Study of polymeric foam growth dynamics using a GPU-accelerated Lattice-Boltzmann model

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1. The current challenge ...

"*Climate Change is the defining issue of our time, and we are at a defining moment.*" United Nation, 2021.

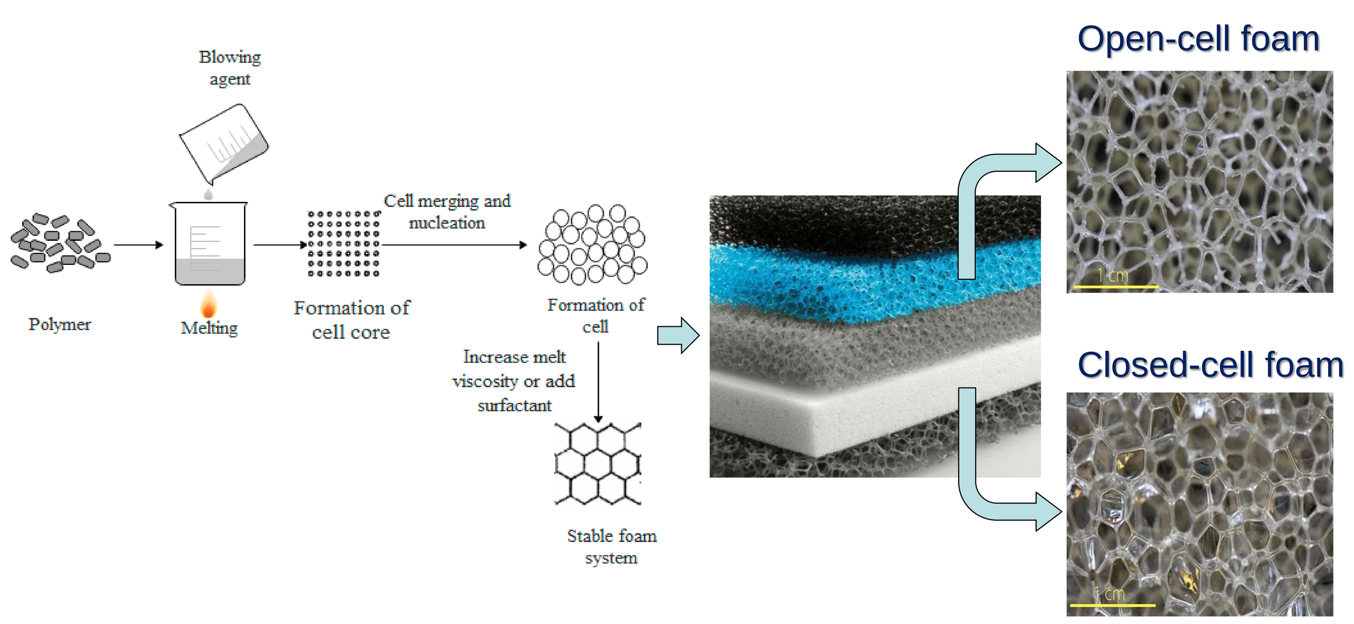
- ❑ **Cause:** human activities such as burning of fossil fuels, deforestation, and agriculture, etc.
- ❑ **Solution:** renewable energy, reducing emissions, conserving biodiversity, and adapting to the impacts of climate change

2. Polymeric foams and their applications

❑ **Polymer foams:** a solid polymer matrix containing a significant number of gas-filled voids, resulting in a low-density structure

✓ The voids can either be interconnected in open-cell foam or completely sealed off in closed-cell foam

✓ Each type, open- or closed-cell, offers unique properties and benefits for various applications



❑ **Applications:**

1. Insulation: thermal and sound insulation materials in buildings and industry for better energy efficiency
2. Packaging: protection for fragile items during shipping and handling
3. Automotive and aeronautic: soundproofing, vibration and energy absorption, and filtration
4. Sports equipment: protective gear, such as helmets, knee pads, and shin guards
5. Medical: wound dressings, orthotics, etc.

