Pattern Formation and Rate of Growth in *Escherichia Coli*

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ABSTRACT

This research aims to observe and mathematically model the radial and spiral stream formation of *Escherichia Coli* colonies. The mathematical model is based on a recent study of the colony formation of *Proteus mirabilis*, a similar species of bacteria. In our research we aim to model the rate of growth, and pattern formation of *Escherichia Coli* to compare with the properties observed in *Proteus mirabilis*. In order to observe the pattern formation and rate of growth we will vary the concentration of an additive. This family of bacteria grows as biofilms and commonly occurs on urinary catheters, leading to infection. Understanding the mathematical model for the radial and spiral stream formation of these bacteria will help us to further understand biofilm formation.

OBJECTIVES

To obtain a better understanding of how bacteria grows by studying the spiral pattern formation and rate of growth of Escherichia Coli, and comparing it to the mathematical model showing the pattern formation in a similar species, Proteus mirabilis.

METHODS

1. Obtain semi-solid agar, E-coli and additive.
2. On the first petri dish, add only E-coli (no additive) this will act as our control.
3. The next two petri dishes will have both E-coli, and a varying concentration of the specified additive.
4. Check for rate and shape periodically throughout the day (every 2 hours), and take a photo showing the growth and shape of bacteria from exactly the same distance each time. Continue up to 12 hours.
5. Using Matlab software, analyze rate of growth and shape of bacteria.
6. Compare results to literature.

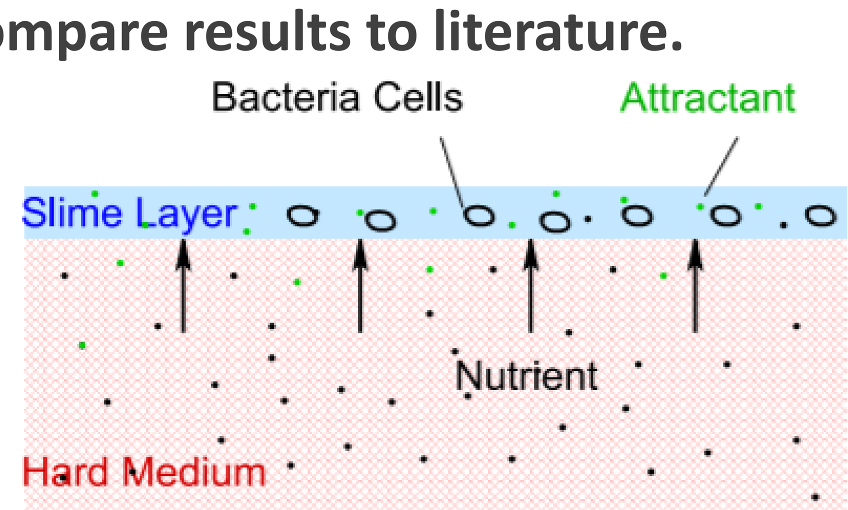

Figure 1. A section view of the medium. (Xue, C., Budrene, E. O., & Othmer, H. G. , 2011)

Figure 2. Proteus mirabilis experimental result. (Xue, C., Budrene, E. O., & Othmer, H. G. , 2011)

RESULTS OF PROTEUS MIRABILIS

- After inoculation, on a hard nutrient rich agar surface, the colony front expands initially as a disc of uniform density.
- For the first 5-7 hours, swarmer cells (adherent) migrate out of the inoculation site, the slime layer gradually builds up and swarmer's de-differentiate into swimmer cells behind the leading edge.
- We observe that swimmer cells in the colony stream inward, forming complex patterns.
- A characteristic feature observed is that the spirals always wind CCW when viewed from above.

