Acoustic characteristics of Boiling in Water and R123

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1. Introduction

Quenching phenomenon occurs when a superheated objected is rapidly cooled by a fluid. Especially in nuclear engineering field, quenching phenomenon is important, since it dominates a heat transfer, or heat removal, during the operation of emergency core cooling system (ECCS) at loss of coolant accident (LOCA). Many studies have worked with various heated surface, various fluids, and so on [1,2], though, the fundamental phenomena during the quenching process, especially the boiling crisis, has not been clarified yet.

Acoustic emission (AE) signal analysis is one of many approaches to study the boiling crisis during the quenching process [3]. Generally, AE is generated by elastic waves following a sudden release of energy in the material. AE measurement has been mainly utilized to various practical applications for its great advantages in non-destructive and in-situ diagnosis and monitoring, while there are few studies on the use of AE measurement to the diagnosis of boiling process.

In this study, the boiling phenomena during the quenching process is investigated by using AE measurement. The analyzed AE signal reveals additional characteristics of boiling phenomena along with the visualized images.

2. Experimental setup

2.1 Quenching test section and apparatus

The main focus of present study is on the relationship between quenching process and AE signals generated during the process. Then, a small SS sphere with the diameter of 10mm is used as a test section to study the fundamental phenomena. Other than the AE sensor, the conventional pool quenching experimental apparatus has been set up. A rodless linear motion transports a test section heated inside a radiation furnace which can raise the temperature up to 1000°C to the quenching pool. The working liquids are distilled water and highly wettable refrigerant, R123, at the atmosphere pressure and room temperature. The temperature at the center of the sphere and the visualized images are recorded during the experiment. The schematic diagram of experimental setup and the experiment procedure are shown in Fig. 1.

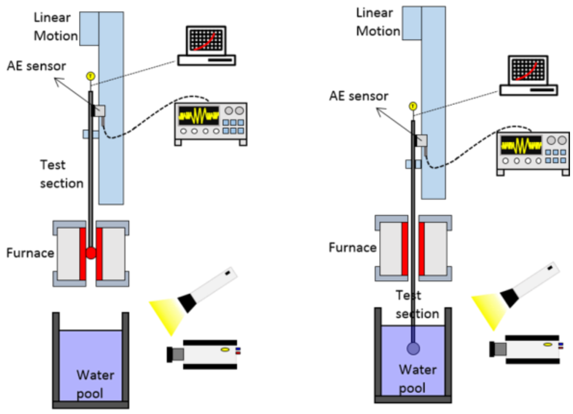


Fig. 1. The schematic diagram of experimental setup. The heated test section from the furnace is transported to the quenching pool during the experiment.

2.2 AE measurement

The AE sensor is a category of the pressure transducer. The previous studies have mainly used the hydrophone as a AE sensor, which is immersed in the working fluid and the pressure waves generated at the site of interest is transferred through the fluid medium to the hydrophone. However, the present study uses contact pressure transducer as a AE sensor to focus on the boiling phenomena itself which is highly associated with the heating surface. The recorded AE signals are manually synchronized with the temperature profile and visualized images. In addition, the spectral analysis of AE signal is performed using Fast Fourier Transform (FFT)-based nonparametric method.

2.3 Experimental condition

The initial temperature of the test section is ~750°C inside the furnace and the temperature loss during the transport to the quenching pool is about ~50°C. Two working fluids are used to cool the test section. One is the distilled water and the other is R123 which is highly wettable fluid. The surface condition is maintained in bare condition without any treatment.

