Contents

	Foreword to the Second Edition xi
	Foreword to the First Edition $xiii$ Preface xv
	rielace av
1	Principles of Drying I
1.1	Introduction 1
1.2	Losses of Crops 2
1.3	Importance of Drying 2
1.4	Principles of Drying 2
	Reference 3
	Further Reading 3
2	Moisture Contents and Equilibrium Moisture Content Models 5
2.1	Introduction 5
2.2	Moisture Content Representation 5
2.3	Determination of Moisture Content 7
2.3.1	Direct Methods 8
2.3.2	Indirect Methods 10
2.4	Grain Sampling 12
2.5	Equilibrium Moisture Content 12
2.6	Determination of Static Equilibrium Moisture Content 17
2.7	Static Equilibrium Moisture Content Models 20
2.8	Net Isosteric Heat of Sorption 22
	Exercises 28
	References 28
3	Psychrometry 31
3.1	Introduction 31
3.2	Psychrometric Terms 31
3.2.1	Humidity Ratio 32
3.2.2	Relative Humidity 32
3.2.3	Specific Volume 33
3.2.4	Vapour Pressure 33
3.2.5	Dry Bulb Temperature 33

vi	Contents	
	3.2.6	Dew Point Temperature 33
	3.2.7	Wet Bulb Temperature 34
	3.2.8	Enthalpy 34
	3.2.9	Adiabatic Wet Bulb Temperature 35
	3.2.10	Psychrometric Wet Bulb Temperature 36
	3.3	Construction of Psychrometric Chart 38
	3.4	Use of Psychrometric Chart 39
	3.4.1	Sensible Heating and Cooling 39
	3.4.2	Heating with Humidification 40
	3.4.3	Cooling with Humidification 41
	3.4.4	Cooling with Dehumidification 41
	3.4.5 3.4.6	Drying 42 Mixing of Air Streams 42
	3.4.7	Mixing of Air Streams 43 Heat Addition with Air Mixing 45
	3.4.8	Drying with Recirculation 46
	5.1.0	Exercises 52
		References 54
		Further Reading 54
	4	Physical and Thermal Properties of Cereal Grains 55
	4.1	Introduction 55
	4.2	Structure of Cereal Grains 55
	4.3	Physical Dimensions 55
	4.4	1000 Grain Weight 56
	4.5	Bulk Density 57
	4.6	Shrinkage 57
	4.7	Friction 58
	4.7.1	Angle of Internal Friction and Angle of Repose 59
	4.7.2	Coefficient of Friction 59
	4.8	Specific Heat 61
	4.9 4.9.1	Thermal Conductivity 63 Theory 63
	4.9.1	Apparatus and Measurement 65
	4.10	Latent Heat of Vaporization of Grain Moisture 66
	4.10.1	Determination of Latent Heat of Vaporization of a Grain 67
	4.11	Heat Transfer Coefficient of Grain Bed 69
	4.11.1	Dimensional Analysis 70
	4.11.2	Comparison of Theory and Experiment 70
	4.11.3	Determination of Volumetric Heat Transfer Coefficient 72
		Exercises 76
		References 78
		Further Reading 80
	5	Airflow Resistance and Fans 81
	5.1	Airflow Resistance 81
	5.1.1	Non-linear Airflow Analysis 83

5.2

Fans 91

5.2.1 5.2.2 5.2.3 5.2.4 5.2.5 5.2.6 5.3	Fan Performance 92 Centrifugal Fan Laws 95 Fan Selection 97 Effect of Change in Fan Speed 98 Effect of Change in Speed and System Resistance 99 Fans in Series and Parallel 99 Duct Design for On-Floor Drying and Storage System 102 Exercises 103 References 105
6	Thin Layer Drying of Cereal Grains 107
6.1	Theory 107
6.2	Thin Layer Drying Equations 109
6.2.1	Empirical Drying Equations 109
6.2.2	Theoretical Drying Equations 110
6.2.3	Semi-Theoretical Drying Equations 113
6.2.4	Comparison of Thin Layer Drying Equations 114
6.3	Development of Thin Layer Drying Equations 116
6.3.1	Drying Rate 119
6.4	Drying Parameters 119
6.4.1	Drying Rate Constant and Diffusion Coefficient 120
6.4.2	Dynamic Equilibrium Moisture Content 127
6.5	Finite Element Modelling of Single Kernel 133
6.5.1	Finite Element Model Formulation 133
6.5.2	Finite Difference Solution in Time 138
6.5.3	Discretization of the Domain 138 Exercises 140
	References 142
	Further Reading 145
	rather reading 110
7	Deep-Bed and Continuous Flow Drying 147
7.1	Introduction 147
7.2	Deep-Bed Drying Models 147
7.2.1	Logarithmic Models 148
7.2.2	Partial Differential Equation Models 148
7.2.3	Comparison of Deep-Bed Drying Models 149
7.3	Development of Models for Deep-Bed Drying 149
7.3.1	Logarithmic Model 150
7.3.2	Partial Differential Equation Model 156
7.3.3	Method of Solution 160
7.3.4	Condensation Procedure 161
7.3.5 7.3.6	Sensitivity Analysis 169 Comparison of Simulated Drying with Experimental Results 169
7.3.6	Comparison of Simulated Drying with Experimental Results 169 Comparison of Direct, Indirect and Recirculating Direct Fired Drying 170
7. 3 .7	Development of Models for Continuous Flow Drying 170
7.4.1	Crossflow Model 173
7.4.2	Fluidized Bed Drying Model 180