3. Objectives

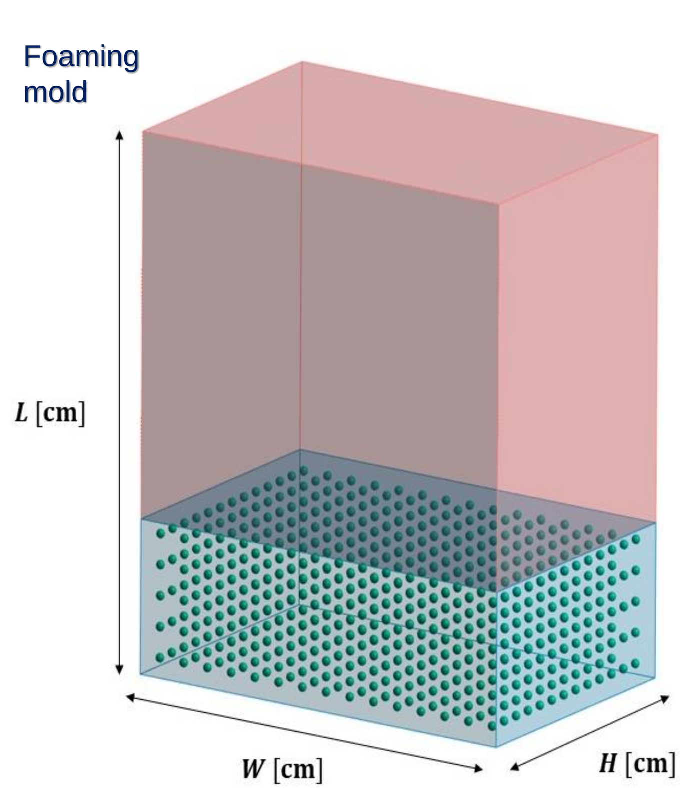
❑ Foam end-use properties can be changed by controlling their structure

✓ **General Objective:** establish relationships between foam properties, processing conditions and final foam structure

✓ **Specific Objectives:**

1. Implement a GPU-accelerated Lattice-Boltzmann algorithm for the numerical study of foam growth
2. Investigate the effects of polymer properties on final foam density and bubble size distribution
3. Study the effects of processing conditions on final foam density and bubble size distribution

4. The governing equations



a) Incompressible fluid flow

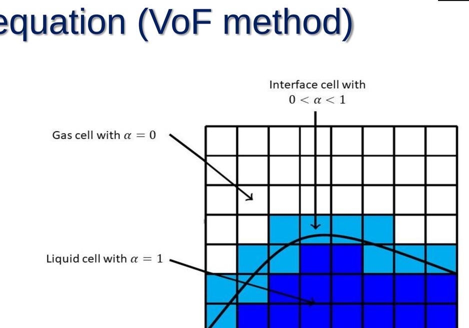
$$\nabla.\mathbf{u} = 0,$$
$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}.\nabla\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\mathbf{u} + \mathbf{g}$$

b) Advection-diffusion equation for the supply gas concentration field

$$\frac{\partial c}{\partial t} + \nabla.(c\mathbf{u}) = \nabla.(\mathcal{D}\nabla c) + q$$

c) Volume fraction advection equation (VoF method)

