**TABLE OF CONTENTS**

***Chapter 0 Introduction to Course 01-03***

* 1. Background and Motivation 01
  2. Organization of the Course 03

**MODULE I: Essential Process Control Basics**

***Chapter 1 Process Dynamics 05-11***

* 1. Standard Input Changes 06
  2. Basic Response Types 06
     1. First Order Lag 06
     2. Higher Order Lags 07
     3. Second Order Response 07
     4. Other Common Response Types 09
     5. Unstable Systems 10
  3. Combination of Basic Reponses 10

***Chapter 2 Feedback Control 12-21***

2.1 The Feedback Loop and its Components 12

2.2 PID Control 13

2.2.1 The Control Algorithm 13

2.2.2 Controller Tuning 14

2.3 Process Identification 17

2.3.1 Process Reaction Curve Fitting 17

2.3.2 Autotuning 19

2.4 Controller Modes and Action 20

2.5 Rules of Thumb for Controller Tuning 20

2.5.1 Flow Loops 20

2.5.2 Level Loops 21

2.5.2 Pressure Loops 21

2.5.3 Temperature Loops 21

2.5.4 Quality Loops 21

***Chapter 3 Advanced Control Structures 23-29***

3.1 Ratio Control 23

3.2 Cascade Control 24

3.3 Feedforward Control 26

3.4 Override Control 28

3.5 Valve Positioning (Optimizing) Control 29

***Chapter 4 Multivariable Systems 31-39***

4.1 Interaction Metrics 32

4.1.1 Niederlinski Index 32

4.1.2 Relative Gain Array 33

4.2 Multivariable Decentralized Control 34

4.2.1 Detuning Multivariable Decentralized Controllers 34

**MODULE II: Control of Common Unit Operations**

***Chapter 5 Control of Distillation Systems 41-64***

5.1 Distillation Basics 41

5.1.1 The Simple Distillation Column 41

5.1.2 Splits in a Simple Distillation Column 42

5.2 Basic Control Structures 43

5.2.1 The Energy Balance (LQ) Structure 43

5.2.2 Material Balance Structures 45

5.2.3 Other Control Structure Variants 45

5.3 Temperature Based Inferential Control 45

5.3.1 Single-Ended Temperature Control 47

5.3.2 Dual-Ended Temperature Control 47

5.4 Temperature Sensor Location Selection 47

5.4.1 Maximum Slope Criterion 47

5.4.2 Maximum Sensitivity Criterion 51

5.4.3 SVD Criterion 51

5.5 Considerations in Temperature Inferential Control 52

5.5.1 Effect of LLK/HHK 52

5.5.2 Flat Temperature Profiles 52

5.5.3 Easy Separations 52

5.6 Control of Complex Column Configurations 53

5.6.1 Side Draw Columns 53

5.6.2 Side Rectifier / Side Stripper Columns 53

5.7 Control of Heat Integrated Columns 58

5.8 Control of Homogenous Extractive Distillation System 60

5.9 Plantwide Considerations 61

***Chapter 6 Control of Reactors 65-81***

6.1 Basic Reactor Types 66

6.2 Plug Flow Reactor 67

6.2.1 PFR Basics 67

6.2.2 Control of PFRs 69

6.2.2.1 Adiabatic PFR 69

6.2.2.1 Cooled Tubular Reactors 70

6.2.3 Intermediate Cooling and Cold Shot Cooled Reactors 72

6.3 Continuous Stirred tank Reactor 73

6.3.1 Jacket Cooled CSTR 75

6.3.2 Reaction Heat Removal as Steam 76

6.3.3 External Heat Exchanger 77

6.3.4 Cooling Coils 78

6.3.5 External Cooling by Content Recirculation 78

6.3.6 Boiling CSTR with External Condenser 78

6.3.7 Reactor Heat Removal Capacity Constraint 80

***Chapter 7 Heat Exchanger Control 82-85***

7.1 Control of Utility Heat Exchangers 82

7.2 Control of Process-to-Process Heat Exchangers 84

***Chapter 8 Control of Miscellaneous Systems 86-93***

8.1 Furnace Controls 86

8.2 Compressor Controls 87

8.3 Decanter Control 89

8.4 Control of Refrigeration Systems 91

8.4.1 Vapor Compression Cycle 91

8.4.2 Vapor Absorption Cycle 91

8.5 Control of Steam Utility System 93

**MODULE III: Issues in Plantwide Control System Design**

***Chapter 9 Control and Steady State Degrees of Freedom 95-107***

9.1 Control Degrees of Freedom 95

9.2 Steady State Degrees of Freedom 96

9.3 Degrees of Freedom, Controlled Variables (CVs) and Control Structures 97

9.4 Control Objectives and Choice of CVs 103

9.5 Illustration of Control Objectives and CVs for Example Processes 105

9.6 Snowball Effect 106

***Chapter 10 The Pairing Issue: Selection of MVs for CVs 109-116***

10.1 Conventional Pairing Approach 109

10.2 Luyben Pairing Approach 109

10.3 Regulatory Control Structure Synthesis Examples: 110

