

Contents

1	Basics of Microbiology for Civil and Environmental Engineers . . .	1
1.1	References for the Chapter	1
1.2	Microorganisms	1
1.3	Groups of Microorganisms	2
1.4	Cells of Microorganisms	2
1.5	Microbial Populations and Communities.	3
1.6	Phenotypic Classifications and Identification of Microorganisms	3
1.7	Phylogenetic (Genotyping) Classification and Identification of Prokaryotes.	4
1.8	Physiological Classification of Prokaryotes Using Periodic Table.	5
1.9	Three Types of Chemotrophic Energy Generation	6
1.10	Three Sources of Origin of Prokaryotes	6
1.11	Nine Physiological Groups of Chemotrophic Prokaryotes.	7
1.12	Additional Periodic Table of Phototrophic Prokaryotes.	7
1.13	Classification and Identification of Fungi	7
1.14	Classification and Identification of Algae	9
1.15	Classification and Identification of Protozoa	9
1.16	Enzymes as the Catalysts of Biochemical Reactions.	9
1.17	Velocity of Biochemical Reaction.	10
1.18	Control of the Enzymatic Reaction Rate.	11
1.19	The Role of Enzyme Kinetics in Engineering.	11
1.20	Induction, Repression and Feed-Back Control of Enzymatic Activity.	12
1.21	The Types of Biogeochemical Reactions	12
1.22	Biogeochemical Reactions that Can be Used for Production of Construction Materials and for Construction Processes in Situ.	13
1.23	Biosafety.	13
1.24	Biosafety in Construction Biotechnology	16

1.25	Disinfection in Construction Biotechnology	17
1.26	Theoretical Screening of Microorganisms for Construction Biotechnology	17
1.27	Use of Anaerobic Fermenting Bacteria in Construction Biotechnology	18
1.28	Use of Anaerobically Respiring (Anoxic) Bacteria in Construction Biotechnology	18
1.29	Use of Facultative Anaerobic and Microaerophilic Bacteria in Construction Biotechnology	19
1.30	Use of Aerobic Bacteria in Construction Biotechnology	20
1.31	Use of Anaerobic Bacteria in Construction Biotechnology	21
1.32	The Major Groups of <i>Bacteria</i> Suitable for Construction Biotechnology Processes	21
2	Basics of Biotechnology for Civil and Environmental Engineers	23
2.1	References for the Chapter	23
2.1.1	Biotechnology	23
2.2	Applicability of Construction Biotechnology	24
2.3	Bioprocesses Used in Construction Biotechnology	24
2.4	The Stages of Biotechnological Process	25
2.5	Upstream Processes in Construction Biotechnology	26
2.6	Upstream: Pretreatment of Raw Materials	26
2.7	Upstream: Preparation of a Medium for Cultivation	26
2.8	Upstream: Components of Medium	27
2.9	Upstream: Isolation and Selection of Microbial Strain (Pure Culture) for Bioprocess	28
2.10	Upstream: Acquiring of Microbial Strain from Collection	28
2.11	Upstream: Selection of an Enrichment Culture	29
2.12	Upstream: Selection of an Ecosystem	30
2.13	Upstream: Construction of Genetically Engineered Microorganisms	30
2.14	Upstream: Preparation of Inoculum	31
2.15	Core Biotechnological Process: Batch Cultivation of Microorganisms in Bioreactor	32
2.16	Core Biotechnological Process: Batch Cultivation of Introduced Microorganisms in Soil	33
2.17	Core Biotechnological Process: Batch Cultivation of Indigenous Microorganisms in Soil	35
2.18	Core Biotechnological Process: Continuous Cultivation of Microorganisms in Bioreactor	35
2.19	Core Biotechnological Process: Continuous Cultivation of Microorganisms in Soil	36
2.20	Downstream Processes	38
2.21	Downstream: Separation and Concentration of Biomass	38

