# Food Packaging Science and Technology

Environment

### DONG SUN LEE KIT L. YAM LUCIANO PIERGIOVANNI

Shelf Life

of

Packaged Food

Package



### Food Packaging Science and Technology

## Food Packaging Science and Technology

### DONG SUN LEE KIT L. YAM LUCIANO PIERGIOVANNI





CRC Press is an imprint of the Taylor & Francis Group, an Informa business

CRC Press Taylor & Francis Group 5000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742

© 2008 by Taylor & Francis Group, LLC CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works Printed in the United States of America on acid-free paper 10 9 8 7 6 5 4 3

International Standard Book Number-13: 978-0-8247-2779-6 (Hardcover)

This book contains information obtained from authentic and highly regarded sources Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The Authors and Publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www. copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at http://www.taylorandfrancis.com

and the CRC Press Web site at http://www.crcpress.com

#### **Table of Contents**

Cha	pter 1: Overview of Food Packaging Systems	1
1.1	Introduction	. 1
1.2	Science and Technology of Food Packaging	.2
	1.2.1 Food Packaging Science	.3
	1.2.2 Food Packaging Technology	
1.3	Socioeconomic Needs	
1.4	Packaging Functions	
1.5	Packaging Environments	
1.6	Food Packaging Systems	
	1.6.1 Levels of Packaging	7
	1.6.2 Package Forms	8
	1.6.3 Primary Food Packaging System	
1.7	Tables for Analyzing Food Packaging Systems	
	1.7.1 Functions/Socioeconomics Table	
	1.7.2 Functions/Technologies Table	0
	1.7.3 Functions/Environments Table	
1.8	Food Package Development	
Disc	ussion Questions and Problems 1	
Bibli	ography 1	5

### Part One: Packaging Material Science

Cha	pter	2: Chemical Structures and Properties of F	Packaging
Mat	erials	· · · · · · · · · · · · · · · · · · ·	
2.1		luction	
2.2	Chem	ical Constituents	20
2.3	Chem	ical Bonding	21
	2.3.1	Ionic Bonding	21
		Metallic Bonds	
	2.3.3	Covalent Bond Model	25
2.4	Interm	nolecular Forces	27
		Ion-Dipole Forces	
		Dipole-Dipole Forces	
	2.4.3	Hydrogen Bonding	29
	2.4.4	Dispersion Forces	
		Consequences of Intermolecular Interaction: Cohesion,	
	and Si	urface Tension ······	
2.5		I Arrangements	
		Tacticity	
	2.5.2	Crystalline vs. Amorphous State	

2.6	Chem	ical Reactivity and Susceptibility of Packaging	35
	2.6.1	Oxidation	36
	2.6.2	Biodegradation and Biodeterioration	38
	2.6.3	Chemical Resistance, Etching, and Weathering	40
Disc	ussion	Questions and Problems	41
Bibl	iograph	ıy	41

Cha	pter :	3: Physical Properties of Packaging Materials	43
3.1	Introd	uction	43
3.2	Therm	al Properties	44
	3.2.1	Thermal Conductivity (k)	45
	3.2.2	Heat Capacity (Cp)	46
	3.2.3	Thermal Expansion (linear and volumetric)	47
	3.2.4	Tolerable Thermal Range	48
	3.2.5	Transition Temperatures (Tm, Tg)	48
	3.2.6	Heat of Combustion (Qc)	50
3.3	Electro	omagnetic Properties	51
	3.3.1	Refractive Index (n)	52
	3.3.2	Transparency (%T)·····	53
	3.3.3	Transmittance/Absorption Spectra in UV, VIS, and IR	55
	3.3.4	Haze	58
	3.3.5	Gloss	
	3.3.6	Behavior to Ionizing Radiations	60
	3.3.7	Behavior to Microwaves	
3.4	Mecha	nnical Properties	63
	3.4.1	Density and Related Properties	63
	3.4.2	Coefficient of Friction	64
	3.4.3	Strength Properties: Tensile, Tear, Burst, and Creep	66
	3.4.4	Response to Dynamic Stresses: Impact Resistance and Cushioning	
Disc	ussion		75
Bibli	ograph	у	76

pter	4: Permeation of Gas and Vapor	.79
Introd	uction	. 79
4.2.2	Diffusion of Permeant	·82
4.2.3	Adsorption and Desorption of Permeant	·82
Theor	etical Analysis of Permeation	.83
4.3.2	Concentration Profile within Film at Steady State	.85
4.3.3	Derivation of Permeation Rate Equation	.85
4.3.4	Physical Meanings of Permeation Rate Equation	·86
Termi	nology and Units for Permeation	.89
	Introd Basic 4.2.1 4.2.2 4.2.3 Theor 4.3.1 4.3.2 4.3.3 4.3.4	Appendix Permeation of Gas and Vapor

	4.4.1	Transmission Rate	.90
	4.4.2	Permeance	-91
	4.4.3	Permeability	.91
4.5		ability of Food Packaging Polymers	
4.6		rs Governing Permeation	
	4.6.1	Nature of Polymer	.96
		Nature of Permeant	
	4.6.3	Ambient Environment	.97
4.7	Measu	arements for Permeation Properties	. 98
	4.7.1	Basic Design Principles	.98
	4.7.2	Isostatic Method	.99
	4.7.3	Quasi-Isostatic Method	100
	4.7.4	Measuring Permeation Rate of Finished Packages	101
	4.7.5	Another Method for Estimating Permeation of Plastic Containers	102
	4.7.6	Gravimetric Method	104
4.8	Gas T	ransport through Leaks	105
Disc	ussion	Questions and Problems	106
Bibl	iograph	1V	108