Conventional vs Luyben’s Approach

10.3.1 Single Column Recycle Process 110

10.3.2 Two Column Recycle Process 113

***Chapter 11 Economic Considerations in Plantwide Control 117-123***

11.1 Economic Process Operation Considerations 117

11.2 Process Operation Modes 118

11.3 Process Constraints and Economic Operation 118

11.4 Approaches for Handling Capacity Constraints 119

11.4.1 Backed-off Operation 119

11.4.2 Use of Valve Positioning (Optimizing) Controller 119

11.4.3 Altering Material Balance Control Structure Using Overrides 119

11.4.4 Using Constraint Variable as Throughput Manipulator 120

***Chapter 12 Economic Plantwide Control Examples 124-133***

12.1 Single Column Recycle Process 124

12.2 Two Column Recycle Process 129

**MODULE IV: Economic Plantwide Control Design Procedure and Case Studies**

***Chapter 13 Systematic Economic Plantwide Control Design Procedure 135-144***

13.1 Degrees of Freedom (DOFs) and Plantwide Control Structures 136

13.2 Two-Tier Control System Design Framework 137

13.3 Active Constraint Regions for a Wide Throughput Range 139

13.4 Systematic Control System Design Procedure 140

13.4.1 Step 0: Obtain Active Constraint Regions for the 141

Wide Throughput Range

13.4.2 Step 1: Pair Loops for Tight Maximum Throughput 141

Economic CV Control

13.4.3 Step 2: Design the Inventory (Regulatory) Control System 142

13.4.4 Step 3: Design Loops for Additional Economic CV Control 143

at Lower Throughputs Along with Throughput

Manipulation Strategy

13.4.5 Step 4: Modify Structure for Better Robustness / 144

Operator Acceptance

***Chapter 14 Economic Plantwide Control of Recycle Process with Side Reaction 145-154***

14.1 Process Description 145

14.2 Economic Plantwide Control System Design 146

14.2.1 Step 0: Active Constraint Regions and Economic Operation 147

14.2.2 Step 1: Loops for Maximum Throughput Economic CV Control 147

14.2.3 Step 2: Inventory (Regulatory) Control System 149

14.2.4 Step 3: Additional Economic CV Control Loops and Throughput 149

Manipulation

14.2.5 Step 4: Modifications for a More Conventional Inventory Control 151

System

***Chapter 15 Economic Plantwide Control of Ethyl Benzene Process 155-162***

15.1 Process Description 155

15.2 Economic Plantwide Control System Design 155

15.2.1 Step 0: Active Constraint Regions and Optimal Operation 155

15.2.2 Step 1: Loops for Tight Control of Full Active Constraint Set 156

15.2.3 Step 2: Inventory (Regulatory) Control System 158

15.2.4 Step 3: Additional Economic CV Loops and Throughput 158

Manipulation

15.2.5 Step 4: Modifications a for More Conventional Inventory Control 158

System

***Chapter 16 Comprehensive Case Study I: Cumene Process 163-183***

16.1 Process Description 163

16.2 Economic Plantwide Control System (CS1) Design 164

16.2.1 Step 0: Optimal Steady State Process Operation 164

16.2.2 Step 1: Loops for Tight Economic CV Control 168

16.2.3 Step 2: Inventory Control System Design 170

16.2.4 Step 3: Throughput Manipulation and Additional Economic Loops 171

16.3 Conventional Plantwide Control Structure (CS2) 172

16.4 Dynamic Simulation Results and Discussion 173

16.4.1 Controller Tuning 173

16.4.2 Closed Loop Results 174

16.4.3 Quantitative Dynamic and Economic Comparison of CS1 and CS2 180

16.4.4 Discussion 182

16.5 Conclusions 183

***Chapter 17 Comprehensive Case Study II: C4 isomerization Process 184-200***

17.1 Process Description 184

17.2 Economic Plantwide Control System (CS1) Design 185

17.2.1 Step 0: Active Constraint Regions and Economic Operation 185

17.2.2 Step 1: Loops for Tight Economic CV Control 187

17.2.3 Step 2: Inventory Control System 187

17.2.4 Step 3: Throughput Manipulation and Additional Economic Loops 188

17.3 Conventional Plantwide Control Structure (CS2) 189

17.4 Dynamic Simulations and Closed Loop Results 193

17.4.1 Tuning of Controllers 193

17.4.2 Closed Loop Results 195

17.4.3 Quantitative Economic Performance Comparison 199

17.5 Conclusions 199

***Bibliography 201-202***