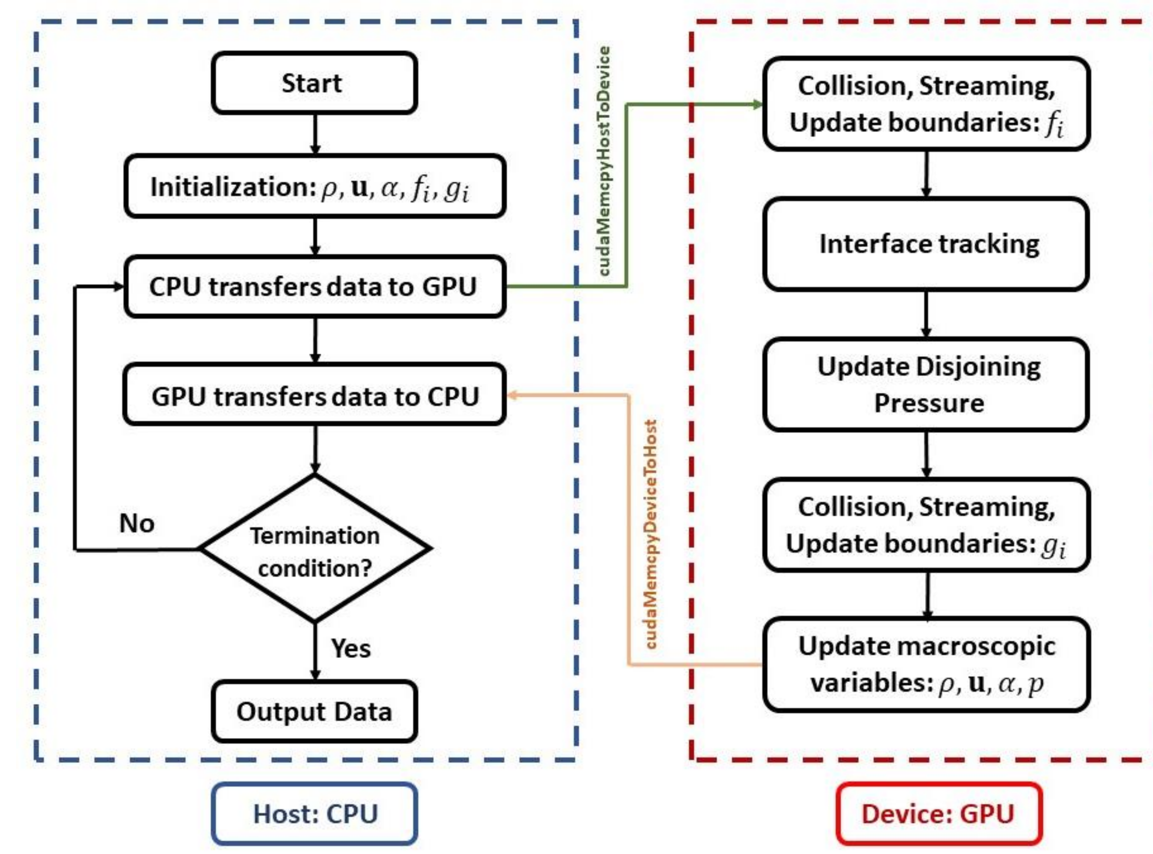
$$\frac{\partial \alpha}{\partial t} + \mathbf{u}.\nabla\alpha = 0, \quad \alpha = \begin{cases} 0 & \forall\, \mathbf{x} \in G \\ 1 & \forall\, \mathbf{x} \in L \\ 0 < \alpha < 1 & \forall\, \mathbf{x} \in I \end{cases}$$



✓ The governing equations are solved using the Free Surface Lattice-Boltzmann Method or FSLBM

5. Numerical method

GPU-accelerated algorithm



The Lattice-Boltzmann Method

Navier-Stokes Equations

$$\nabla.\mathbf{u} = 0,$$
$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}.\nabla\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\mathbf{u} + \mathbf{g}$$

