TABLE 9.1 Examples of Cell Immobilization by Entrapment Using Different Support Materials

Cells	Support matrix	Conversion
S. cerevisiae	κ-Carrageenan or polyacrylamide	Glucose to ethanol
E. aerogenes	κ-Carrageenan	Glucose to 2,3-butanediol
E. coli	κ-Carrageenan	Fumaric acid to aspartic acid
Trichoderma reesei	κ-Carrageenan	Cellulose production
Z. mobilis	Ca-alginate	Glucose to ethanol
Acetobacter sp.	Ca-alginate	Glucose to gluconic acid
Morinda citrifolia	Ca-alginate	Anthraquinone formation
Candida tropicalis	Ca-alginate	Phenol degradation
Nocardia rhodocrous	Polyurethane	Conversion of testosterone
E. coli	Polyurethane	Penicillin G to G-APA
Catharantus roseus	Polyurethane	Isocitrate dehydrogenase activity
Rhodotorula minuta	Polyurethane	Menthyl succinate to menthol

In mixed-culture microbial films, the presence of some polymer-producing organisms facilitates biofilm formation and enhances the stability of the biofilms. Microenvironmental conditions inside a thick biofilm vary with position and affect the physiology of the cells.

In a stagnant biological film, nutrients diffuse into the biofilm and products diffuse out into liquid nutrient medium. Nutrient and product profiles within the biofilm are important factors affecting cellular physiology and metabolism. A schematic of a biofilm is depicted in Fig. 9.11. Biofilm cultures have almost the same advantages as those of the immobilized cell systems over suspension cultures, as listed in the previous section.

The thickness of a biofilm is an important factor affecting the performance of the biotic phase. Thin biofilms will have low rates of conversion due to low biomass concentration, and thick biofilms may experience diffusionally limited growth, which may or may not be beneficial depending on the cellular system and objectives. Nutrient-depleted regions may also develop within the biofilm for thick biofilms. In many cases, an optimal biofilm thickness resulting in the maximum rate of bioconversion exists and can be determined. In some cases, growth under diffusion limitations may result in higher yields of products as a result of changes in cell physiology and cell–cell interactions. In this case,

TABLE 9.2 Examples of Cell Immobilization by Surface Attachment

Cells	Support surface	Conversion
Lactobacillus sp.	Gelatin (adsorption)	Glucose to lactic acid
Clostridium acetobutylicum	Ion-exchange resins	Glucose to acetone, butanol
Streptomyces	Sephadex (adsorption)	Streptomycin
Animal cells	DEAE-sephadex/cytodex (adsorption)	Hormones
E. coli	Ti(IV) oxide (covalent binding)	
B. subtillis	Agarose–carbodiimide (covalent binding)	
Solanum aviculare	Polyphenylene oxide-glutaraldehyde (covalent binding)	Steroid glycoalkaloids formation