Though the Yeasty Waves Confound

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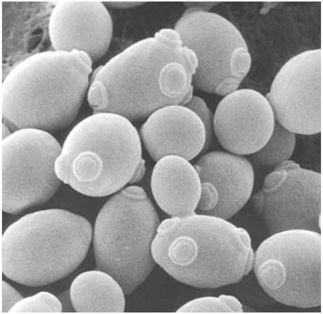
University of South Australia

Australian Government
Australian Research Council

Yeasts

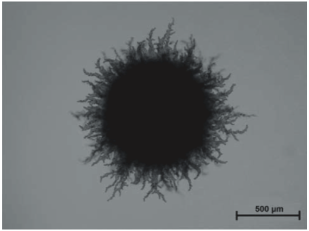
- Single-cell fungal micro-organisms ($\sim 10^{-6}$ m).
- Model organism in cell biology research.
- Used in food and drink production.
  - e.g. Wine, $\sim$ \$5 billion per year in Australia.
- Cause infections, growing antimicrobial resistance.
  - e.g. Systemic candidiasis, $\sim 250,000$ cases per year worldwide, 30–50% mortality rate.



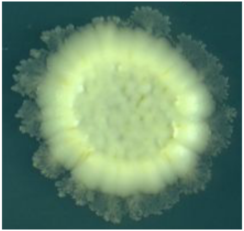
Yeast Colonies

- Collective growth key to understanding yeast impacts.
- Same yeast species can exhibit very different growth.

$\sim$1 mm



$\sim$7 mm



$\sim$90 mm

- ASKE Yeast Research Group investigates all forms of yeast colony growth.
- **A**delaide/South Australia, **S**outhampton, **K**ent, **E**ssex.

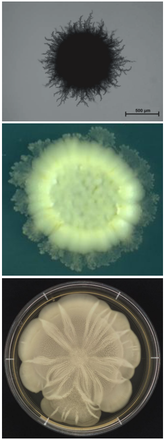
ASKE Yeast Research Group

MACBETH

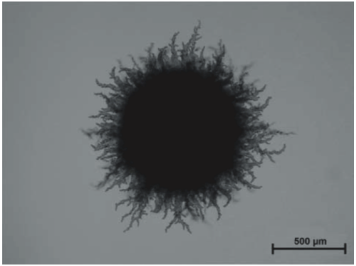
I conjure you by that which you profess
(Howe'er you come to know it), answer me.
Though you untie the winds and let them fight
Against the churches, though the yeasty waves
Confound and swallow navigation up,
Though bladed corn be lodged and trees blown down,

ASKE YEAST GROUP

Weïrd Sisters



ASKE Yeast Research Group



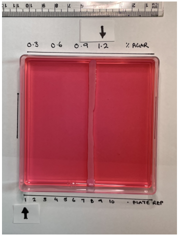
- Off-lattice agent-based model.
- Unipolar vs. bipolar budding.
- Invasive growth.
- Quorum sensing.
- Hyphal growth.

- Nutrient-limited growth.
- Mechanics: thin-film modelling.
- Cell death.
- Biofilm/agar elasticity.
- Agar concentration, vertical growth.

Preliminary Rectangular Experiments

- Sliding motility depends on agar density.
    - Expansion speed, interface shape, height profile.

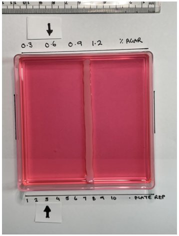
Hard agar (1.2%)



Day 3

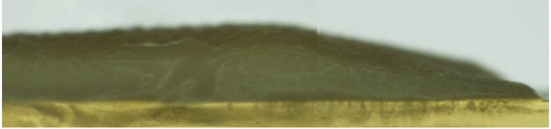
Day 19

Soft agar (0.6%)



