A Thermodynamic Approach to Engineering Antifouling Surfaces

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Statement of Purpose: Unintended colonization of biomaterial surfaces remains one of the most significant problems in our world today. The accumulation of biological material on a surface is pervasive in every aspect of our lives. Fouling by bacteria continues to plague our health care system. Nosocomial infections are the single largest contributor to patient time in hospitals [1, 2]. Our severe limitations of potable water have lead to the development of desalination and water treatment plants which are limited in performance by fouling issues [4,5]. In the marine industry by which over 80% of all goods are transported, biofouling reduces fuel efficiency, speed, operational readiness for navies and increases the transportation of invasive species [6,7]. Yet, after thousands of years research and development, we do not have a fundamental relationship between biofouling and surface properties. It is absolutely essential that we develop models that relate the observed attachment behavior of biological organisms with the physics and chemistry of the surfaces to which they attach. Ideally, this model would be insensitive to the systems biology, and would instead focus on the surface aspects that the engineer can control. This presentation will describe for the first time a thermodynamics-based method for predicting microbe-biomaterial interactions, and demonstrate the method's effectiveness at predicting attachment of both human pathogens and marine fouling organisms.

Methods: Our model was developed using the Boltzmann distribution for particle energy states to describe the probability for cell attachment to a microtopography:

$$\ln\left(\frac{N_t * g_s}{N_s * g_t}\right) = -n * \left(\frac{\Delta A_{ts}}{A_s}\right)$$

The resultant energy function is based on a simple wetting analogy and was simplified to a relative area term which can be easily applied to existing literature data as well as future designs. The predicted values for fouling density for two bacteria species, *Staphylococcus epidermidis* and *Staphylococcus aureus*, as well as two algae species, *Ulva linza* and *Navicula incerta*, were calculated using the model, and compared to experimental results either available in literature or generated through new experimentation. Additionally, a Monte Carlo simulation was performed for *Ulva linza* on topographies with unique attachment points within the unit cell and compared to analogous maps of experimental data.

Results: The model showed excellent correlation to experimental data ($R^2 = 0.88$) . Both organisms were able to be placed on the same plot (Figure 1) with a slope of

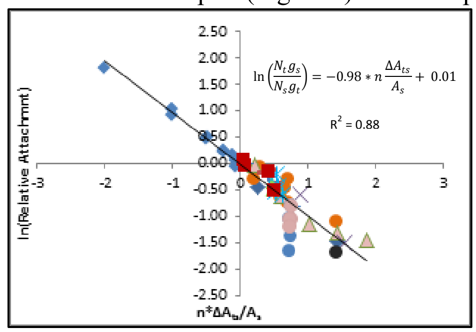

Figure 1. Comparison of attachment density data of bacteria and algal species to proposed model

nearly 1 as predicted by the model. Additionally, the Monte Carlo simulation supported the model predictions. The model predicts a slightly less distinct distribution between states than is seen in experiment

Conclusions: We have demonstrated a new method for predicting the antifouling behavior of a series of microtopographies for multiple fouling organisms. This model borrows methods from statistical mechanics, in which the probability of attachment was related to the relative attachment energy at a given site. The attachment energy for different topographies was estimated in a simple way by relating it to the attachment area. The relative attachment area was also shown to be a good predictor of both total attachment density for topographies with well-defined areas for four disparate organisms. Interestingly, both bacteria and algal species follow the same relationship with attachment area, indicating that this model may applied to a wide variety of biomaterial applications, including implant design and antifouling coating technologies. We believe that this approach offers the opportunity to develop antimicrobial strategies that are nontoxic, more environmentally neutral, and more stable in a biological environment.

References

[1] Nery, P. J Cardiovasc Electrophysiol. 2010; 21: 786-790

[2] Wald H. J Am Med Assoc. 2007; 298: 2782-2784

[3] Callow J. Nat Com. 2011; 244

[4] Schultz M. Biofouling. 2010; 27: 87-98

[5] Dudley L. Desalination.1998; 118: 81-89

[6] Liao B. Wat Environ Res. 2004;76: 425-436