The Characterization of Acoustic Cavitation Bubbles by Sonoluminescence, Sonochemistry and Acoustic Emission

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Abstract: Acoustic cavitation process involves the ultrasound-induced growth and collapse of dissolved gas nuclei in liquids [1]. The collapse of the cavitation bubbles generates light emission, radicals and acoustic waves. In a multibubble system, the characterization of the acoustic bubbles is a difficult process due to the complexities involved that arise from bubble-bubble interaction (cluster formation, coalescence, etc.). However, an understanding of the physical characteristics of the acoustic bubbles is important for controlling specific sonochemical reactions. Over the past 10 years, we have developed a number of simple techniques, based on sonoluminescence, sonochemistry, acoustic emission and bubble-bubble coalescence, for characterizing the behaviour of cavitation bubbles in an acoustic field [2].

Acoustic cavitation bubbles are generally classified into two categories: transient and stable (repetitive transient) cavitation bubbles. Using multibubble sonoluminescence as an analytical tool, we have shown the existence of these types of bubbles at different frequencies [3]. In Figure 1, it is shown that multibubble sonoluminescence (MBSL) is quenched at a higher frequency whereas no quenching is observed at 20 kHz. It has been suggested that the cavitation bubbles at higher frequencies undergo hundreds of oscillations prior to collapse leading to the accumulation of water insoluble hydrocarbon products within the bubbles that cushion the collapse of the bubbles and consume the thermal energy generated on collapse. As a result of this, the maximum temperature of the bubble is lowered and hence less light emission is observed. At 20 kHz, the acoustic bubbles oscillate only a few times – during this short lifetime, they do not accumulate gaseous products and hence the SL intensity is not significantly affected.

Acoustic emission spectra, recorded in low and high frequency systems also suggest that the type of cavitation is different at 20 kHz and ~500 kHz [4]. We have studied the effect of a charged surfactant, sodium dodecyl sulfate (SDS), on the characteristics of the acoustic emission spectra at 20 kHz and ~500 kHz. In SDS solutions at ~500 kHz, there is a significant difference in the acoustic spectra around the second harmonic peak at ~1.03 – 1.04 MHz is shown in Figure 2. This is illustrative of the observations for the other harmonic peaks across the whole spectrum. The change in emission in terms of the reduction of broadband "noise" for low concentrations of SDS is readily apparent, as is the return to water like levels as the concentration of SDS is increased.

However, there is no difference between the acoustic emission spectra recorded at 20 kHz in water and SDS solutions. This significant difference in the acoustic emission characteristics between 20 kHz and ~500 kHz in the presence of SDS also supports the view that the cavitation bubbles are of different types at these frequencies.

![Figure 1: Relative MBSL intensity observed at 20 kHz and ~500 kHz in aqueous solutions containing ethanol and butanol [3].](image1)

![Figure 2: The 2nd harmonic region of the acoustic emission spectra observed from aqueous solutions of SDS sonication at ~ 500 kHz with the indicated concentrations [4].](image2)
The direct measurement of the size and size distribution of acoustic cavitation bubbles is difficult to achieve due to the dynamic nature of the system. The bubbles are constantly oscillating and moving around in an acoustic field. Using pulsed sonoluminescence technique, we have measured the size and size distribution of the cavitation bubbles at different frequencies. For example, at ~500 kHz, the bubble sizes in water are in the range 2.8 - 3.7 μm [5]. It has also been observed that the presence of surfactants (e.g., SDS) decreased the size (0.9 - 1.7 μm).

Recently, we have extended this investigation to pulsed sonoluminescence for estimating the size and size distribution of the sonochemically active bubbles [5]. The size distribution results presented in Figures 3 and 4, estimated using pulsed SL and SCL as a function of pulse separation, reveal some interesting aspects of cavitation bubbles. The sonochemically active bubbles seem to have relatively smaller bubble radii with a broader size distribution. The sonoluminescence bubbles seem to have larger bubble radii with a narrow size distribution. What these results indicate is that there are two different bubble populations in a sonication medium. The bubbles located in the areas where the local acoustic pressure is higher can grow to a larger size. On collapse, these bubbles generate relatively higher temperatures required for the light emission to occur. In the regions where the local acoustic pressure is relatively lower, acoustic bubbles grow to a smaller size. However, the temperatures generated within these bubbles may be enough to generate radicals, but insufficient for the emission of light. This observation has a direct implication on the development of sonochemical reactors. The design of large scale sonochemical reactors should take into account of the fact that the acoustic energy should be moderately distributed throughout the reactor to grow the bubbles to a size where they can generate enough temperature for the generation of active radical species.

In summary, a range of analytical tools have been developed for characterising acoustic cavitation bubbles, which could be used to optimise the efficiency of sonochemical reactors.

References:
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