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Effect of Electric Power-Supplies on Acoustic Emission Signal during Boiling Process

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Abstract

The dynamic bubble phenomena in two-phase, liquid/gas systems occur in many different hydraulic processes such as valves, centrifugal pumps, fluid piping transportation, boiling processes and nuclear reactors. Bubble activity phenomena cause some problems such as vibration, noise, decreased of equipment efficiency and surface pitting. Monitoring and detection of bubble activity at an early stage during the boiling process is very important to nuclear safety and many industrial processes. Acoustic emission (AE) technique in this work investigation covers the frequency between 100 kHz and 1000 kHz. Obtained results show a high feasibility of AE technology in detection and diagnosis of bubble dynamic at an early stage during pool boiling. It was observed that bubble activity is detectable with AE method, and there is a clear relationship between increasing AE signals with increase electric power-supply levels and the bubble formation during pool boiling..

Keywords: *Acoustic Emission, bubble activity, pool boiling*

1. Introduction

Bubble cavitation is an undesirable phenomenon because causes increase in maintenance costs, reduction of production and revenue and decrease the life of the equipment. It is also a dynamic phenomenon that occurs in fluid flows when local pressure is lower than the saturated vapour pressure at ambient temperatures [1]. Cavitation is a phenomenon that occurs in rotating machines and flow process, which is characterised by the collapse of voids in the flow with an explosive effect generating localised high pressures and temperatures. Cavitation occurs when the liquid is subjected to a drop in pressure, which is equal or lower than the saturated vapour pressure at a given temperature [2][3]. To reduce the damage caused by cavitation, bubble formation must be monitored and detected in rotating machines and valves [4]. The growth and collapse of cavitation bubbles lead to the erosion or pitting of metal surfaces and causes high vibration and noise [5].

Operating a pump under cavitation conditions for a long time causes impeller vane pitting. The amount of metal lost depends on the material of the impeller, the degree of cavitation and the time between two successive pressure waves [4]. Noise and vibration phenomenon are an index of cavitation, caused by the implosion of bubbles near a solid surface. This phenomenon causes component damage of pumps and valves. The intensity of the noise and the vibration depends on the number and size of bubbles. In other words, large numbers of small bubbles produce a high-frequency noise and vibration, while a limited number of large bubbles create a low-frequency noise and vibration [6]. Leighton [7] concluded that the sources of sound emitted from oceans were caused by pressure waves produced by gas bubbles inside the liquid. Strasberg [8] found that the sound occurs only when the bubble is in volume pulsation; he also found that smaller bubbles, with a smaller surface area, radiate less energy for a given volume rate of bubble formation.

Alhashan et al. [9] used the AE technique in the monitoring of bubble formation during the boiling process. They found that there is a clear association between increasing AE levels and the bubble formation during the boiling process. Carmi et al. [10] used the AE technique in a flow boiling experiment to detect bubble transit, noting the possibility of using AE in the detection of bubble dynamic events at the early stages in the boiling process. The AE technique has been used to diagnose the bubble formation process and monitor bubble departure from the heating surface of the boiler to the surface of the liquid container during pool boiling [11]. Benes and Uher [12] found that the parameters of the AE signal have a correlation with overheating during heat transfer. It was established that the AE signal could be used to predict the boiling phenomena. In another investigation, centring on two-phase flows, Alfayez et al. found that the AE method is a useful technique for incipient detection of cavitation with the root-mean-square (RMS) value of the AE signal. Also, there is a high possibility of determining the best efficiency point (BEP) of a centrifugal pump or system [13]. Neill et al. monitored cavitation phenomenon of a centrifugal pump based on the AE method and got a more accurate result than that produced by the vibration signal [14]. Masjedian et al. used two methods; characteristic diagrams and acoustic analysis in the detection of cavitation phenomena in globe valves. The two methods find similar results with acceptable levels of accuracy. Furthermore, they investigated acoustic waveform of cavitation in the globe valve and analysed the waveform and its important parameters using fast Fourier transform (FFT) [15]. Addali [16] found that the gas void fraction (GVF) can be determined by measurement of the acoustic emission. Moreover, it was concluded that there is a direct correlation between the AE energy and GVF. It was also noted that an increase in superficial gas and liquid velocities caused an increase in AE energy levels. Husin et al. [17] found that AE was a suitable technique for the detection of a single bubble formation and burst, with AE being used to measure the velocity of the acoustic wave. Derakshan et al. monitored cavitation of hydraulic turbines through the measurement and analysis of the true RMS of AE signals [18]. Kim et al. found that the inception of cavitation causes head and efficiency of the primary pump to reduced significantly and generates vibration and noise.