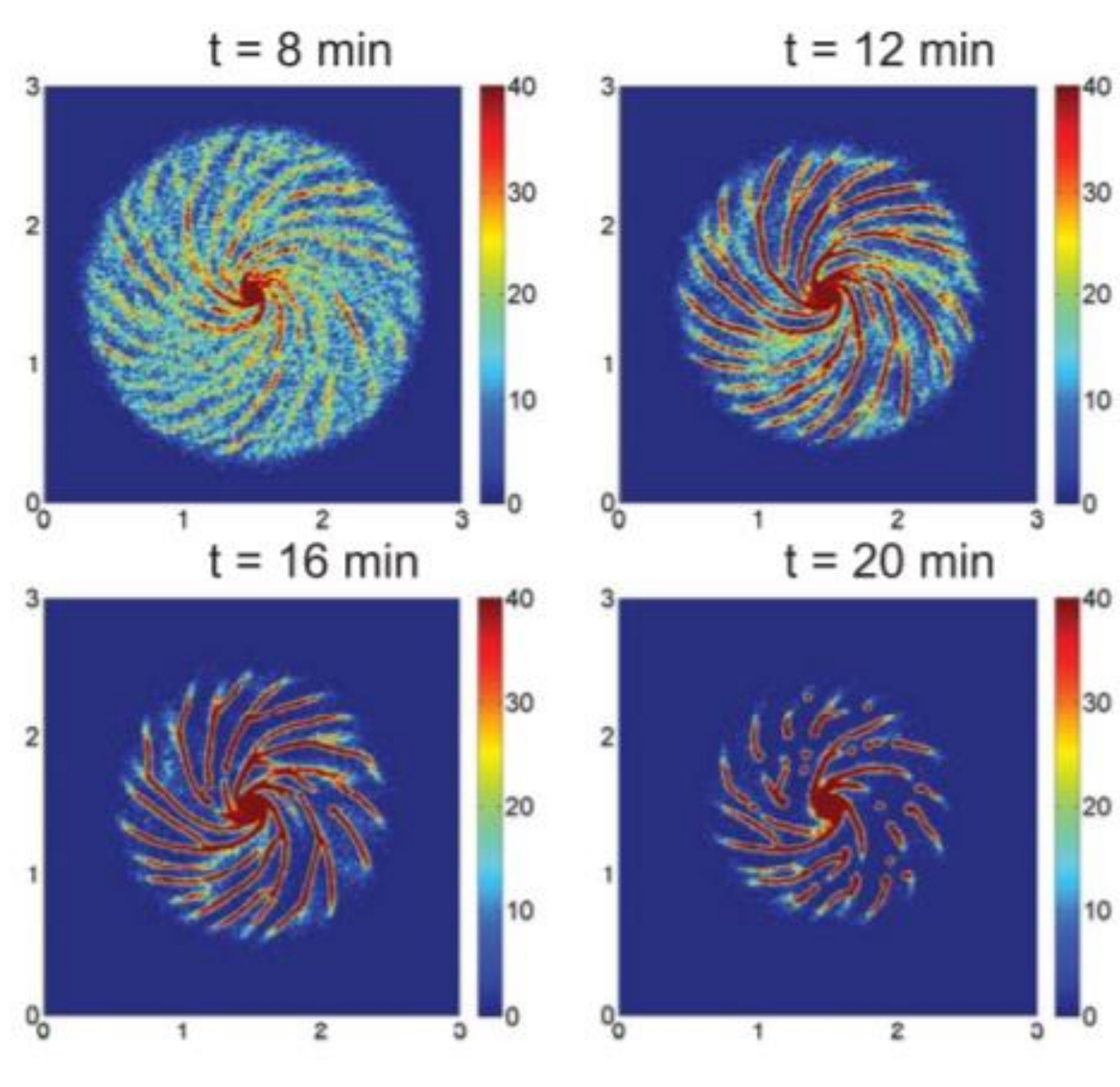

Figure 3. Using a mathematical model to create simulated radial spirals. (Xue, C., Budrene, E. O., & Othmer, H. G. , 2011)

$$T_{gc}\left(x_1^i, x_2^i\right) = \frac{A_4}{A} S_{n-1,m-1} + \frac{A_3}{A} S_{n,m-1} + \frac{A_2}{A} S_{n-1,m} + \frac{A_1}{A} S_{n,m} \quad \text{(Eq.1)}$$

$$\frac{S_{p,q}^{l-\frac{1}{2}} - S_{p,q}^{l-1}}{\frac{k}{2}} = D_S \cdot \frac{S_{p+1,q}^{l-\frac{1}{2}} - 2S_{p,q}^{l-\frac{1}{2}} + S_{p-1,q}^{l-\frac{1}{2}}}{h_x^2} + D_S \cdot \frac{S_{p,q+1}^{l-1} - 2S_{p,q}^{l-1} + S_{p,q-1}^{l-1}}{h_x^2} - \gamma \frac{S_{p,q}^{l-1} + S_{p,q}^{l-\frac{1}{2}}}{2} + f_{p,q}^{l-\frac{1}{2}}$$

$$\frac{S_{p,q}^{l} - S_{p,q}^{l-\frac{1}{2}}}{\frac{k}{2}} = D_S \cdot \frac{S_{p+1,q}^{l-\frac{1}{2}} - 2S_{p,q}^{l-\frac{1}{2}} + S_{p-1,q}^{l-\frac{1}{2}}}{h_x^2} + D_S \cdot \frac{S_{p,q+1}^{l} - 2S_{p,q}^{l} + S_{p,q-1}^{l}}{h_x^2} - \gamma \frac{S_{p,q}^{l-\frac{1}{2}} + S_{p,q}^{l}}{2} + f_{p,q}^{l-\frac{1}{2}} \quad \text{(Eq.2)}$$

Figure 4. Mathematical model of *Proteus mirabilis*. (Xue, C., Budrene, E. O., & Othmer, H. G. , 2011)

Mathematical Model: (fig. 4)

- Position: (x_1^i, x_2^i)
- Internal Variables: (y_1^i, y_2^i)
- Direction of Movement: θ^i
- Age: : T^i
- Time step: *k*
- Grid sizes: h_1, h_2
- Concentration before cell moves: $(S^i)_{l-1}$
- Concentration after cell moves: $(S^i)_l$

FUTURE WORK

Currently we are in the process of growing e-coli in vitro on a semi-solid agar. We are working on studying how an additive can affect the radial and spiral streams of growing bio-film. Assuming that cells secrete and respond to a chemoattractant we can provide an explanation of the radial and spiral streams using a hybrid cell-based model.

References

Xue, C., Budrene, E. O., & Othmer, H. G. (2011). Radial and Spiral Stream Formation in Proteus mirabilis Colonies. *PLoS Computational Biology, 7*(12). doi:10.1371/journal.pcbi.1002332

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