2.22	Downstream: Aggregates of Cells	38
2.23	Downstream: Separation and Concentration of Products	39
2.24	Downstream: Drying, Mixing and Packing of Biotechnological Products	40
3	Biotechnological Admixtures for Cement and Mortars	41
3.1	The Types of Biopolymers	41
3.2	Structural and Metabolically Active Biopolymers	41
3.3	Historical Use of Biopolymers in Construction	42
3.4	The Bioadmixture for Cement	43
3.5	Applications of Microbial Polysaccharides as Bioadmixture	43
3.6	Effect of Biopolymers on Cement Hydration	45
3.7	Microbial Polysaccharides as Viscosity-Modifying Admixtures	45
3.8	Pseudoplasticity of Microbial Polysaccharides	46
3.9	Biotechnological Water and Permeability Reducers	46
3.10	Industrial Biotechnology Wastes as Admixture	47
3.11	Biotechnological Production of Polysaccharide Admixtures	47
3.12	Low Cost Biotechnological Admixtures	49
3.13	Biotechnological Production of Biopolymers on Biorefineries	50
4	Construction Biotechnological Plastics	51
4.1	Bio-Based and Biodegradable Plastics	51
4.2	Biotechnologically Produced Biodegradable Bioplastics	52
4.3	Biotechnological Production of Biodegradable Bioplastics for Construction	53
4.4	Cost-Efficient Production of PHAs	54
4.5	Crude PHAs Composite Material	55
4.6	Biotechnological Production of Polylactic Acid	55
4.7	Biorefinery as a Facility Producing Bioplastics for Construction Industry	56
4.8	PHAs Production from Municipal Solid and Liquid Wastes	59
4.9	Municipal Solid Wastes (MSW) as a Resource for Bioplastics Production	60
4.10	Use of Non-carbohydrates for PHA Accumulation	61
4.11	Acidogenic Fermentation as First Step of Bioplastic Production of PHAs	61
4.12	Transformation of Volatile Fatty Acids to Bioplastic	64
4.13	PHAs Recovery	66
4.14	Cost of Bioplastics Production	66
4.15	Biodegradability of Biotechnologically Produced Bioplastics	67

4.16	Environmental Impacts of Bioplastics	68
4.17	Applicability of Crude PHAs	69
4.18	The Applications of PHAs in Construction	71
4.19	The Applications of PLA in Construction	72
4.20	Advantages of Construction Biodegradable Bioplastics	73
4.21	Composite and Blended Bioplastic Materials	73
5	Biogeochemical Basis of Construction Bioprocesses	77
5.1	The Functions of Microorganisms in Hydrosphere and Lithosphere	77
5.2	The Biogeochemical Carbon Cycle	78
5.3	Applications of the Biogeochemical Carbon Cycle in Construction Bioprocesses	79
5.4	The Biogeochemical Nitrogen Cycle	80
5.5	Applications of the Biogeochemical Nitrogen Cycle in Construction Bioprocesses	80
5.6	The Biogeochemical Phosphorus Cycle	82
5.7	The Biogeochemical Sulfur Cycle	82
5.8	Applications of the Biogeochemical Sulfur Cycle in Construction Bioprocesses	83
5.9	The Biogeochemical Iron Cycle	83
5.10	Applications of the Biogeochemical Iron Cycle in Construction Bioprocesses	86
5.11	The Biogeochemical Cycle of Calcium	88
5.12	Applications of the Biogeochemical Cycle of Calcium in Construction Bioprocesses	88
5.13	The Biogeochemical Cycle of Magnesium	89
5.14	Applications of the Biogeochemical Cycle of Magnesium in Construction Bioprocesses	89
5.15	The Biogeochemical Cycle of Silicon	90
5.16	Applications of the Biogeochemical Cycle of Silicon in Construction Bioprocesses	90
6	Biotechnological Improvement of Construction Ground and Construction Materials	91
6.1	The Stages of Biotechnological Improvement of Ground	91
6.2	The Types of Construction Biotechnological Processes	93
6.3	Bioaggregation to Control Wind Soil Erosion and Dust Emission	95
6.4	Dust Control Technologies	95
6.5	Biotechnological Methods for Dust and Wind Erosion Control	96
6.6	Biotechnological Control of Air-Born Movement of Sand Dust and Dust-Associated Chemical and Bacteriological Pollutants	97