To date, most published studies showed that there were a few attempts at the application of the AE technique for monitoring and early diagnosis of bubble occurrence. In fact, the boiling process offers a good opportunity to study bubble formation due to the increase in liquid temperature.

Thus, the aimed objective of this work is:

- Use of AE to monitor the bubble formation process.
- Study of the effect of different electric power-supplies on AE signals levels during pool boiling process.
- Study of the effect of threshold levels on AE signals levels.

2. Experimental Setup

This investigation was built on previously carried out work in this area. In these experiments, a deep vessel was used to separate the bubble formation and bursting regions substantially. Furthermore, tap water, two different electric power-supplies and three different liquid levels during pool boiling tests, as shown in Table 1.

Table 1: Experimental Procedures of boiler test.

Water Type	Electric Power-Supplies (kw)	Water Level (mm)
Tap Water	2.5-3.0	100-200-300

For this study, boiling tests were performed using a specially purpose test-rig, as shown in Figure 1. It consisted of a manual fill water boiler with 270 mm internal diameter and 440 mm height. The maximum capacity of the boiler is 26 litres. The boiler is made of stainless-steel and has been coated to prevent any heat losses to its surrounding environment. The boiler is integrated with a heater, located at the boiler bottom, to heat up the water inside the boiler. The rounded heater has an external diameter of 150 mm. A constant electrical power of 2500 W is supplied to the boiler heater throughout the boiling experiments.

A commercially available piezoelectric sensor (Physical Acoustic Corporation type “PICO”) with an operating range of 100-1000 kHz was used. Two acoustic sensors, together were attached to the external surface of the boiler using superglue. It is worth mentioning that two AE channels were distanced 200 mm apart. The first channel was attached to the bottom of the boiler, 100 mm from the bottom surface, to detect the initiation of bubble formation whilst channel 2 was positioned 200 mm atop channel 1 to monitor bubble bursts and oscillations when the bubbles rise up to the free surface at high water levels, see Figure 1. The acoustic sensors were connected to a data acquisition system via a preamplifier, set at 40 dB gain. The system was continuously set to acquire AE waveforms at a sampling rate of 2 MHz. The software (signal processing package "AEWIN") was incorporated within a PC to monitor AE parameters such as RMS and absolute energy (recorded at a time constant of 10 ms and sampling rate of 100 Hz). The absolute energy is a measure of the true energy and is derived from the integral of the squared voltage signal divided by the reference resistance (10 k-ohms) over the duration of the AE signal. In addition to continuous recording of AE absolute energy (atto-Joules - 10^{-18} Joules), traditional AE parameters such as hit, counts, amplitude and rise time were also measured.

