Modeling Porosity Development during Drying of Liquids and Slurries

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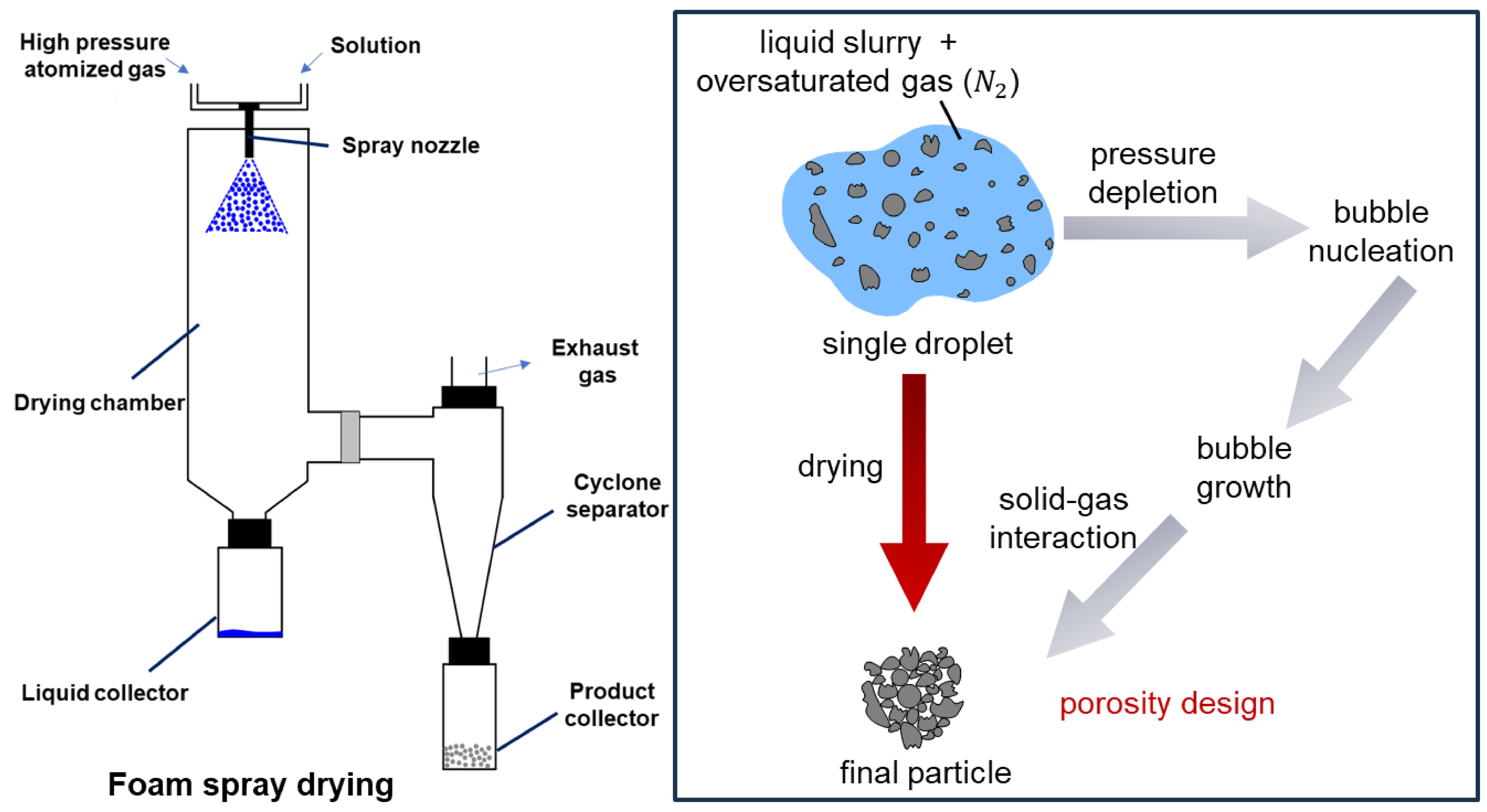
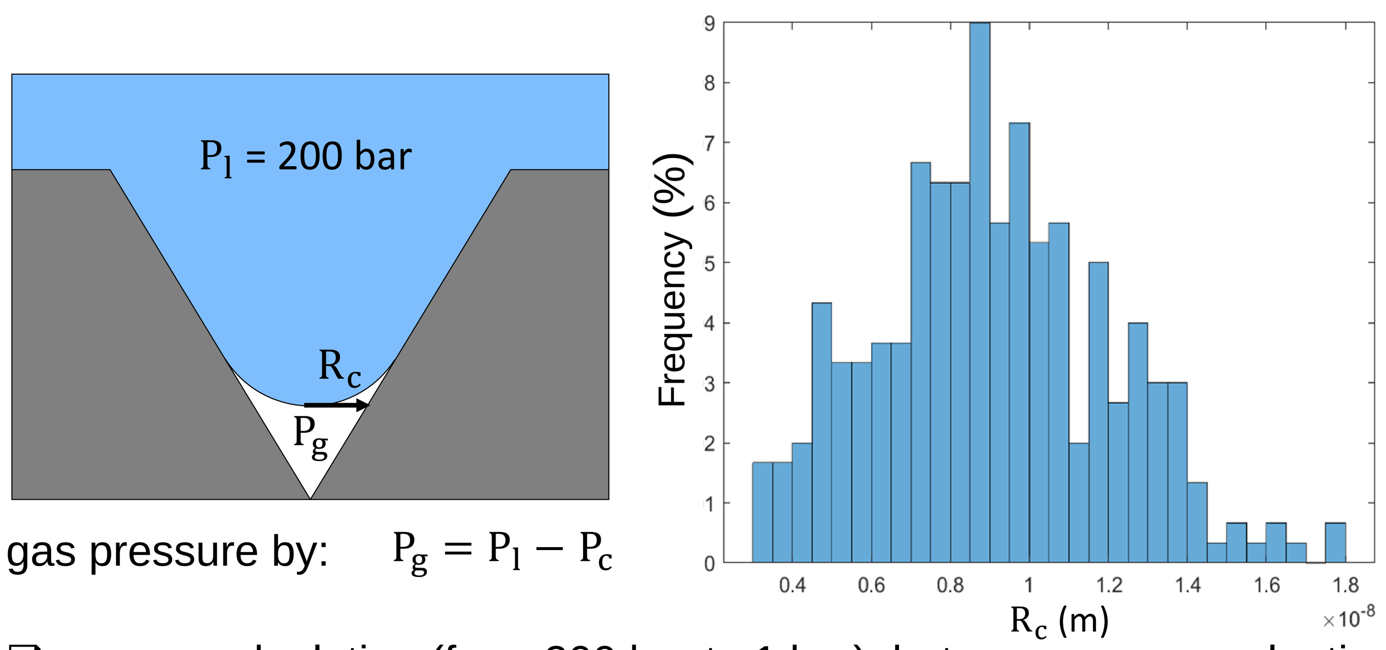
Foam spray drying and single slurry droplet