viii	Contents	
	7.5	CFD Modelling of Fluidized Bed Drying 185
	7.5.1	Continuity Equation 185
	7.5.2	Momentum Conservation Equations 186
	7.5.3	Energy Conservation Equation 186
	7.5.4	User-Defined Scheme (UDS) 187
	7.5.5	CFD Analysis 187
		Exercises 190
		References 193
		Further Reading 194
	8	Grain Drying Systems 195
	8.1	Introduction 195
	8.2	Solar Drying Systems 195
	8.3	Batch Drying Systems 199
	8.4	Continuous-Flow Drying Systems 200
	8.4.1	Crossflow Dryer 200
	8.4.2	Concurrent Flow Dryer 200
	8.4.3	Counterflow Dryer 202
	8.5 8.6	Safe Temperature for Drying Grain 202
	8.7	Hydrothermal Stresses during Drying 203 Energy and Exergy Analysis of Drying Process 204
	8.7.1	Drying Efficiency 205
	8.7.2	Exergy Analysis through the Analysis of Second Law of Thermodynamics 205
	8.8	Neural Network Modelling 206
	8.8.1	Structure of ANN Model 207
	8.8.2	Training of ANN Model 208
	8.9	Selection of Dryers 209
		Exercises 211
		References 212
		Further Reading 213
	9	Principles of Storage 215
	9.1	Introduction 215
	9.2	Principles of Storage 215
	9.3	Interrelations of Physical, Chemical and Biological Variables in the
		Deterioration of Stored Grains 218
	9.4	Computer Simulation Modelling for Stored Grain Pest Management 219
		References 220
		Further Reading 221
	10	Temperature and Moisture Changes During Storage 223
	10.1	Introduction 223
	10.2	Qualitative Analysis of Moisture Changes of Stored Grains in
		Cylindrical Bins 223
	10.3	Temperature Changes in Stored Grains 225
	10.4	Temperature Prediction 225

10.4.1	The Differential Equation of Heat Conduction in Cylindrical
	Coordinate System 226
10.4.2	Numerical Method 227
10.5	Numerical Solution of One-Dimensional Heat Flow 227
10.6	Numerical Solution of Two-Dimensional Heat and Moisture Flow 232
10.6.1	Heat Transfer Equation 233
10.6.2	Mass Transfer Equation 234
10.7	Simultaneous Momentum, Heat and Mass Transfer during Storage 249
10.7.1	The Energy Balance Equation 250
10.7.2	The Mass Balance Equation 251
10.7.3	The Momentum Balance Equation 251
10.7.4	Finite Difference Formulation 252
10.8	CFD Modelling of Grain Storage Systems 258
10.8.1	Continuity Equation 258
10.8.2	Momentum Conservation Equations 258
10.8.3	Energy Conservation Equation 258
10.8.4	User-Defined Function 258
10.0.4	Exercises 260
	References 262
	Further Reading 262
	Turner Reading 202
11	Fungi, Insects and Other Organisms Associated with Stored Grain 263
11.1	Introduction 263
11.2	Fungi 263
11.2.1	Field Fungi 265
11.2.2	Intermediate Fungi 265
11.2.3	Storage Fungi 265
11.3	Insects 267
11.3.1	Insect Species 268 Grain Temperature and Moisture Content 269
11.3.2	Grant Temperature and second
11.4	Mites 270
11.5	Rodents 270
11.6	Respiration and Heating 270
11.7	Control Methods 271
	References 272
	Further Reading 272
12	Design of Grain Storages 273
12	3
12.1	Introduction 273 Structural Requirements 273
12.2	•
12.2.1	,
12.2.2	Rankine Equation 277
12.2.3	Airy Equation 278
12.3	Construction Materials 280
	Exercises 288
	References 288

13	Grain Storage Systems 289
13.1	Introduction 289
13.2	Traditional Storage Systems 290
13.3	Modern Storage Systems 290
13.3.1	Bagged Storage System 290
13.3.2	Silo Storage System 291
13.3.3	Airtight Grain Storage 292
13.3.4	Aerated Storage System 297
13.3.5	Low-Temperature Storage System (Grain Chilling by Refrigeration) 30.
13.3.6	Controlled Atmosphere Storage Systems 304
13.3.7	Damp Grain Storage System with Chemicals 306
	References 310
	Further Reading 313
	Appendix A: Finite Difference Approximation 315
	Appendix B: Gaussian Elimination Method 317
	Appendix C: Finite Element Method 321

Appendix D: Computational Fluid Dynamics 325

Index 333