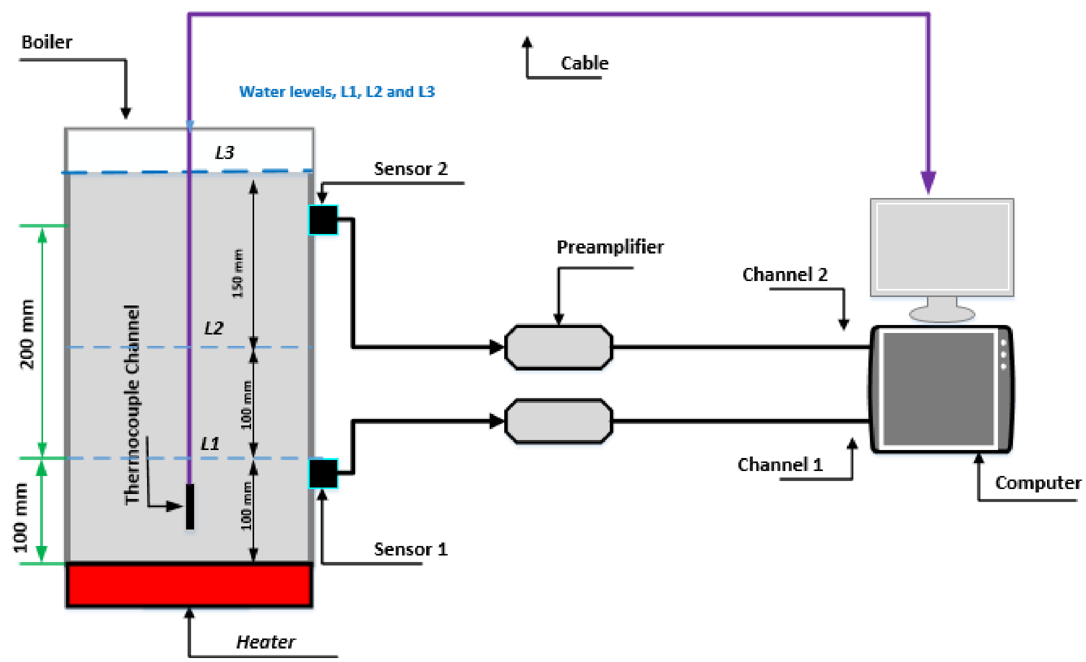

Figure 1: Schematic of the data acquisition systems

3. Results, Observations, and Discussions

The next phase of the analysis was the use of the AE-RMS to identify bubble formation during the test period with different rates of power-supply to the plate heater. Figure 2 shows the plots of AE-RMS against measured water temperature for two rates of heat input, 3.0 kW and 2.5 kW.

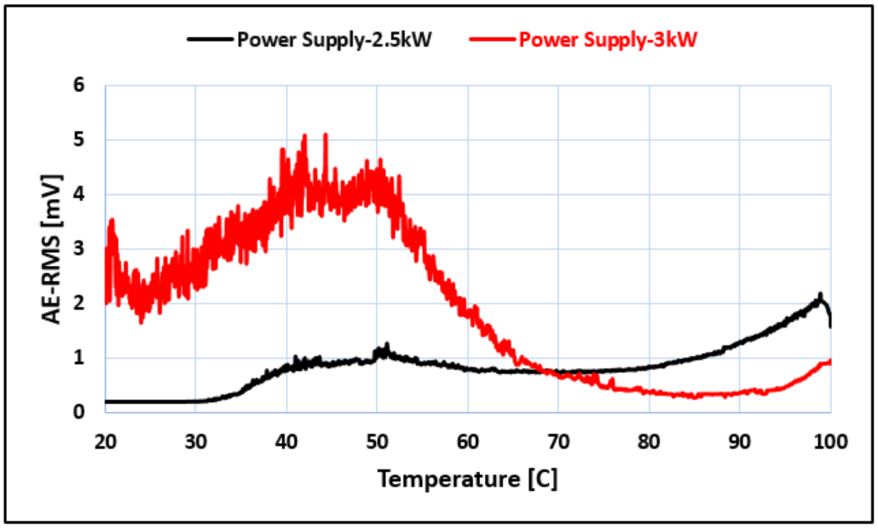

Figure 2: AE-RMS as a function of temperature for two rates of heat input. Signal from sensor 1 with tap water, depth of 200 mm.

Figure 2 shows correlation between AE-RMS signal and temperature for sensor 1, where red signal presents electric power-supply at 3 kW, and black signal provides electric power-supply at 2.5 kW. There is an increase in AE signal level with measured water temperatures. Bubbles started to detach from the heated surface to the surrounding water at about 35^0C with an electric power-supply of 2.5 kW. The value of the AE signal decreased slowly between 50 and 80^0C. In this period, attenuation occurs due to some bubbles sticking to the heated surface of the boiler, causing a reduction in the AE signal. In the last moments of the test (100^0C), large bubbles were bursting at the free surface, and the corresponding value of the AE-RMS at 2.5 kW was recorded as 2 mV.

With a power supply of 3 kW, the bubbles start to detach from the heated surface at the bottom of the boiler at around 22^0C with a substantial increase in the level of the AE-RMS between 22 and 50^0C. The AE signal level is much greater than for the 2.5 kW source, with the increased power supply generating a higher heat flux and causing more bubbles to form. The AE-RMS level for the 3 kW heater peaked at 5 mV between 40 and 50^0C, because in this period the bubbles formed at a faster rate, due to the increased heat flux and heated surface temperature. After that, there was a gradual decrease in the value of AE signal with increase in temperature from 50 to 100^0C. During this period, the water temperature and bubble size increased, causing bubbles to burst near the free surface.

It was observed that the electric power-supply has a significant effect on AE levels such that when the power supply increases, the trend of the AE signal changes as well.