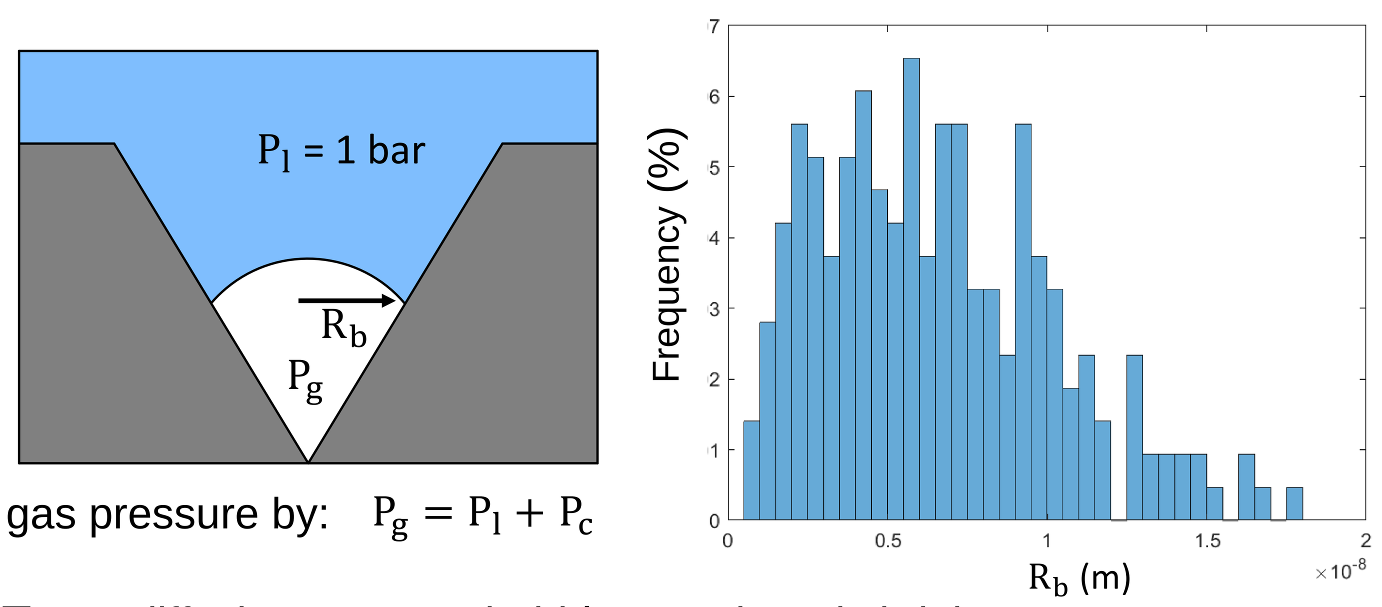
Bubble nucleation and growth algorithm

❑ nucleation sites and their size distribution



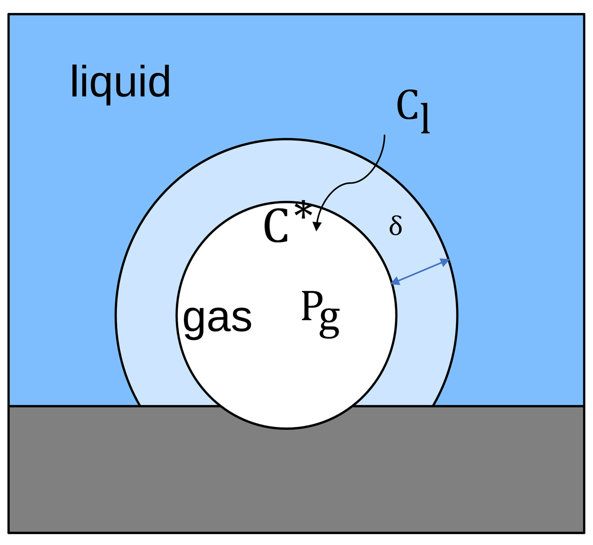
gas pressure by: $P_g = P_l - P_c$

❑ pressure depletion (from 200 bar to 1 bar): heterogeneous nucleation



gas pressure by: $P_g = P_l + P_c$

❑ gas diffusion process: bubble growth and shrinkage



A: surface area of bubble
Sh: Sherwood number
D: diffusivity of gas in liquid bulk
δ: thickness of the gas-liquid boundary layer
C_l: bulk gas concentration
C^*: interface gas concentration
H: Henry's law solubility constant
n: number of gas moles