Cha	pter	5: Migration and Food-Package Interactions109
5.1	Introd	uction
5.2	Pheno	menal Description of Migration Process
		Phenomenal Description of Migration Process111
		Kinetic and Thermodynamic Approach114
5.3	Migra	tion Issues in Food Packaging116
	5.3.1	Chemicals from Plastics 117
	5.3.2	Recycled Plastics 117
	5.3.3	Microwave Susceptor 120
5.4		Scalping and Sorption
5.5	Migra	tion Testing
	5.5.1	General Principles 123
	5.5.2	Food Simulants 124
	5.5.3	Analytical Techniques124
5.6	Predic	tive Migration Models
	5.6.1	Models for Simplified Systems125
		Estimation of Diffusion Coefficient and Partition Coefficient128
	5.6.3	Modeling for Worst Case Scenario130
5.7	Regula	atory Considerations
	5.7.1	Commons and Differences between Regulations133
	5.7.2	Sensory Tainting136
Disc	ussion	Questions and Problems
Bibli	ograph	iy

Cha	pter	6: Food Packaging Polymers1	41
6.1	Basic	Concepts of Polymers	142
	6.1.1	Chemical Structure	142
	6.1.2	Molecular Shape	143
	6.1.3	Thermoplastics versus Thermosets	144
	6.1.4	Homopolymers versus Copolymers	144
	6.1.5	Polymer Blends	145
6.2	Polym	erization Reactions	145
	6.2.1	Addition Polymerization	145
	6.2.2	Condensation Polymerization	146
6.3	Plastic	cs versus Polymers	147
	6.3.1	Production of Polymers and Plastic Resins	147
	6.3.2	Advantages and Disadvantages of Plastics	148
6.4	Comp	osition/Processing/Morphology/Properties Relationships	148
6.5	Chara	cteristics of Packaging Polymers	149
	6.5.1	Molecular Weight-	149
	6.5.2	Chain Entanglement	
	6.5.3	Summation of Intermolecular Forces between Polymer Chains	151
		Polymer Morphology	
6.6		Packaging Polymers	154
	6.6.1	Polyethylene (PE)	155
	6.6.2	Polypropylene (PP)	157
	6.6.3	Polystyrene (PS)	157
	6.6.4	Polyvinyl Chloride (PVC)	158
	6.6.5	Polyethylene Terephthalate (PET) ·····	158
	6.6.6	Polyvinylidene Chloride (PVDC)······	
	6.6.7	Ethylene Vinyl Alcohol Copolymer (EVOH)	160
	6.6.8	Ionomer	
	6.6.9	Ethylene Vinyl Acetate (EVA) Copolymer	161
	6.6.10 Polyamides (Nylons) 16		
	6.6.11	Polycarbonate (PC)	162
	6.6.12	Edible Coatings and Films	163
		Recycling Symbols	
6.7	Polym	er Processing	163
	6.7.1	Extrusion	164
	6.7.2	Coextrusion	164
	6.7.3	Cast Film Extrusion	165
		Blown Film Extrusion	166
	6.7.5	Injection Molding	168
	6.7.6	Blow Molding	168
		Extrusion Coating	171
	6.7.8	Extrusion Lamination	172
	6.7.9	Adhesive Lamination	173
	0. /. 10	Thermoforming	174

6.7.11 Vacuum Metallization	174
Discussion Questions and Problems	175
Bibliography	

Cha	pter 7: Glass Packaging	177
7.1	Introduction	
7.2	Chemical Structure	
	Glass Properties	
	7.3.1 Mechanical Property	
	7.3.2 Thermal Property	
	7.3.3 Electromagnetic Property	
	7.3.4 Chemical Inertness	184
7.4	Glass Containers Manufacturing	
	7.4.1 Glass Making	
	7.4.2 Container Manufacturing	
	7.4.3 Post Blowing Operations	
7.5	Glass Container Strengthening Treatments	
7.6	Use of Glass Containers in Food Packaging	
	Other Ceramic Containers	
	ussion Questions and Problems	
	iography	

Cha	pter	8: Metal Packaging19	97
8.1		uction1	
8.2			
	8.2.1	Aluminum Foil2	01
8.3	Coate	d Steels	03
	8.3.1	Tinplate2	04
		Tin Free Steels2	
	8.3.3	Polymer Coated Steels2	08
8.4	Stainle	ess Steel	09
8.5		Corrosion	10
	8.5.1	Basic Corrosion Theory2	10
	8.5.2	Corrosion of Tinplate2	15
	8.5.3	Corrosion of TFS2	
	8.5.4	Corrosion of Aluminum2	18
	8.5.5	Corrosion of Stainless Steel	18
	8.5.6	Microbiologically Induced Corrosion2	19
8.6	Metal	Container Manufacturing	20
	8.6.1	Three-piece Can	21
	8.6.2	Two-piece Can - D&I2	24
	8.6.3	Two-piece Can - DRD2	25
	8.6.4	Can Ends2	26
	8.6.5	Double Seaming2	28