6.7	Biocrusting	97
6.8	Formation of Soil Crust by Filamentous and Photosynthetic Microorganisms	98
6.9	Biocrusting Using Microbial Polysaccharides	100
6.10	Biocrusting Using Calcium-Based Biocementation	100
6.11	Bioclogging	101
6.12	Biocementation of Soil	103
6.13	Biodesaturation of Water-Saturated Cohesionless Soil	103
6.14	Bioencapsulation of Soft Soil	104
6.15	Bioimmobilization of the Pollutants in Soil	105
6.16	Sanitation of Soil	106
6.17	Comparison of the Different Mechanisms of Ground Improvement.	107
7	Biocementation and Biocements	109
7.1	Calcium-Based Microbial Cementation in Nature	109
7.2	Calcium-Based Cementation in Macroorganisms	109
7.3	Urease-Dependent, Calcium-Based Microbial Cementation (MICP) in Engineering	110
7.4	Biochemistry of MICP	112
7.5	Use of Urease for MICP	112
7.6	Bacteria Used in MICP	113
7.7	Comparison of the Strains.	113
7.8	Selection of Enrichment Culture of UPB	115
7.9	Pure or Enrichment Cultures Must Be Used?	115
7.10	Biodiversity in Enrichment Culture.	116
7.11	Presence of the Potential Pathogens in Enrichment Culture of UPB	117
7.12	Use of Enrichment Culture of Indigenous Microorganisms with Urease Activity In Situ	118
7.13	Biosafety of MICP Using Pure Culture.	119
7.14	MICP Using Dead but Urease-Active Bacterial Cells	119
7.15	Bioclogging of the Sand Using Dead but Urease-Active Cells of <i>Yaniella</i> sp. VS8	120
7.16	Biocementation by Injection, Percolation, and Spraying	122
7.17	Types of Crystals Produced in MICP	123
7.18	Effect of Chemical Factors on MICP	124
7.19	Problems of MICP Applications	125
7.20	Media for Production of Bacterial Biomass for Biocement.	125
7.21	Constitutive and Inducible Urease.	126
7.22	Activated Sludge of Municipal Wastewater Treatment Plants as Raw Material	127
7.23	Dry Calcium-Based Biocement.	130

7.24	Unconfined Compressive (UC) Strength of Sand After MICP	131
7.25	Engineering Applications of MICP	132
7.26	Biocementation Based on Production of Carbonates by Aerobic Heterotrophic Bacteria	133
7.27	Biocementation Based on Production of Carbonates by Anaerobic Heterotrophic Bacteria	134
7.28	Effect of Magnesium Ions on MICP	135
7.29	Calcium Phosphate Biocementation	137
7.30	Self-healing of Concrete Using MICP	138
8	Bioclogging and Biogrouts	139
8.1	Microbial Processes of Bioclogging	139
8.2	Parameters to Measure Bioclogging	139
8.3	Bioclogging Using Production of Microbial Polysaccharides in Situ	142
8.4	Microorganisms that Can Be Used for the Formation of Polysaccharides in Situ	142
8.5	Slow Bioclogging with Microbial Exopolysaccharides Production in Situ	143
8.6	Experimental Bioclogging of Sand with Pure Culture of <i>Paracoccus Denitrificans</i> DSMZ 413	144
8.7	Application of Enrichment Culture of Soil Microorganisms for Sand Bioclogging	145
8.8	Use of Waste Organic Matter for Bioclogging	147
8.9	Use of Industrially Produced Microbial Polysaccharides for Ground Improvement	147
8.10	Laboratory Bioclogging Using MICP	148
8.11	Effect of Precipitated Calcium Carbonate on Hydraulic Conductivity	149
8.12	Applications of MICP Clogging	150
8.13	Bioclogging in Oil and Gas Recovery	150
8.14	Idea on Sequential Biogas Production and Biofixation of Its Bubbles in Sand	150
8.15	Clogging Due to Biogas Production in Situ	151
8.16	Instability of Biogas Bubbles in Sand	152
8.17	Bacterial Strains Used for Biogas Production and Their Fixation in Sand	152
8.18	Laboratory Examination: Biogas Production and Its Stabilization in 1 L Sand Columns	153
8.19	Laboratory Examination of Simultaneous Denitrification and Biocementation	154
8.20	Sequential Denitrification and Bioclogging in the Sand Columns	155
8.21	Biosafe Bioclogging Using MICP	159

