Surface Modification Approach to Control Biofouling

T. Vladkova

Abstract There are three principal approaches to control biofouling: (1) mechanical detachment of biofoulers if possible; (2) killing or inactivation of biofouling organisms using antibiotics, biocides, cleaning chemicals, etc. and (3) surface modification turning the substrate material into a low-fouling or non-sticking (non-adhesive) one. Such modification usually alters the surface chemical composition and morphology, surface topography and roughness, the hydrophilic/hydrophobic balance, as well as the surface energy and polarity.

In marine applications especially, current non-toxic biofouling control strategies are based mainly on the third approach, i.e., on the idea of creating low-fouling or non-adhesive material surfaces, an approach that includes development of strongly hydrophilic "water-like" bioinert materials. Strongly hydrophobic low-energy surfaces are preferable in industrial and marine biofouling control because of their relative stability in aqueous media and reduced interactions with living cells.

This chapter presents a brief overview of some possibilities for biofouling control by surface engineering. A number of related ideas will be discussed in this chapter, including: (1) the use of protein adsorption as a mediator of bioadhesion and biofouling, (2) physicochemical parameters influencing these phenomena, (3) theoretical aspects of cell/surface interactions, (4) some popular surface modification techniques, and (5) examples of successful biofouling control approaches.

1 Introduction

Biofouling may be defined as any non-desirable accumulation and growth of living matter on material surfaces (see Pasmore 2008). It is a worldwide problem affecting a multitude of industrial water-based processes, including pulp and paper manufacturing,

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T. Vladkova
Department of Polymer Engineering, University for Chemical Technology and Metallurgy, 8 "Kliment Ohridsky" Blvd. 1756, Sofia, Bulgaria
e-mail: tgv@uctm.edu

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food processing and packaging, cooling towers, biomaterials production, membrane technologies, underwater constructions and sensors, ship hulls, fishing farms, heat exchangers, and water desalination systems. The cumulative cost of biofouling due to lost production and only partially successful remedial efforts may run into billions of dollars per year worldwide, which explains the outstanding interest in the development of effective and economical control measures.

There are three principal approaches to solving the biofouling problem: (1) mechanical detachment of biofouling organisms and/or adsorbed biomolecules (i.e., biofoulers and biofoulants, respectively), (2) inactivating or killing the biofilm using antibiotics, biocides, cleaning chemicals, etc., and (3) surface modification with the aim of turning the substrate material into a low- or non-sticking (i.e., non-adhesive) one. Such modification usually alters the surface chemical composition and morphology, surface topography and roughness, the hydrophilic/hydrophobic balance, and the surface energy and polarity. The most effective antifouling coatings available today contain toxic biocides and will therefore be banned by the year 2008 (Brady 2003).

Current non-toxic biofouling control is based mainly on the third approach, i.e., on creation of low-fouling or non-adhesive material surfaces, an approach first applied to the development of bioinert materials where strongly hydrophilic "water-like" surfaces appear more promising. Strongly hydrophobic low-energy surfaces are preferable in industrial and marine biofouling control settings because of their stability in aqueous media and reduced interactions with living cells (Abarzua and Jacubowski 1995).

Biofouling is perceived as a multistage process starting with a "conditioning film" (biofilm) formation in which the adhesion of microfoulers (i.e., bacteria, diatoms, algae, etc.) to the surface is an important step. The industrial and marine biofouling usually continues with settlement of soft and hard macrofoulers such as algae, barnacles, mussels, tubeworms, etc. In principle, it should be possible to prevent or at least reduce biofilm formation by creating material surfaces to which bacteria cannot initially attach. In practice, synthetic materials that are capable of preventing bacterial adsorption are still rather elusive, despite a significant volume of research (Callow and Fletcher 1994).

Surface modification approaches leading to the creation of low-energy, low-adhesive, non-sticking surfaces is accepted nowadays as the most promising ecology-friendly alternative to the use of toxic biocides.

2 Biofouling and Bioadhesion

Upon submersion in a non-sterile aqueous liquid, most surfaces become rapidly colonized by bacteria and other microorganisms. These attached cells and extracellular polymeric substances (EPS), along with extracellular material (e.g., extracellular biopolymers) constitute a biofilm (Costerton et al. 1987). Biofilm frequently forms even on antifouling surfaces containing biocides. According to Brusscher et al. (1995), initial (reversible) bacterial adhesion to a surface is the primary determinant