3.1 Difference between rise times of AE-signals for bubble formation and bubble burst using tap water

In this test, two solid acoustic waveguides, made from stainless steel of square cross section 25 x 25 x 500 mm were used. To measure the signals associated with bubble formation, acoustic waveguide 1 with a sensor attached was positioned with its end 5 mm from the bottom (heated) surface of the boiler. To monitor bubble burst at the surface, acoustic waveguide 2 was placed with its end 195 mm from the bottom heating surface. The AE signal rise times measured by waveguide 1 were greater than those for waveguide 2; 6494 µs compared to 1753 µs. This increase in rise time is because as the bubbles neared the surface their diameter increased, the bubbles became larger. The biggest bubbles burst on the surface of the water.

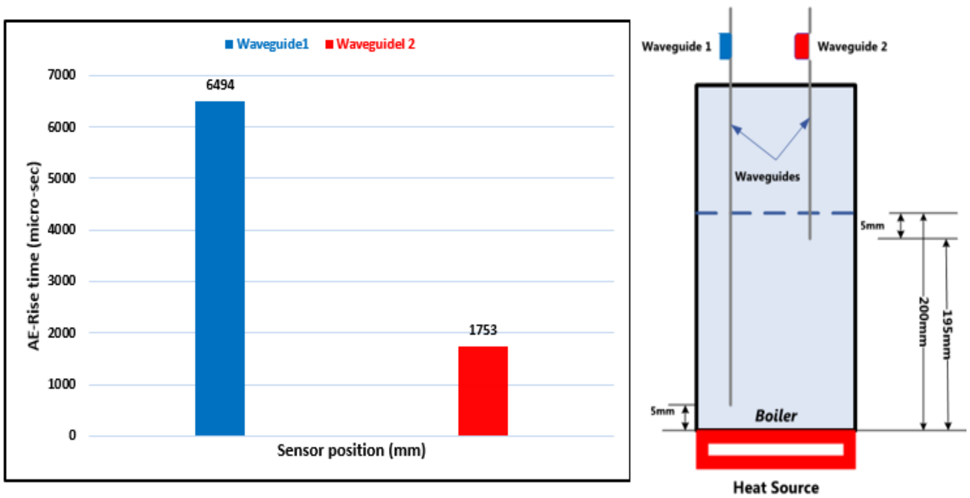

Figure 3: AE-rise times for both acoustic waveguides using tap water of depth 200 mm and 3 kW supply.

The identical setup was used to measure AE-RMS to identify characteristics of bubble activity such as bubble formation and burst, as shown in Figure 2. This analysis was performed to assess the ability of the RMS parameter to monitor bubble formation and burst during pool boiling. The results showed the AE signal for waveguide 1 was higher than that for waveguide 2; 3.5 mV and 0.7 mV respectively at 40^{0}C, see Figure 4. The peak values for waveguide 1, measuring activity 5 mm above the heated surface, was for the temperature range 20 to 100^{0}C, see Figure 4. In this period, there was greater bubble formation on the heated surface with a few bubbles bursting on the water’s free surface as bubbles started to detach from the heating surface of the boiler vessel into the surrounding water.

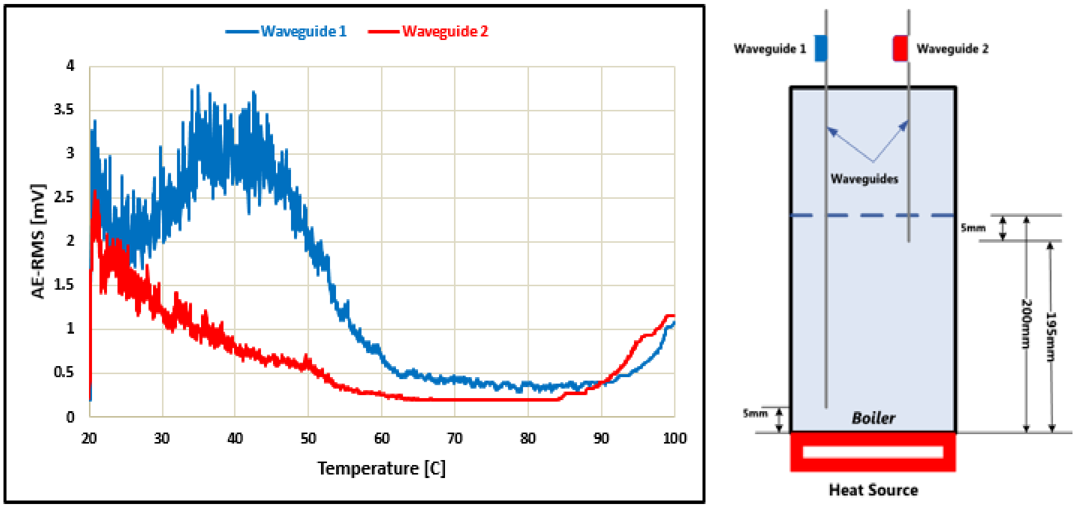

Figure 4: AE-RMS for different waveguide positions using tap water of depth 200 mm and 3 kW supply.