8.22	Calcium Bicarbonate Bioclogging.	162
8.23	Effect of Partial MICP on Calcium Bicarbonate Decay.	164
8.24	Bioclogging of the Fissured Rocks with Calcium Bicarbonate Solution.	164
8.25	Delayed Calcium Bicarbonate Decay	166
8.26	Microbially Mediated Precipitation of Iron Minerals.	168
8.27	Anaerobic Bioproduction of Dissolved Fe(II).	169
8.28	Kinetics and Stoichiometry of Ferrous Bioproduction from Iron Ore	171
8.29	Combined Application of Urease-Producing Bacteria and Iron-Reducing Bacteria for the Continuous Biogrouting of Porous Soil	172
8.30	Bioclogging on the Geochemical Barriers.	174
8.31	Two Different Kinetics of Bioclogging	174
8.32	Comparison of the Biogrouting Methods	176
8.33	Development of the Biogrout	176
9	Soil Surface Biotreatment.	179
9.1	Wind Erosion of Soil and Dust Emission	179
9.2	Dust Control Technologies	179
9.3	Biotechnological Methods for Dust and Wind Erosion Control	180
9.4	Biotechnological Control of Air-Born Movement of Sand Dust and Dust-Associated Chemical and Bacteriological Pollutants.	181
9.5	Formation of Soil Crust by Filamentous and Photosynthetic Microorganisms	181
9.6	Functions of the Soil Crust.	183
9.7	Functions of Microorganisms in Soil Crust.	183
9.8	The Role of Microbial Exopolysaccharides in Biocrusting	184
9.9	Artificial Formation of Biocrust	185
9.10	Formation of Thick Crust Using Calcium-Based Biocementation	186
9.11	Formation of Crust to Diminish the Hydraulic Conductivity	188
9.12	Formation of Crust to Diminish Soil Erosion and Dispersion of Soil Pollutants	191
9.13	Biosafe Formation of Crust or Layer of Calcite	191
9.14	Design of the Biocemented Layer of Sand	192
9.15	Cost Comparison for Biosealing	193
9.16	Scale-up Factors	194
9.17	Aerobic Bioaggregation and Biocementation of Soil Surface	195

10	Biocoating of Surfaces	199
10.1	Coating of Concrete Surface	199
10.2	Biocoating of Concrete Surface	200
10.3	The Biocoating Procedure	200
10.4	Calcium Carbonate Layer on the Concrete Surface	201
10.5	The Mechanism of Biocoating Using MICP	203
10.6	Effect of Gravity on Adhesion of UPB Cells and Calcite Crystals	205
10.7	Effect of Biocoating on Water Adsorption	206
10.8	Freezing—Heating and Wetting-Drying Tests of the Coated Surfaces	207
10.9	Corrosion-Protecting Carbonate Layer	208
10.10	MICP on Granite Surface	209
10.11	MICP Coating of the Surface of Different Materials	210
10.12	Biotechnological Enhancement of Low-Crested Coastal Defense Structures	214
10.13	Artificial Coral Reefs	214
10.14	Biotechnological Construction of Artificial Coral Reefs	215
10.15	Biocoating of Aquaculture Frames	219
10.16	Biocoating (Biocapsulation) of Soft Clay Aggregates	219
10.17	Other Biotechnologies of Biocoating	221
11	Bioremediation and Biodesaturation of Soil	223
11.1	Toxic Pollutants	223
11.2	Bioremediation of Soil	223
11.3	Bioremediation Options	224
11.4	Advantages and Disadvantages of Biogeotechnologies for Remediation	225
11.5	Problems of Bioremediation	225
11.6	In Situ, on-Site, and off-Site Bioremediation	226
11.7	Microbiological Preparations for Bioremediation	226
11.8	Biotechnological Control of Dispersion of Pollutants	227
11.9	Leaching of the Pollutants from Sand	229
11.10	Biomediated Immobilization of Sand-Associated Lead	230
11.11	Potential Application of MICP Against Accidental Pollution	230
11.12	Biomitigation of Soil Liquefaction Through Biogas Production in Situ	231
11.13	Denitrification as a Source of Biogas Production in Situ	232
11.14	Stability of Biogas Bubbles in Soil	233
11.15	Biogas Production in Situ Decreased Primary Consolidation Settlement in Clayey Soils	234