Day 3

Day 19



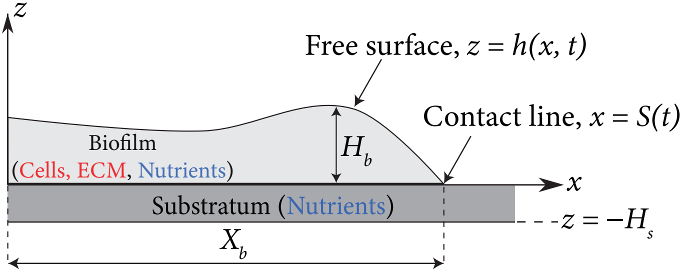
Zoomed cross-section: biofilm on soft (0.3%) agar

Two-Phase (Viscous) Fluid Model

- Non-motile cells in self-produced extracellular matrix (ECM).

Model cells and ECM as viscous fluids with similar properties.

- $\phi_n(x, z, t)$: Cell volume fraction.
- $\phi_m(x, z, t)$: ECM volume fraction.
- $g_s(x, z, t)$: Nutrient concentration (solid substratum).
- $g_b(x, z, t)$: Nutrient concentration (biofilm).
- $\boldsymbol{u}(x, z, t) = (u, v, w)$: Fluid velocity (same for both phases).



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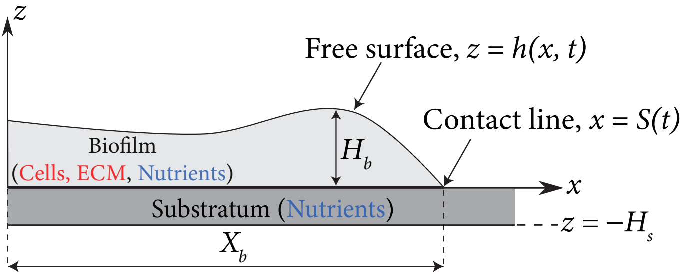
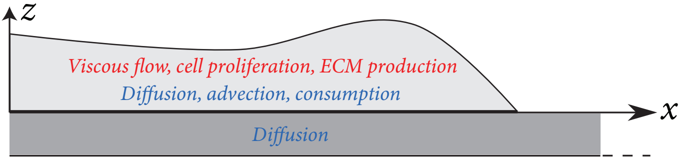
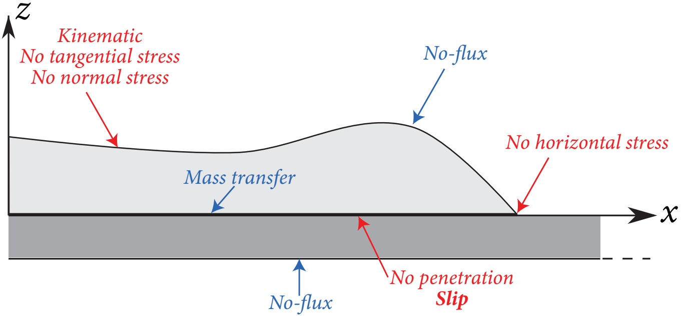


- Mass and momentum balance for fluids (cells/ECM).
- Mass balance for nutrients in substratum and biofilm.



Boundary Conditions

Boundary conditions (fluids and nutrients)



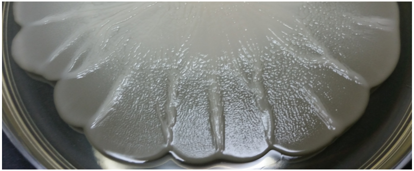
Tangential stress (slip) condition on substratum–biofilm interface:

$$\widehat{\boldsymbol{t}} \cdot (\boldsymbol{\sigma} \cdot \widehat{\boldsymbol{n}}) = \lambda \left(\boldsymbol{u} \cdot \widehat{\boldsymbol{t}}\right) \implies \mu \frac{\partial u}{\partial z} = \lambda u \quad \text{on} \quad z = 0.$$

- λ: Adhesion strength (slip parameter).
  - $\lambda = 0$: Perfect slip (no tangential stress, weak adhesion).
  - $\lambda \to \infty$: No slip (strong adhesion).