It was noted that the AE signal levels for waveguide 1 gradually decreased to approximately 0.4 mV between 55^0C and 80^0C but picking up slightly when the temperature rose above 95^0C. During this stage, some of the bubbles combined with adjacent bubbles and stuck to the heated surface of the boiler, causing attenuation of AE signals.

As the water approached the boiling phase between 95 and 100^0C, a gradual increase in AE signal levels to around 1 mV for both waveguides was observed, see Figure 4. This increase was attributed the heat gained by the water. Furthermore, this heat caused a significant departure of the bubbles towards the top surface, and finally, large bubbles began to burst on the surface as both their size and internal energy increased. These results again lead to the hypothesis that the AE-signals of bubble formation are higher and more violent than those of bubble burst at the free surface. For temperature 90^0C and above the AE-RMS for Waveguide 1 is greater than for Waveguide 2 due to the bubbles bursting on the free surface.

3.2 Observation of the effect of threshold levels on AE signal levels using tap water

Figure 5 shows that there is a clear link between the number of hits for channel 2 and the level of the water in the container. This is obvious, because with the water level below the level of sensor 2 there is no direct transmission through the water to the sensor. At a threshold level of 36 dB the number of AE-Hits reached 160,000 hits for a water depth of 350 mm (water level above the sensor) compared with about 60,000 when the water level was below the sensor. As would be expected there was a slight increase in number of hits when the water level was increased from 100 mm to 200 mm due to the slight decrease in attenuation in the signal's path. Also, as would be expected, the number of hits decreased with increase in threshold level, as shown in Figure 5.

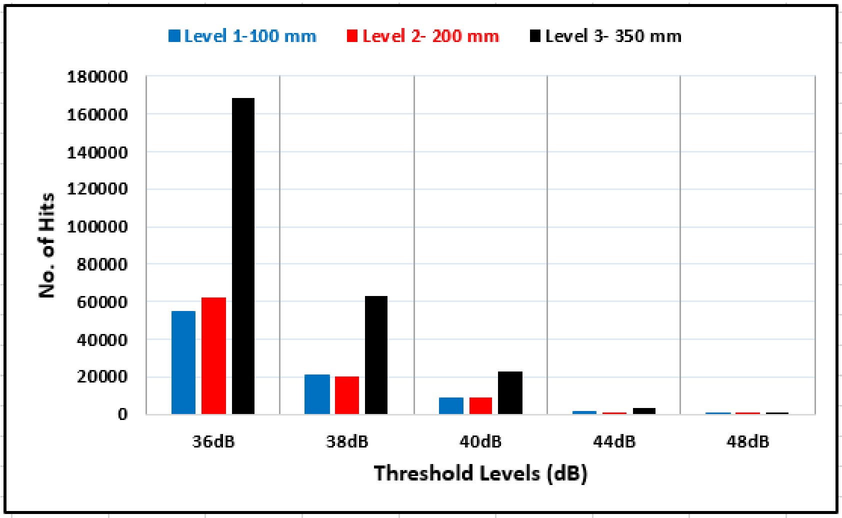

Figure 5: Effect of level of tap water and threshold levels on a number of AE-hits for channel 2.

Conclusions

The study has demonstrated that AE parameters such as energy, RMS, Rise time, and Hits are reliable, robust and sensitive to the detection of bubble activity and its propagation to the top water surface levels during the boiling processes. It is concluded that condition monitoring of bubble formation using AE technology can complement other existing condition monitoring technologies all of which are aimed at reducing energy losses and improving life cycle costs. It was indicated that the presence of bubble formation in boiling processes is detectable with AE technology. Finally, this paper presents the early investigations in the application of the AE technology to monitoring bubble formation in pool boiling under influence of different temperature and future developments will be reported in the soon future.

Recommendations

Investigate the effect of varying molecular weight of the compressor working gas to the anti- surge control systems.

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