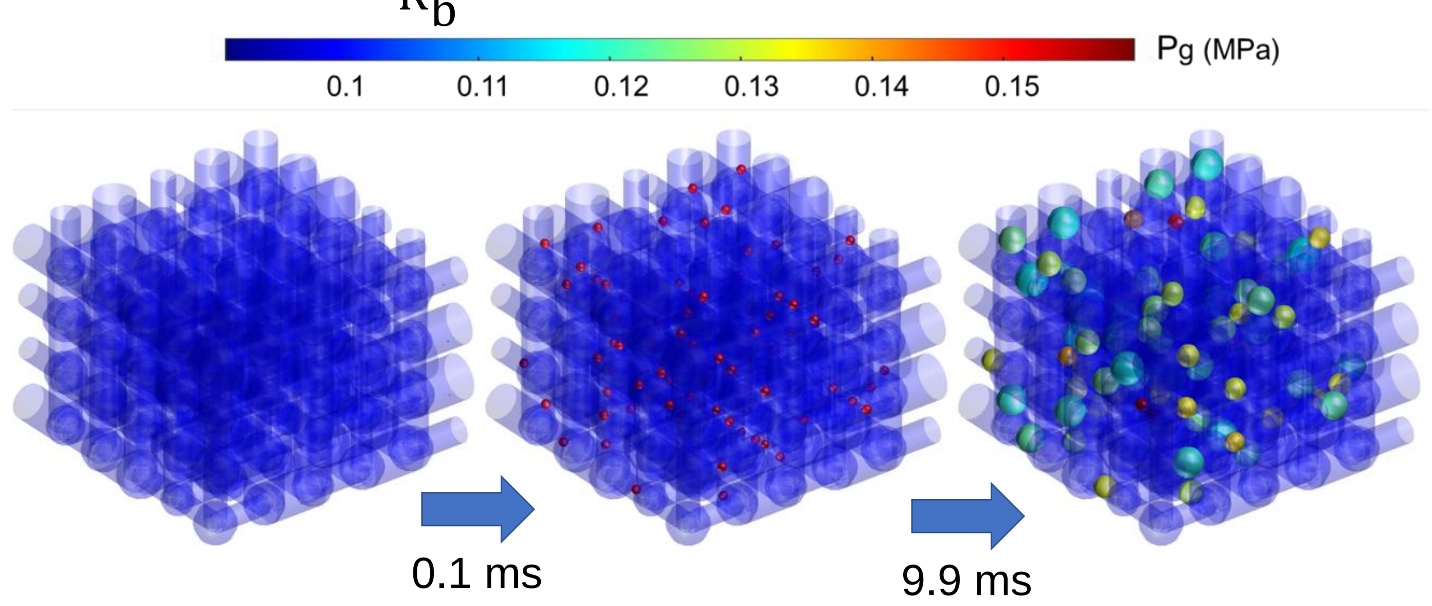
$$\frac{dn}{dt} = \frac{A \cdot D \cdot (C_l - C^*)}{\delta} = \frac{A \cdot sh \cdot D \cdot (C_l - C^*)}{2R_b}, \quad C^* = \frac{P_g}{H}$$