12 Optimization and Design of Construction Biotechnology

Processes	235
12.1 Urease Activity of MICP Agent	235
12.2 Kinetics of Urease	236
12.3 Genetically Engineered Strains of UPB	236
12.4 Media for Cultivation of Bioagent	236
12.5 Optimum of Urease Activity for MICP	239
12.6 Extra- and Intracellular Urease	239
12.7 Influence of Calcium Concentration on MICP	239
12.8 Calcium: Urea Molar Ratio for MICP	240
12.9 Source of Calcium for MICP	240
12.10 UPB Distribution and Immobilization	241
12.11 Rate of MICP Per Cell During Bioclogging	242
12.12 Effect of Temperature on MICP	242
12.13 Formation of Nanocomposites	242
12.14 Effect of Surfactants	243
12.15 Design of Biocementation and Bioclogging Using MICP	243
12.16 Parameters of Design	244
12.17 Stoichiometry of Bioclogging and Biocementation	244
12.18 Technological Calculations	245
12.19 Optimization and Design of Biodesaturation	246
12.20 Field and Pilot Tests of the Biotreatment of Sand and Porous Soil	247
12.21 Tests of the Biotreatment of the Fractured Rocks	248
12.22 MICP Bioclogging of the Mixture of the Rocks and Sand	250
12.23 MICP Pilot Bioclogging of the Space Between Granite Sheets Using Dead but Urease-Active Bacterial Cells	255

13 Biocorrosion, Biodeterioration, and Biofouling in Civil

Engineering	261
13.1 Microbial Biodeterioration of Construction Materials	261
13.2 Deterioration of Cultural Heritage	262
13.3 Microbial Biofouling	262
13.4 Microbially Influenced Corrosion	263
13.5 Microbial Formation of Acids	265
13.6 Prevention of Microbially Influenced Corrosion, Biofouling and Biodeterioration	265
13.7 Wood Preservatives	266
13.8 Bioaerosols	266
13.9 Sources of Bioaerosols in the Buildings	267
13.10 Virus Aerosols	267
13.11 Bacterial Aerosols	267

13.12	Fungal Aerosols	268
13.13	Fate of Bioaerosols	268
13.14	Treatment of Odorous and Toxic Gases	269
14	Advances and Future Developments of Construction	
	Biotechnology	271
14.1	Advances of Biotechnological Construction Materials	271
14.2	Known Applications of Biocements and Biogroups.	272
14.3	The Existing Problems of Biotechnological Ground Improvement and the Ways of Their Potential Solution	273
14.4	New Potential Applications of Biotechnological Ground Improvement.	273
14.5	Future Products of Construction Biotechnology and Their Applications	273
14.6	Eco-Efficient Biocement	276
14.7	Calcium Carbonate Precipitation and CO ₂ Sequestration	276
	References	279

Construction Biotechnology

Biogeochemistry, Microbiology and Biotechnology of
Construction Materials and Processes

Ivanov, V.; Stabnikov, V.

2017, XXI, 317 p. 98 illus., 44 illus. in color., Hardcover

ISBN: 978-981-10-1444-4