Getting to the Root of Bacterial Hair

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Abstract

Many bacteria use their extracellular polymers to attach to surfaces
- Leads to industrial biofouling, medical device infections
- Physicochemical and physiomechanical properties of these polymers may be deduced from AFM force curves
- For these data to be useful, it is necessary to define a zero of separation and to understand what that zero represents
- Previous researchers have defined the point of zero separation as the cell wall, and assumed the constant compliance region of the force curve to be representative of that location
- The force at the cell wall has been used to calculate the equilibrium length of the brush, as well as the grafting density of the polymers at the point of zero separation

Here, we show:
- I. That the constant compliance region frequently occurs in the middle of the layers
- II. How the layer thickness may be more accurately quantified
- III. A quantitative method of establishing the position of the “roots of the hairs” at the cell wall
- IV. The more appropriate use of mesh density of the polymer brush, in lieu of the polymer grafting density

Experimental System

- AFM approach curves show no attractive minima
- Interactions are dominated by steric compression of the polymer brush
- Presents significant difficulty in assigning a coordinate system

System Schematic

- On approach, the probe passes through several phases:
  - Zero Interaction – Deflection is dominated by instrument noise
  - Polymer Interaction – Deflection is dominated by compression of the polymer brush
  - Constant Compliance – Deflection is equal to PZT displacement
  - Tip “Rolling” – Under high load, deflection is due to in-plane forces
- Plotting data series in semilogarithmic coordinates amplifies these phases

Derivation of the Model

- From de Gennes’ expression for the energy per unit volume, we may integrate across the surface of the probe to determine the force as a function of tip-sample separation

\[ F(h) = 100 k T \int_{\varepsilon_1}^{\varepsilon_2} \exp \left[ -\frac{2 \pi n}{\varepsilon_1} \right] d\varepsilon \]

- The zero of separation will be defined according to the intersection of the function previously derived with the noise level of the instrument

Removal of Noise Artifacts

- Applying the noise filter defined above, we see that a periodic interference pattern provides a significant signal at large separations

Model Application and Results

- The more appropriate use of the mesh density of the polymer brush, in lieu of the polymer grafting density

Discussion and Conclusions

- Model parameters derived from the experimental data are consistent with data obtained from empirical methods
- Polymer lengths and populations have been measured using TEM cryo-sectioning techniques
- In all cases, the point of zero separation rests within the constant compliance region, and often beyond the point at which the photodiode becomes saturated
- Indicates that the polymer brush is compressible to a finite degree, but that the surface of the cell can never be reached
- Further, since the diode is saturated at force values of >20 nN, that the forces exerted by the polymer brush are larger than those previously reported

References


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