Survey of basics: biology, chemistry, and physics of biofilms.

(1) W.G. Characklis, K.C. Marshall, Eds., *Biofilms*, John Wiley & Sons, Inc., New York (1990).

This is an anthology of contributed chapters introducing, from an engineering point-of-view, many aspects of biofilms to a general audience. Such books aren't always entirely successful; however this one consistently hits the mark. Further, though more than 20 years old, it is still very relevant though some of the biology is out of date (microbiology has radically transformed over the past two decades).

(2a) W.B. Whitman, D.C. Coleman, W.J. Wiebe, Prokaryotes: the unseen majority, *Proc. Natl. Acad. Sci. USA* **95**, 6578-6583 (1998).

(2b) A. Konopka, Microbial ecology: searching for principles, *Microbe* **1**, 175-179 (2006).

(2c) J.A. Fuhrman, Microbial community structure and its functional implications, *Nature* **459**, 193-199 (2009).

Microbiology is in the midst of a technology bonanza. Molecular analysis methods are becoming more accessible and more powerful by the day. These reviews discuss the new vistas and challenges facing microbial ecologists and, implicitly, the need for mathematical models.

(3) R.E. Ley, D.A. Peterson, J.I. Gordon, Ecological and evolutionary forces shaping microbial diversity in the human intestine, *Cell* **124**, 837-848 (2006).

Description of an example (and important) microbial ecosystem: note the investigative power of molecular methods.

(4) T.C. Zhang, Y.C. Fu, P.L. Bishop, Competition in biofilms, *Wat. Sci. Tech.* **29**, 263-270 (1994).

Pioneering study of biofilm spatial structure, comparing model predictions to reality, using the relatively new (at the time) microprobe technology. Microprobes continue to be important in characterizing spatial variation of the chemical environment within biofilms. The combination of molecular and microprobe technology has revolutionized the field of microbiology over the last two decades

Survey of basics: modeling of biofilms.

(1) W.G. Characklis, Fouling biofilm development: a process analysis. *Biotech. Bioeng.* **23**, 1923-1960 (1981).

An (again) remarkably forward-looking presentation of basic biofilm modeling issues in the context of biofouling *(accumulation of undesirable microbes and their attendant effects, e.g. biocorrosion).*

(2a) O. Wanner, W. Gujer. Competition in biofilms, *Wat. Sci. Tech.* **17**, 27-44 (1984).

(2b) O. Wanner, W. Gujer. A multispecies biofilm model. *Biotech. Bioeng.* **28**, 314–328 (1986).

(2c) O. Wanner, P. Riechert. Mathematical modeling of mixed-culture biofilm. *Biotech. Bioeng.* **49**, 172–184 (1996).

A series of influential papers exploring 1D biofilm models from an engineering point of view. (Much of the work to date on biofilm modeling has been done by engineers particularly in the context of water treatment.)

(3a) J.D. Dockery and I. Klapper. Finger formation in biofilms, *SIAM J. Appl. Math* **62**, 853-869 (2002).

(3b) E. Alpkvist and I. Klapper. A multidimensional multispecies continuum model for heterogenous biofilm. *Bull. Math. Biol.* **69**, 765-789 (2007)

Two papers extending 1D models to 2D and 3D and exploring structural and ecological consequences.

(4a) N.G. Cogan, J.P. Keener, Channel formation in gels, *SIAM J. Appl. Math.* **65**, 1839-1854 (2005).

(4b) I.Klapper, J.Dockery Role of Cohesion in Material Description of Biofilms, *Phys. Rev. E* **74**, 031902 (2006)

(4c) E. Alpkvist, I.Klapper, Description of Mechanical Response Including Detachment Using a Novel Particle Method of Biofilm/Flow Interaction, *Wat. Sci. Tech.* **55**, 265-273 (2007)

(4d) T. Zhang, N. Cogan, Q. Wang, Phase-field models for biofilms II. 2-D numerical simulations of biofilm-flow interactions, *Comm. Comput. Phys.* **4** 72-101(2008).

Biofilms acclimate and tune themselves to their environment. As a result, local physical and

chemical conditions couple closely to biofilm processes. Here are several papers discussing aspects of modeling biofilm material physics in the context of mechanical interaction with the local hydrodynamics. This is an area of active interest!

(5) I.Klapper, J. Dockery, Mathematical Description of Microbial Biofilms, *SIAM Review* **52**, 221-265 (2010).

A relatively recent (though already somewhat out-of-date in places!) review of the modeling issues listed above plus a bunch more.