3. Results & Discussion

3.1 Time-domain analysis

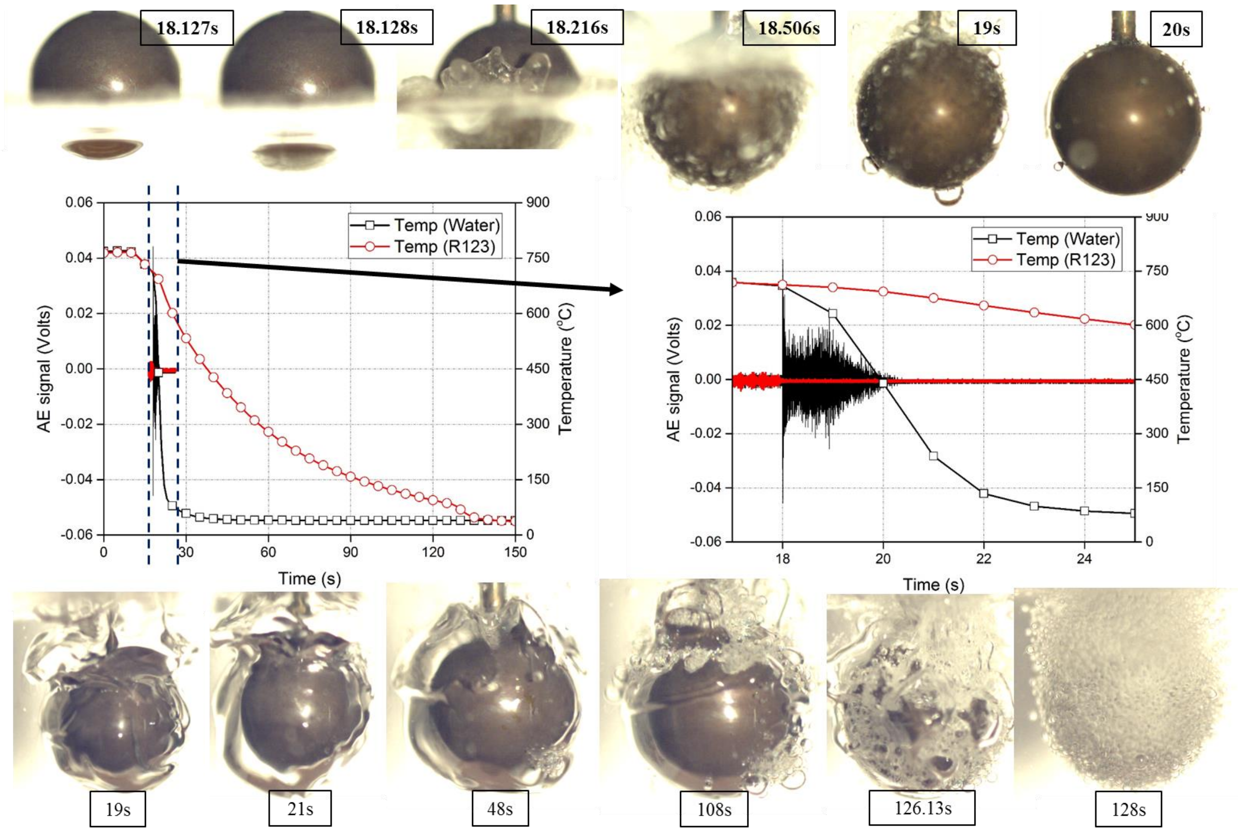


Fig. 2. Temperature, AE intensity (Volt), and visualized images with time during the pool quenching of distilled water and R123

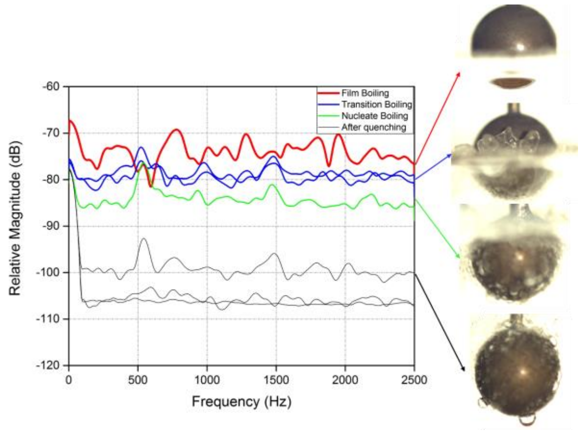
The temperature profile of water show the typical curve which has been reported in many previous studies. On the other hand, the temperature curve of R123 shifts to the right compared to that of water. As a result, the quenching curve of R123 becomes similar to that with hydrophobic heating surface reported in the previous study [4]. The right-shifted quenching curve normally refers the delay of nucleate region, which is attributed to the hindrance of liquid supply by vapor generation. In the present study, low latent heat of R123 (170.2 kJ/kg) produces large amount of vapor generation, which blocks the liquid inflow to the heating surface. The corresponding phenomena are visualized by high-speed camera shown in Fig. 2. As mentioned, the vapor film of R123 that covers the heating surface is maintained longer and more stable compared to that of water.