Thin-Film Model

- Exploit slender biofilm aspect ratio, $\varepsilon = H_b/X_b \ll 1$.
- Nondimensionalise and expand variables in powers of ε^2.



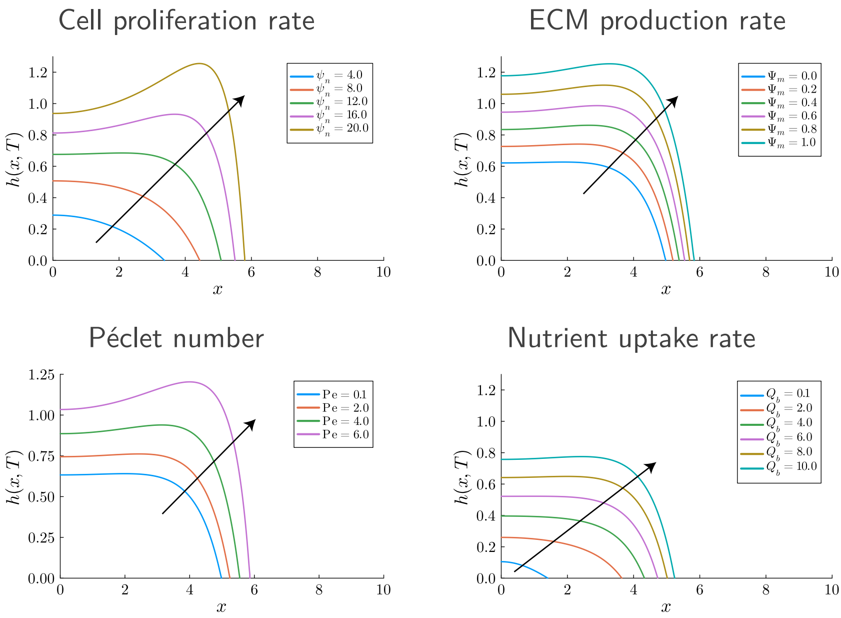
- Extensional flow regime: 1D moving-boundary problem.
  - 5 coupled PDEs for $h(x,t)$, $\phi_n(x,t)$, $g_s(x,t)$, $g_b(x,t)$, $u(x,t)$.
- Seven important dimensionless parameters:

$$\Psi_m = \frac{\psi_m}{\psi_n}, \quad D = \frac{D_s}{G\psi_n X_b^2}, \quad Q_s = \frac{X_b Q}{\varepsilon D_s},$$

$$Q_b = \frac{X_b Q}{\varepsilon D_b}, \quad \mathrm{Pe} = \frac{\psi_n X_b^2 G}{D_b}, \quad \Upsilon = \frac{\eta X_b}{D_b}, \quad \lambda^* = \frac{\lambda X_b}{\varepsilon \mu}.$$

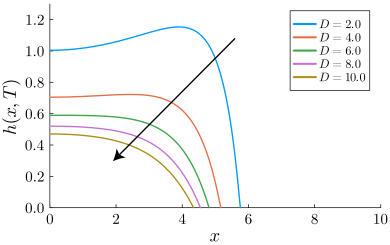
- Solve numerically until t reaches fixed time, $T = 10$.
- Vary one parameter at a time from a default value.