$C^* > C_l$ bubble size decreases

$C^* < C_l$ bubble size increases

Update bubble size/gas concentration

$$P_g V = nRT, \quad P_g = P_l + \frac{2\sigma}{R_b}$$



As liquid pressure drops, bubbles expand with decreasing gas pressure

Acknowledgement

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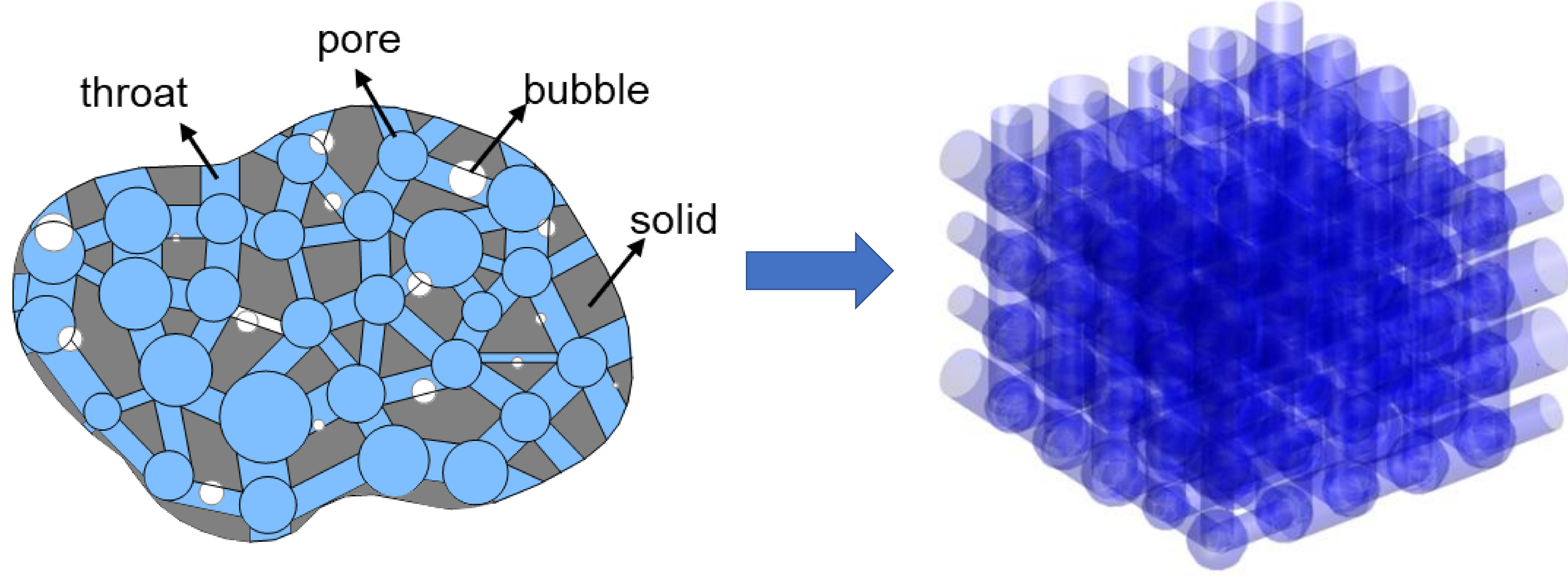
Our aim in the project

Deliver high-resolution single droplet models for foam spray drying to accurately describe micro-scale physical phenomena, including:

- ❑ heterogeneous nucleation and bubble growth
- ❑ capillary action coupled with liquid flow resistance
- ❑ dissolved gas transport, vapor diffusion
- ❑ liquid-to-gas phase change

This systematic method allows for the study of how slurry characteristics and process parameters impact porosity development during the drying of slurries.

