Sonically Induced Growth of Gas Bubbles by Diffusion

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Abstract: Small gas bubbles that might normally dissolve and disappear may instead grow if set into pulsations by an applied sound field. The mechanism involved is a fundamental asymmetry related to the spherical geometry that favors diffusion of gas into the bubble during its expanded state over diffusion out of the bubble during a contracted state. Values of the threshold acoustic pressure for growth were computed by a theory that accounts for spherical bubble dynamics as well as convection terms in the diffusion equation and show general agreement with measured counterparts. Rates of bubble growth for above threshold conditions can be unexpectedly high if non-spherically symmetric acoustic streaming occurs. A closely related phenomenon - the onset of non-spherical bubble vibration - occurs within the same general range of acoustic pressures observed for bubble growth.

BACKGROUND

One of the cavitation issues that interested Hugh Flynn, as well as several other researchers in the late 1950's and early 60's, was whether small gas bubbles that might normally dissolve and disappear could instead grow by a process that was termed "rectified diffusion" when set into pulsation by an applied sound field. The underlying hope, at least for Hugh who was interested primarily in the violent growth and collapse cycles typical of vaporous cavitation, was that such a diffusional growth mechanism could account for growth of subvisible size gas-filled cavitation nuclei until they reached a threshold size for violent expansion. Under Flynn’s encouragement a theory for rectified diffusion growth rates and threshold pressures was devised and was substantiated by later measurement.

THEORY AND MEASUREMENT

The rectification mechanism depends on a fundamental asymmetry in the pulsation cycle related to the spherical geometry that favors diffusion of gas into the bubble during its expanded state over diffusion out of the bubble during a contracted state. Two mechanisms are at work. First, during bubble expansion the area of the bubble is greater than during contraction, thereby causing a gating effect that favors growth. Second, during expansion an imaginary shell around the bubble is stretched thinner, causing a corresponding increase in the dissolved gas concentration gradient, again giving preference to inward diffusion during the expansion phase of the cycle over outward diffusion during contraction. Based on these postulated mechanisms, Eller and Flynn worked out a theory of rectified diffusion that allows one to compute threshold acoustic pressure amplitudes at which growth could begin and subsequent rates of growth for above threshold conditions. Values of the threshold for growth were computed with the help of a theory that describes spherical bubble dynamics as a function of the applied acoustic field, and subsequent measurements of the threshold supported the theoretical work.

NON-SPHERICAL DYNAMICS

Rates of bubble growth for conditions above threshold, however, were at times unexpectedly high, and it was presumed that non-symmetric acoustic streaming had set in and greatly enhanced the transfer rate, beyond what could be attributed to diffusion alone. A closely related phenomenon - the onset of non-spherical bubble motion - was found in a separate set of experiments to occur within the same general range of acoustic pressures observed for bubble growth. Companion theoretical results linked observed bubble shape oscillations to solutions of Hill’s equation for parametric excitation and helped to substantiate the hypothesis that non-spherical motions were likely to be present and responsible for the rapid bubble growth.

REFERENCES