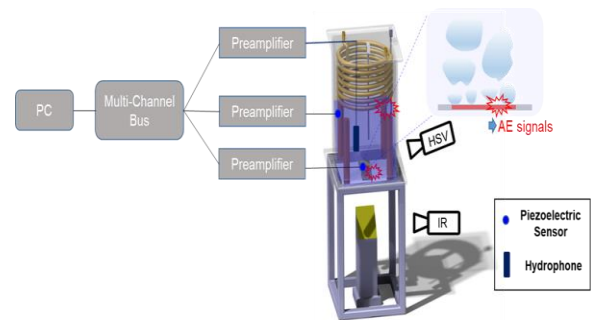

Fig.1. Experimental apparatus for the detection of acoustic emission signals from pool boiling condition.

For the detection, AE signals of boiling in the heater surface, the piezoelectric AE sensor (Micro30, MISTRAS) is attached to the SiO_2/Si heater surface to reduce the signal attenuation as shown in Fig.2. The piezoelectric AE sensor has a sensitivity of 65 dB, a resonant frequency of 125 kHz, and an operating frequency range of 150–400 kHz. After receiving the AE signals, their amplitudes are augmented by a preamplifier and transformed by a Fast Fourie Transform (FFT) method that varies from an original

energy spectrum of AE signals to frequency spectrum. The measured AE signal will be compared with the bubble images on the heating surface to find the relationship with the bubble dynamics.
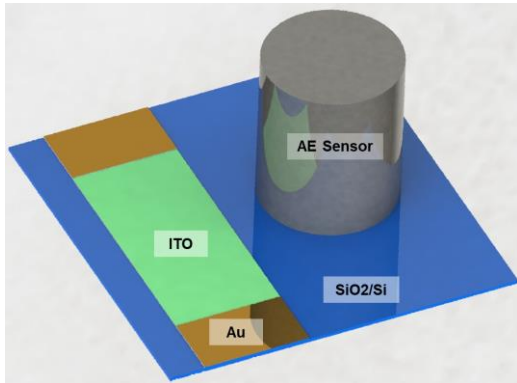

Fig.2. The heater surface consisting of SiO_2/Si, ITO, and Au with the piezoelectric contact type AE sensor.

2.2 Previous AE experiment in quenching condition

The AE acquisition experiment was conducted in a quenching condition [4]. This study analyzed the results of the quenching experiments to find out the relationship between the boiling regime and the AE signal by comparing with the high-speed visualized image. It was also a basic study on whether the AE signal detection technology could be used to determine the boiling regime.

Experimental equipment used the radiation furnace, test section, rod-less linear motion, quenching pool, optical visualization apparatus, AE sensor, and DAS. The center temperature was measured by putting TC into the stainless-steel sphere, and the surface temperature of the sphere was numerically inverted using the inverse heat transfer method.
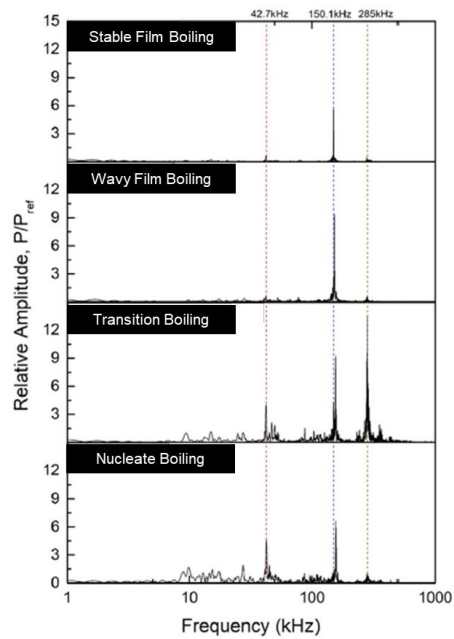

Fig.3. Power spectrum density of vapor-liquid interface wave in different boiling regimes [4].

As a result, there was a peak only in the high-frequency region in the film boiling regime and the peak in the low-frequency region in the nucleated boiling regime. On the other hand, the transient boiling regime showed peaks in both the high and low frequency ranges, and CHF (boiling crisis) showed a very unusual form of amplitude as shown in Fig.3.

2.3 Preliminary pool boiling experiment

Before the detecting experiment of AE signals, preliminary pool boiling experiments were performed on SiO_2, Si heater surfaces, and uniformly hydrophobic surface [11]. The purpose of the experiment of uniformly hydrophobic is to observe the film boiling regime where the working fluid is DI water, which the heater temperature is rapidly increased and destroyed at CHF. However, in the case of a hydrophobic material (commercial hydrophobic spray, Hydrobead Corp.) coated heater, even though a vapor film is formed on the surface, the film boiling regime can be observed because of the relatively low temperature rise rate. Therefore, from the nucleate boiling to the film boiling regime, the boiling phenomena can be observed, and the AE signal can be received, and it is possible to compare pool boiling data with previous quenching studies.
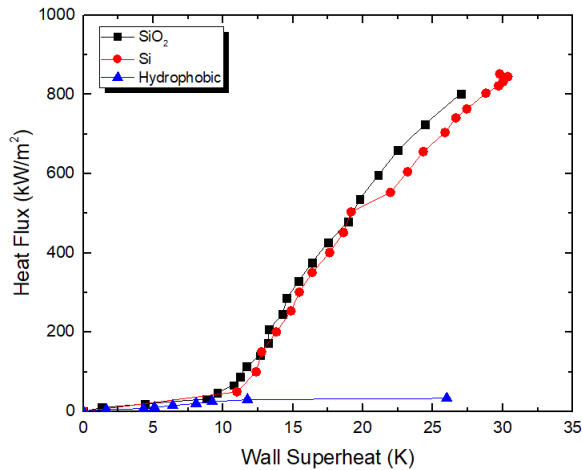
Fig.4. Boiling curves for the plain Si, SiO$_2$, hydrophobic surface [11].

As shown in Fig.4, CHF of SiO$_2$, Si, hydrophobic surface is 803.7kW/m^2, 851kW/m^2, and 40.6 kW/m^2, respectively. Figure 5 shows the visualization images and temperature distribution of nucleate boiling regime for SiO$_2$ surface and of film boiling regime for the hydrophobic surface.
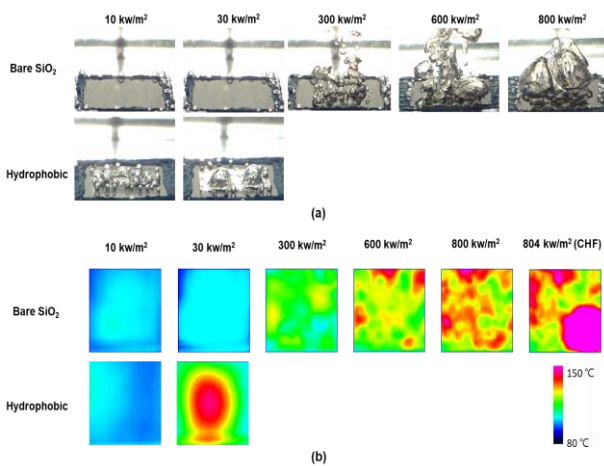

Fig.5. (a) High-speed images and (b) temperature distribution images of SiO$_2$ and hydrophobic surface as an increase of heat flux [11].

3. Summary and Future work

To figure out the accurate relationship between the boiling phenomenon and the AE signal, the experiment was designed, and preliminary experiments were performed to measure the AE signal under the pool boiling condition. As future work, the AE sensor will be attached directly to the heater to perform pool boiling experiments, and the characteristics of AE signals for boiling regime and CHF will be derived.

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