The AE signals from water and R123 also show different characteristics. The boiling process during the quenching in water produces vigorous pressure waves. Right after the test section enters into the water surface, the maximum peak amplitude of AE signal appears. The first peak is attributed to a formation of vapor film through the entire heating surface. Then, the following peaks come from the transition boiling which is visualized as a continuous collapse of vapor film and sequent nucleation generation along the vertical direction. Compared to the amplitude of AE signal generated from the vapor film formation, that from the transition boiling is relatively lower. The main attribution that makes the difference is the area change rate covered by the vapor. The drastic increase of vapor area in film boiling produces large pressure waves, while the sequent transition from the vapor film to the nucleation produces relatively lower AE signal.

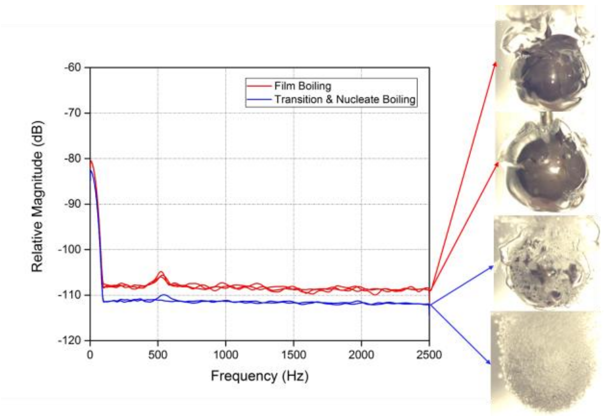
In the same manner, the slow collapse of vapor film of R123 produces very small pressure waves, which cannot make a distinction between AE signals from boiling and background noise.

3.2 Frequency-domain analysis

For the additional analysis of AE signals, spectral analysis is performed using FFT-based nonparametric method. Fig. 3. show the AE signals in frequency-domain and corresponding images. There are large differences in AE waveforms between water and R123. AE signal from water boiling shows distinct waveforms among the boiling regions from film boiling to nucleate boiling. The relative amplitude of AE signal decreases as the boiling region changes from the film boiling to nucleate boiling. In addition, the frequency of peak amplitude decreases, which implies low occurrence of boiling event, especially the vapor generation and growth. It is physically reasonable description, since the occurrence of boiling, or nucleation, is weaken due to the decreasing superheated temperature. On the other hand, boiling of R123 gives no evident difference in frequency domain. The results are attributed to the low AE signal intensity that makes hard to transform to frequency-domain.



(a)



(b)

Fig. 3. AE signal in frequency-domain: (a) AE signal from water boiling, (b) AE signal from R123 boiling.

4. Conclusions

Acoustic emission (AE) signal analysis is introduced to study the boiling crisis during the quenching process. The boiling phenomena during the quenching process is investigated by using AE measurement. The AE signals from water boiling and R123 boiling are analyzed along with the visualized images. During the quenching in water, the rapid expansion of vapor film through the entire heating surface firstly produces vigorous pressure waves, while the sequent collapse of vapor film and generation of nucleation bubble produces relatively lower AE signals. Also, in frequency-domain, the lowered occurrence of boiling event from film boiling to nucleate boiling leads to the decrease in frequency of AE waveforms. On the other hand, due to the slow collapse of vapor film of R123, AE signals are not clearly measured and analyzed in both time-domain and frequency-domain. Therefore, further work should be focused on the AE signal analysis of various heating surface conditions and fluids to verify the unique characteristics of AE depending on the boiling phenomena.

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