Discrete representation of a single slurry droplet

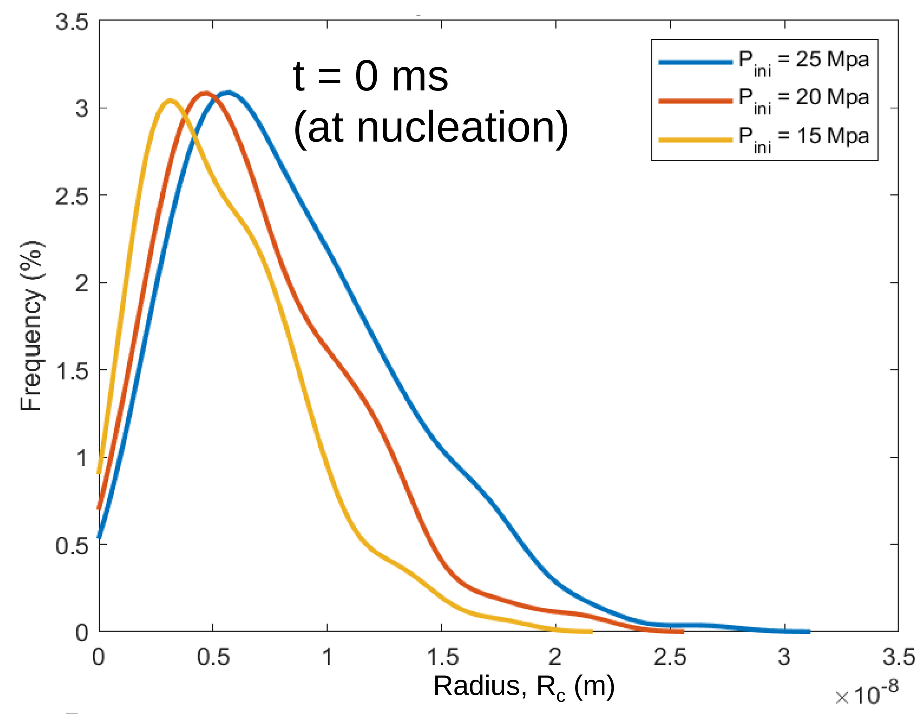


Pore network modeling (PNM):

Simply put, the PNM effectively captures key aspects of real structures, such as pore size distribution, spatial distribution of pores, topology, and internal and external transfer processes.

Influence of initial operating pressure

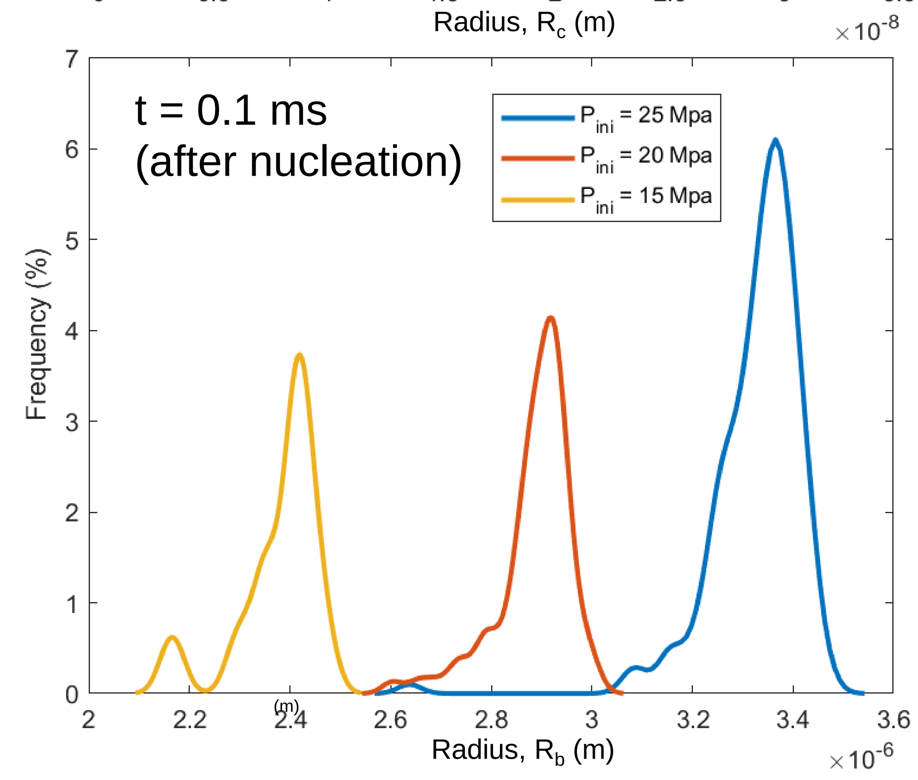
bubble radius distribution at nucleation sites