Discretize in space & time using FEM/FDM/FVM

$$A\mathbf{u} = b \text{ or } \mathbf{u}^{t+\Delta t} = f(\mathbf{u}^t)$$

$$\mathbf{u}(\mathbf{x}, t)$$

Boltzmann Equation

$$\partial_t f + \mathbf{e}.\nabla f = -\frac{f - f^{eq}}{\tau}$$

Discretize in velocity space

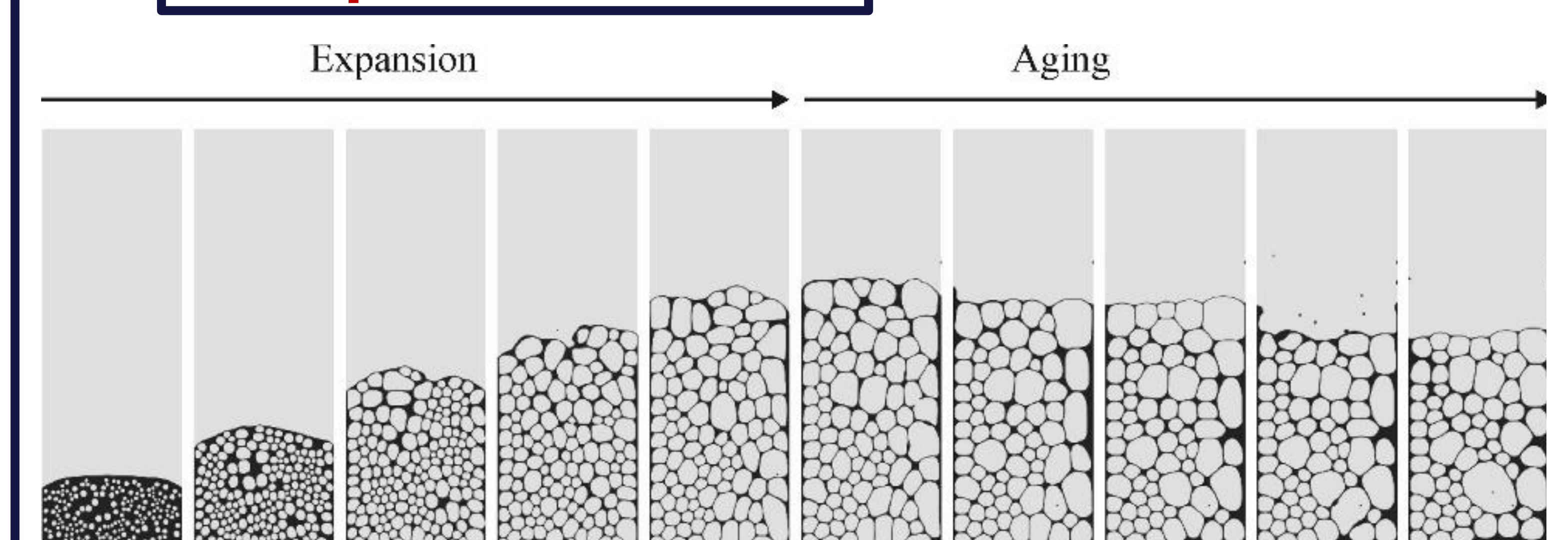
$$\partial_t f_i + \mathbf{e}_i \partial_i f_i = -\frac{f_i - f_i^{eq}}{\tau}$$

Discretize in time & space by FDM

$$f_i(\mathbf{x} + \mathbf{e}_i\Delta t, t + \Delta t) - f_i(\mathbf{x}, t) = -\frac{f_i(\mathbf{x}, t) - f_i^{eq}(\mathbf{x}, t)}{\bar{\tau}}$$

$$\mathbf{u} = \frac{1}{\rho}\sum_i f_i \mathbf{e}_i$$

6. Expected Results



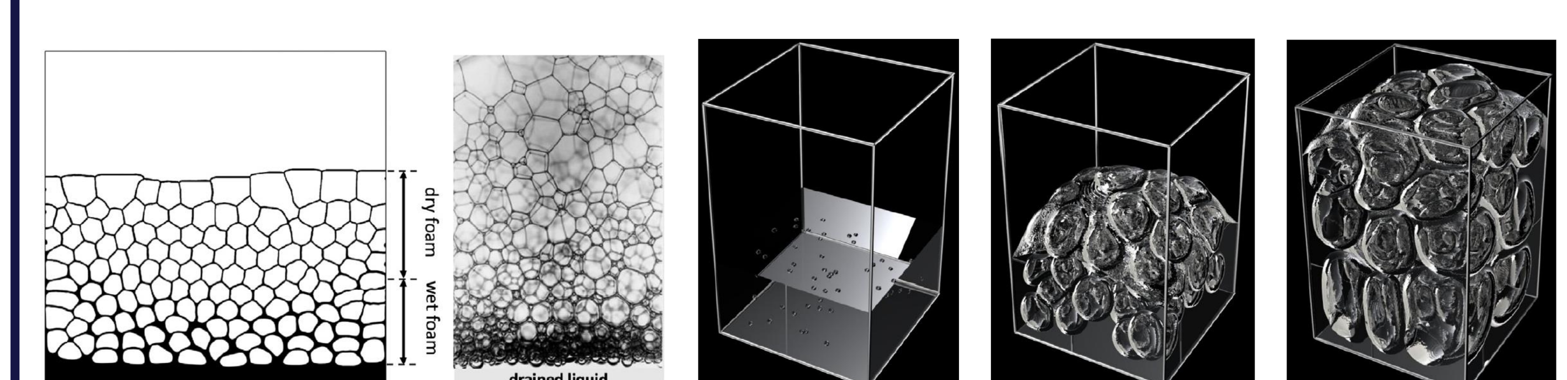
Koerner et al. [1]: Numerical simulation of metal foam evolution using FSLBM