Parameters Promoting Expansion and Vertical Growth

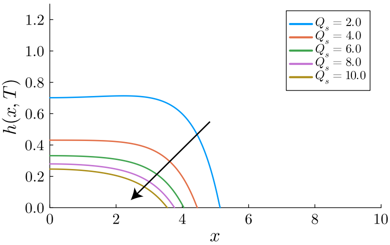


Parameters Inhibiting Expansion and Vertical Growth

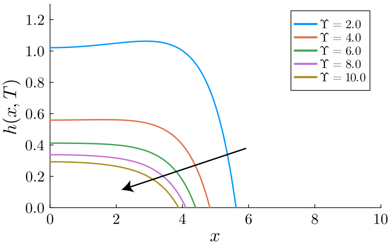
Nutrient diffusivity



Nutrient depletion rate

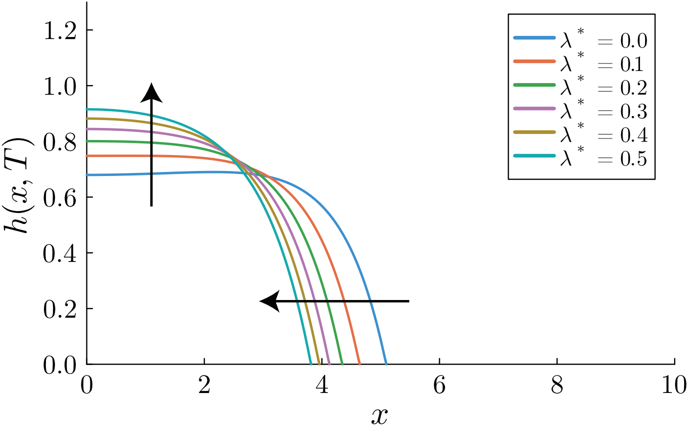


Amount of nutrient required to proliferate



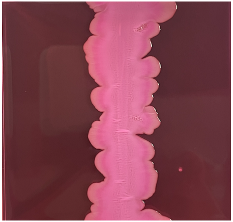
Effect of Adhesion Strength

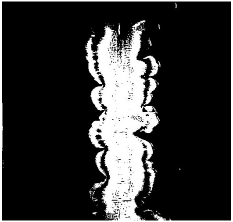
- Increasing λ^* (Stronger adhesion, harder agar):
  - Slower horizontal expansion.
  - More vertical growth.



Ongoing Work

- Detailed comparison: 1D model and rectangular experiments.
  - Expansion speed.
  - Biofilm profile.
- Interface pattern formation.
  - Linear stability analysis (simplified model).
  - 2D numerical solutions.
- Model extensions:
  - Biofilm elasticity: predict wrinkling.
  - Cell death.





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PhD Position

I have a **PhD scholarship** available related to an ARC Discovery Project.

- Mathematical modelling and computation of biofilm growth and cell death.
  - Agent-based modelling.
  - PDE models (reaction–diffusion, thin-film, viscous flow).
  - Scientific computing and numerics.
- Please chat if you know someone who might be interested!

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  - Jennie Gardner, Ee Lin Tek, Jo Sundstrom, Jin Zhang, Campbell Gourlay, Vlad Jiranek.
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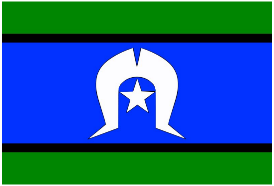

Full Model (Thin-Film Equations)

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) = (1 + \Psi_m)\,\phi g_b h,$$

$$\frac{\partial \phi_n}{\partial t} + \frac{\partial}{\partial x}(u\phi_n) = \phi_n\left[g_b - \Psi_d - (1 + \Psi_m) g_b \phi_n\right],$$

$$\frac{\partial g_s}{\partial t} = D\frac{\partial^2 g_s}{\partial x^2} - DQ_s\,(g_s - g_b)\,H\left[x - S(t)\right],$$

$$\mathrm{Pe}h\frac{\partial g_b}{\partial t} + \mathrm{Pe}\frac{\partial}{\partial x}(uhg_b) = \frac{\partial}{\partial x}\left(h\frac{\partial g_b}{\partial x}\right) + Q_b\,(g_s - g_b) - \Upsilon \phi g_b h,$$

$$4\frac{\partial}{\partial x}\left(h\frac{\partial u}{\partial x}\right) = 2\,(1 + \Psi_m)\,\frac{\partial}{\partial x}(\phi_n g_b h) + \lambda^* u - \gamma^* h\frac{\partial^3 h}{\partial x^3},$$

$$\frac{\mathrm{d}S}{\mathrm{d}t} = u(S(t), t).$$

Effect of Surface Tension