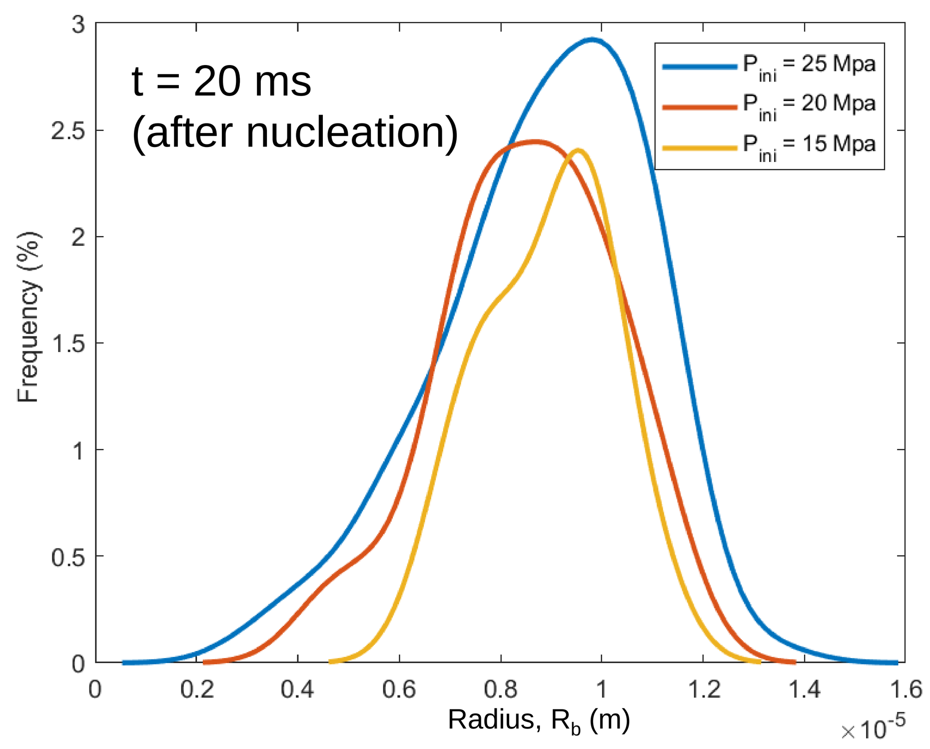


Initial liquid pressure (MPa)	Initial concentration C (mol/m^3)	Ultimate liquid pressure (MPa)	Diffusion coefficient D (m^2/s)
15/20/25	100	0.1	2×10^{-9}

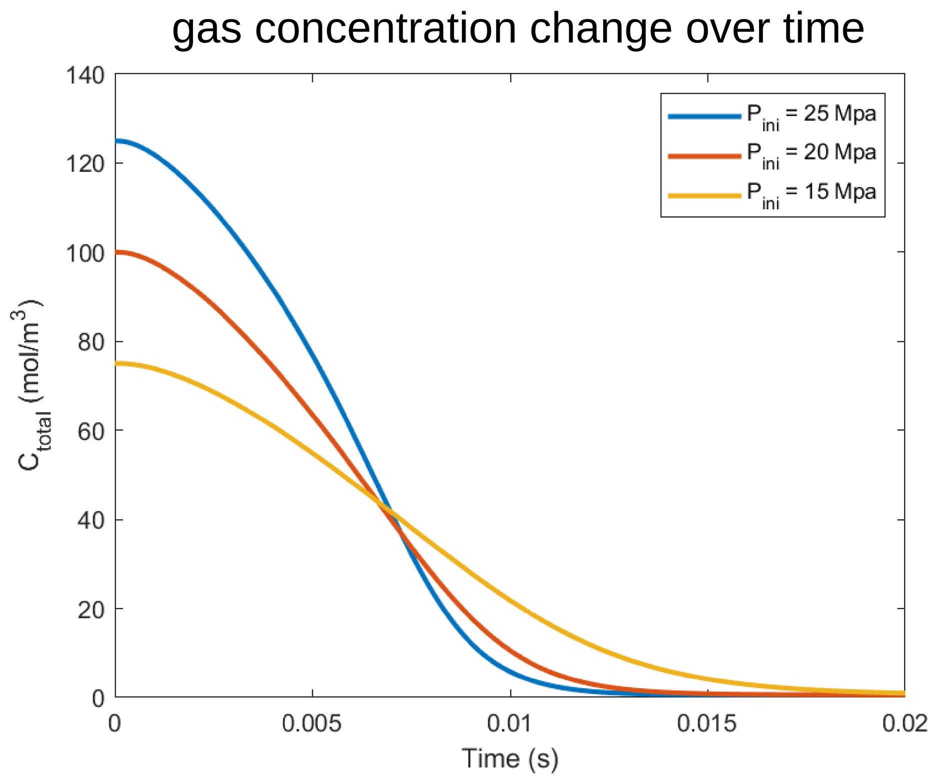
Fraction of activated nucleation sites over the initial nucleation sites

