

Dynamics and vaporization threshold of bubble/droplet system within a nonlinear elastic shell during ADV: a model

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CONTEXT

- ▶ Nanoparticles with a liquid core for medical applications
- ▶ Suitable dimensions for extravasation in tumoral tissues and capillary vessels
- ▶ Vaporization "triggered" by ultrasound
- ▶ Drug delivery, contrast imaging or embolotherapy



OBJECTIVE

To derive a model for optimization of vaporization

HYPOTHESES

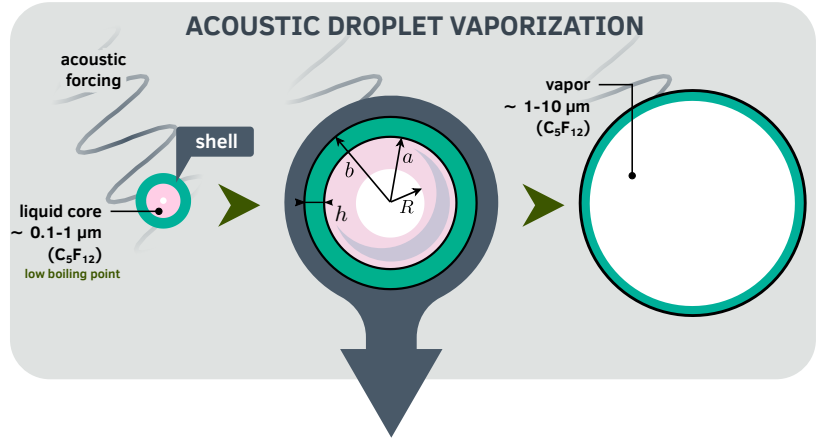
- ▶ Spherical symmetry
- ▶ Incompressibility (liquid and shell)

vapor

- ▶ Perfect fluid and homobaricity
- ▶ Vapor nucleus exists (at initial time)
- ▶ Adiabatic
- ▶ No viscous dissipation

elastic shell

- ▶ Polymeric shell
- ▶ Homogeneous, isotropic
- ▶ Strain-softening material



RADIAL DYNAMICS

$$\bar{\rho} \left(R\dot{U} + \frac{3}{2} MU^2 \right) = p_V - 2\frac{\sigma}{R} - 4\frac{\bar{\eta}}{R} U + J^2 \Delta v - p_0 + P \sin \omega t + S(W)$$

inertial part
vapor pressure
surface tension
apparent viscosity
mass flux at $r=R$
far field forcing
shell

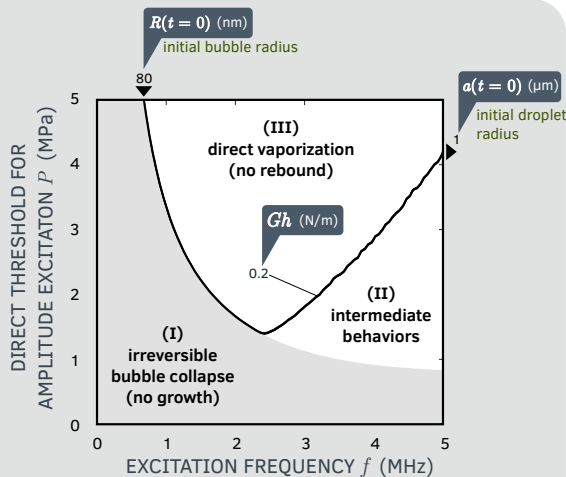
HYPERELASTIC SHELL

$$W = G \left[(1+\beta)(I_1-3) + (1-\beta)(I_2-3) \right]$$

energy
strain invariant
strain invariant

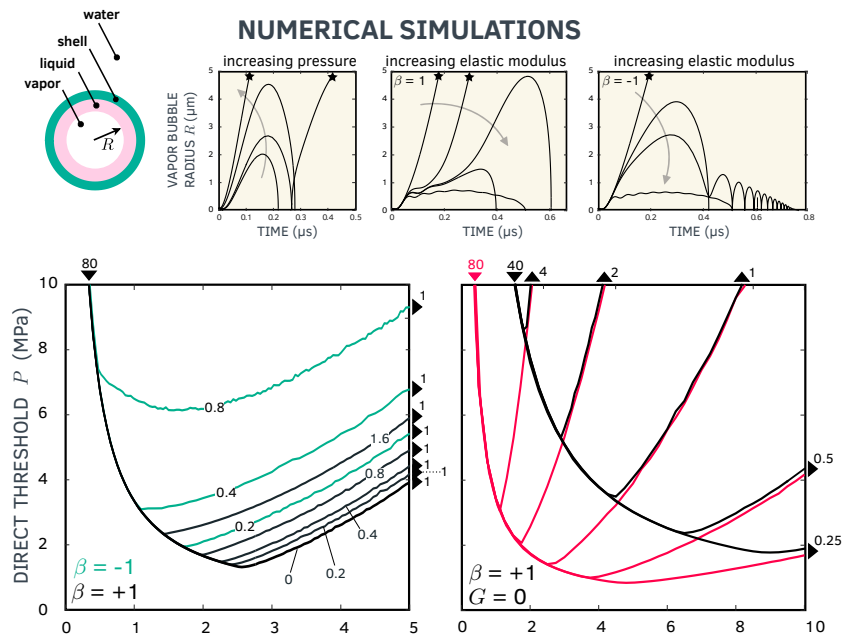
HEAT EQUATIONS and BOUNDARY CONDITIONS

THRESHOLD FOR VAPORIZATION



DIRECT THRESHOLD: minimum acoustic amplitude to completely vaporize (★) the inner liquid core without any rebound.

NUMERICAL SIMULATIONS



THIS MODEL

- ▶ three regimes for bubble dynamics: (I) collapse, (III) direct vaporization and (II) intermediate behaviors
- ▶ direct threshold decreases and then increases with frequency
- ▶ encapsulation stiffness slows down the process and increases the threshold
- ▶ the "direct" threshold depends on **acoustical** (frequency and amplitude), **mechanical** (shell) and **geometrical** (initial radii) parameters

EXPERIMENTAL RESULTS FROM LITERATURE

- ▶ threshold usually decreases with frequency then, rebounds within the regime (II) should be explored
- ▶ increasing is reported but for larger droplets
- ▶ more complex acoustic field (distortion, focusing)
- ▶ coupling with nucleation theory