➢ Predicting foam growth dynamics:

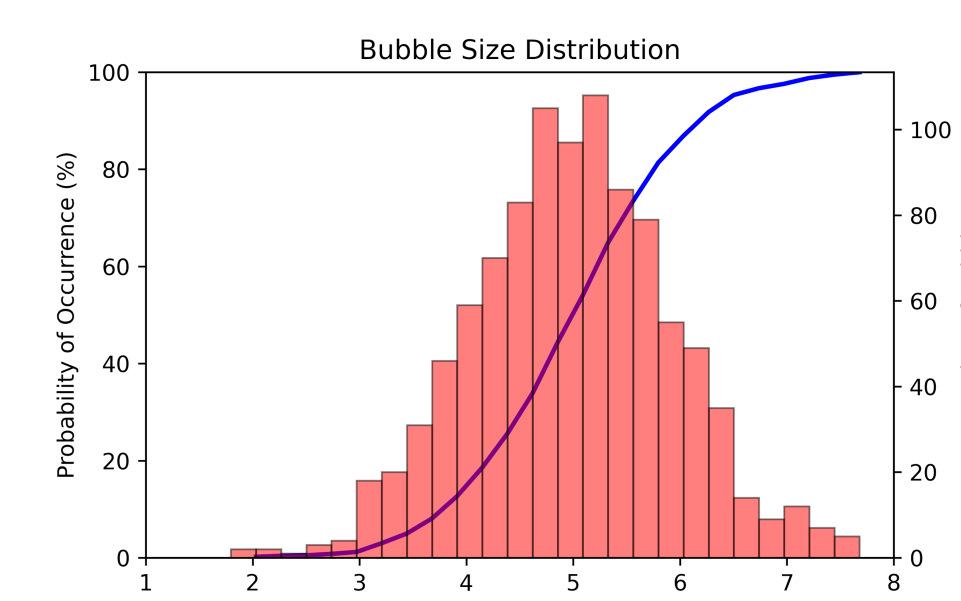
✓ Final foam structure

✓ Final bulk density

✓ Bubble size distribution



Ataei et al. [2]: An open-source software package for the simulation of foaming using FSLBM



Bubble size distribution for an arbitrary bubble size data

ACKNOWLEDGMENTS

CRSNG NSERC · compute • calcul CANADA · Calcul Québec

NOMENCLATURE

$\mathbf{u}$:	velocity	$\mathbf{g}$:	gravity	α:	volume fraction
p:	pressure	c:	gas concentration	G:	gas phase
t:	time	$\mathcal{D}$:	gas diffusion coefficient	L:	liquid phase
ρ:	melt density	q:	constant or reaction source term	I:	interface
ν:	melt kinematic viscosity	f:	population distribution function		

References

[1] Koerner, C., *Lattice Boltzmann Model for Foam Evolution*, in *Integral Foam Molding of Light Metals: Technology, Foam Physics and Foam Simulation*, C. Koerner, Editor. 2008, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 171-183.

[2] Ataei, M., et al., *LBfoam: An open-source software package for the simulation of foaming using the Lattice Boltzmann Method.* Computer Physics Communications, 2021. **259**: p. 107698.