P_{ini}=25 MPa	P_{ini}=20 MPa	P_{ini}=15 MPa
87%	73%	41%

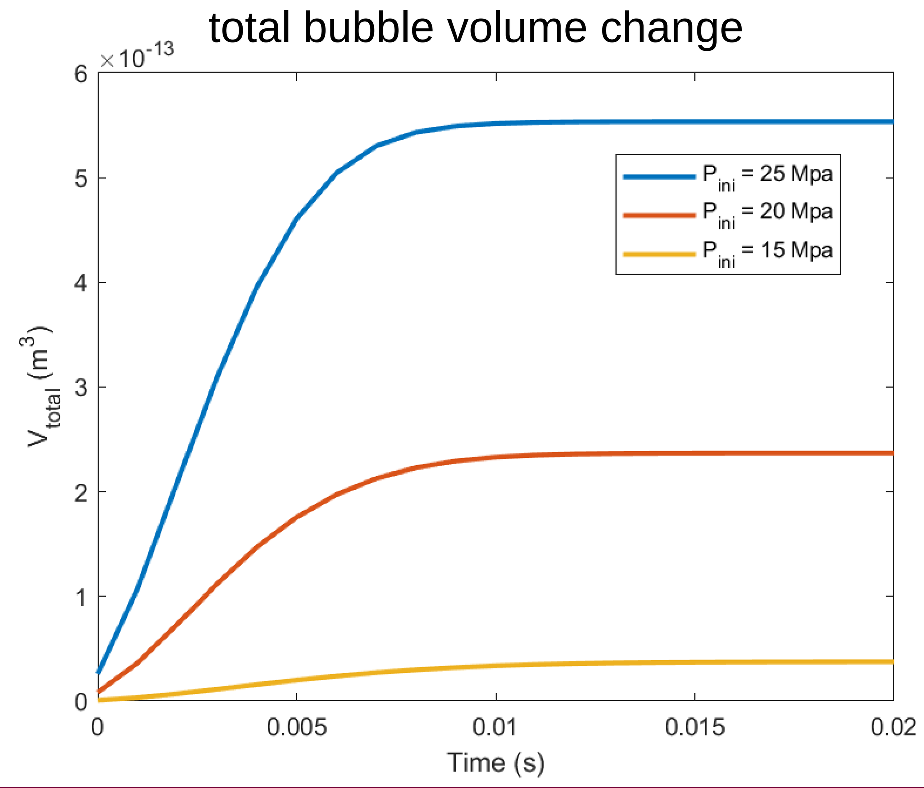




gas concentration change over time



total bubble volume change



Summary

- ❑ A 3D dynamic pore network model (PNM) is developed to simulate the bubble nucleation and growth in a single liquid slurry droplet.
- ❑ Gas bubble formation and evolution are simulated under steady-state conditions.
- ❑ The initial operation pressure affects the nucleation rate and the size change of bubbles.

On-going work

The model will be expanded to include liquid evaporation, the transport of liquid and vapor, and their impacts on gas concentration, as well as liquid redistribution resulting from bubble growth.