Nonlinear mechanisms of energy dissipation of ultrasonically excited bubbles: Role of thermal and radiation damping and encapsulating shell at various excitation pressures

AJ Sojahrood[1,2,3], H. Haghi [1,2,3], R. Karshafian[3] and M.C. Kolios[1,2,3] ,1-Department of Physics, Ryerson University, Toronto, Ontario, Canada, 2 -Institute for Biomedical Engineering Science and Technology, St. Michael's Hospital, Toronto, Ontario, Canada, 3 -Keenan Research Centre for Biomedical Science, Toronto, Ontario, Canada,

Background, Motivation and Objective

Bubbles attenuate the ultrasound through viscous damping (damping due to shell (dS) and liquid friction dL), radiation damping (dR) and thermal damping (dT). Numerous studies have investigated the mechanisms of damping in bubbly media; using linear approximations neglecting the dependence of the dissipated energy on the local pressure. Additionally, the role of dT is simplified using models that are derived based on linear approximations. Majority of encapsulated bubble models neglect the effect of the compressibility of liquid thus role of dR is not accurately captured. A correct estimation of the wave attenuation in bubbly media requires a realistic estimation of the power dissipated by the nonlinear oscillation of the bubbles.

Statement of Contribution/Methods

A generalized model (GM) for encapsulated bubbles accounting for the effect of compressibility is derived; the model reduces to keller-miksis model when the shell effects are neglected. GM was then coupled with nonlinear ODEs that account for the thermal effects. Starting with mass and momentum conservation equations for a bubbly liquid and using GM, nonlinear pressure dependent terms were derived for dT, dR , dL and dS. The dissipated energies were solved for uncoated and encapsulated 1-20µm bubbles over a frequency range of 0.1fr-3fr (fr is the bubble resonance) and for acoustic pressures of 1kPa-2MPa. Thermal effects were examined for Air and C3F8 gas cores in each case. Scattering to attenuation ratio (STAR), which is a good measure of the effectiveness of bubble applications is calculated and regions of bubble activity enhancements are characterized.

Results/Discussion

Predictions of the linear model significantly deviate from the nonlinear model when pressure increases. For uncoated bubbles with Air gas core dT is the most dominant effect for bubbles bigger than 4 µm. For C3F8 uncoated bubbles dT is suppressed and dL is higher at lower pressures. When pressure increases, dR grows faster and becomes the dominant damping mechanism for pressure dependent resonance freqeuncies (e.g. super harmonic resonances). For encapsulated bubbles enclosing a C3F8 core, dS is the strongest damping mechanism for all pressures; however, as pressure increases dR gets stronger than dL and dT. For f=~2fr-3fr and when subharmonics are generated STAR has the highest value. In case of Air bubbles, linear thermal model largely deviates from the nonlinear model and accurate modeling requires inclusion of the nonlinear thermal model. However, for encapsulated C3F8 bubble with 1-8µm sizes used in medical ultrasound thermal effects maybe neglected even at higher pressures. We showed that STAR is pressure dependent and can be maximized for optimum frequency ranges and pressures. The analysis in this work provide a framework for optimizing bubble related applications by enhancing the STAR.