5 Biodegradation of surfactants
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5.1 Introduction

5.1.1 Background

The purpose of this chapter is to outline the principles and pathways involved in the biodegradation of synthetic surfactants. Biodegradation may be defined concisely as a biologically catalysed reduction in complexity of chemicals.\(^1\) Although higher organisms metabolize surfactants,\(^2,3\) we are concerned here with biodegradation by microorganisms, of which the most versatile and important contributors to surfactant biodegradation are the bacteria.

Restricted availability of animal fats for soap making during the 1914–18 and 1939–45 World Wars led to the production of alternative synthetic surfactants based on petrochemical feedstocks. Subsequent diversification within the synthetic surfactant industry spawned a range of surfactants with properties suitable for the more varied applications evident in the accompanying chapters. The growth in the use of synthetic surfactants in detergent formulations faltered in the 1960s when significant pollution episodes became apparent.\(^4,5\) Investigations in Europe and the USA enabled the detergent industry to trace the cause of the resistance of some surfactants, especially highly branched alkylbenzene sulphonates, to biodegradation by bacteria. This period saw the beginning of much work on the biodegradation of surfactants which continues to this day, so that synthetic surfactants are probably the most thoroughly studied group of compounds in terms of their biodegradability by bacteria. Necessarily, therefore, this account can only attempt to distil an essence of the extensive literature that exists on biodegradation of surfactants. More detailed accounts and compilations of data can be found in Cain,\(^6,7\) Karsa and Porter,\(^8\) Swisher,\(^5\) White and Russell\(^9,10\) and White.\(^11\)

What we know about surfactant biodegradation is largely a reflection of the environmental pollution background against which the work has developed. Thus most work has focused on the biodegradation of spent/waste surfactants in relatively dilute solution (e.g. effluent streams, river water) using environmental isolates from activated sewage sludge, river water and sediments, or soils. Moreover, the perspective usually taken has
been that of seeking to achieve maximum biodegradation (extent and rates) in order to minimize environmental impact. In contrast, in the present context we are concerned not so much with the biodegradation of spent or waste surfactant formulations (ultimately desirable though that may be), but rather with minimizing the undesirable biodeterioration of surfactants before they have served their intended purpose. Unfortunately, there are very few published studies on the microbial processes and mechanisms involved in the biodeterioration of surfactants in formulations, so our metabolic and mechanistic knowledge must, at least for now, be based on studies of the biodegradation process in microbes in the environmental context.

5.1.2 Surfactants and bacterial nutrition

To provide a framework in which to describe the how and why of surfactant degradation in microbes, we need first to appreciate some aspects of environmental microbiology.

Although there is an anthropocentric distinction between the desirable biodegradation of waste surfactant and the undesirable spoilage of surfactant formulations, from a microbial perspective the difference all but vanishes because in both situations opportunistic microorganisms are exploiting potential sources of nutrition. Microbes do not collude to spoil our formulations, any more than they are altruistic in clearing up our waste! Bacterial life is characterized by periods of rapid growth of the population by cell division when nutrients are plentiful, interspersed with periods of starvation. Successful proliferation of bacteria means that nutrients are depleted rapidly so that for much of the time bacteria exist in low nutrient conditions. Consequently microorganisms have evolved several adaptations to survive such widespread privation. A central requirement for the survival of microbial cells is that they must be able to generate a minimum metabolic energy in order to maintain their structural and functional integrity. The vast majority of microorganisms are chemo-organotrophs, i.e. they obtain their energy by breaking down organic nutrients (catabolism) and oxidizing the reduced carbon/hydrogen that is present. Consequently for many microorganisms, survival depends on scavenging for reduced organic carbon compounds in their environment and organisms which develop catabolic diversity enabling them to utilize a wider range of chemicals as potential nutrients will have an advantage. This brings us back to synthetic surfactants.

In recent times on the evolutionary timescale, microbial survival has been assisted by human mobilization of organic carbon in fossil deposits. Hitherto, this organic carbon has been of relatively restricted accessibility to microorganisms because of the localized nature of such deposits. However, the exploitation of fossil carbon for feedstocks in the chemical