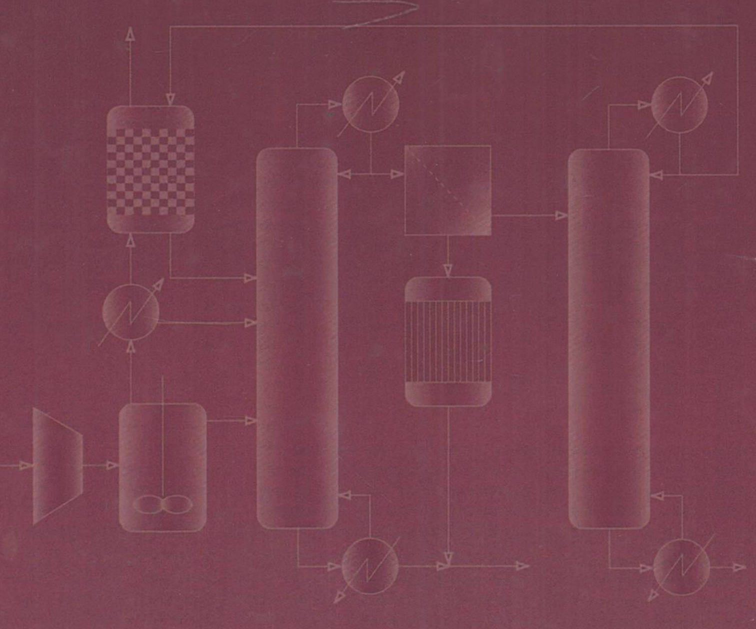
Mahmoud M. El-Halwagi

Process Integration



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Volume 7

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PROCESS INTEGRATION

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To my parents, my wife, and my sons with love and gratitude

PREFACE

Processing facilities are among the most important contributors to the World's economy and sustainable development. Examples of these processes include chemical, petroleum, gas, petrochemical, pharmaceutical, food, microelectronics, metal, textile, and forestry-product industries. These industries are characterized by the processing of enormous quantities of material and energy resources. As such, there is a significant need for continuous process improvement by targeting key goals such as conserving natural resources, enhancing productivity, and mitigating the discharge of ecologically harmful materials. The question is how can engineers achieve these goals methodically and efficiently? For a given process with numerous units and streams, how can engineers maneuver through the complexities of the process, identify opportunities, and pursue them?

Chemical engineering education and training have provided an arsenal of generally applicable design and analysis tools for individual processing units (e.g., reactors, heat exchangers, distillation columns, absorbers, strippers, pumps, compressors, etc.). A typical process engineer is expected to address a wide variety of applications for these individual units by using a consistent set of fundamental and generic design and analysis tools. Until recently, these powerful tools have been *limited to the level of individual units*. Regrettably, the much-encountered problem of synthesizing, designing, or optimizing a whole process (or parts of the process) with multiple units and streams has been mostly handled as a subjective exercise which is primarily guided by experience and conjecture. It is worth noting that the solution of individual problems must not be done in isolation of the rest of the process but rather in the context of how such problems interact with the rest of the process. Unfortunately, the knowledge and skill sets needed to address open-ended problems involving multiple units and streams are seldom covered in engineering education and professional training. This has been a key limitation that restricted the power of chemical engineering education and training in addressing real-life process-improvement objectives.

Since the process operates as an integrated system of units and streams, it must be understood as such and it must be treated as such. Recent research in the area of process systems engineering has led to a remarkable breakthrough referred to as process integration. This breakthrough has expanded the power of engineering design to methodically and insightfully address systems of multiple units and streams using a consistent basis of fundamental concepts of chemical and systems engineering. Process integration is defined as a holistic approach to design and operation that emphasizes the unity of the process. There are two distinct hallmarks of process integration. First, there are insights and performance targets for the process that can be identified only by addressing the process as a whole system. These insights and targets are unseen by looking at the individual components as separate "silos". Second, the whole effect (of the integrated system) is greater than the sum of the individual effects (of individual units and streams). Process integration provides an excellent framework for benchmarking process performance, characterizing root causes of problems limiting the performance, identifying opportunities, methodically generating efficient strategies that achieve the desired performance targets, and inventing innovative solutions.

This textbook presents state-of-the-art fundamentals, tools, and applications of process integration. It describes how to effectively integrate the process units and streams and conserve natural resources in a systematic and generally applicable way. The book places a great deal of emphasis on targeting techniques that determine process potential, attractive opportunities, root causes of problems, and performance benchmarks ahead of detailed design and without commitment to the specific selection of units or technologies. The book also presents methodical tools and techniques that guide the engineers in synthesizing and detailing integrated solutions while enhancing creativity and incorporating relevant data and expertise. Graphical, algebraic, and mathematical approaches are presented to furnish a host of tools appropriate for various groups of readers and different problems with increasing level of complexity and sophistication. The techniques described throughout the book have proven their worth through numerous industrial applications with impressive track record and results.

In keeping with the tutorial theme of the book, the treatment of theoretical foundations is limited to that needed to provide the basis for the reasoning behind the presented materials. Additional references and suggested reading materials are listed throughout the book to provide more details on the theoretical foundations and mathematical proofs. Numerous examples are given to demonstrate the power and applicability of the tools and techniques.

This book is appropriate for senior-level design classes and introductory graduate classes. The book is also tailored to serve as a self-study sourcebook for process engineers and working professionals interested in optimizing process performance and managing natural resources. Finally, the book can be used as a resource for researchers in the area of process synthesis and integration.

Many extraordinary people have contributed to my career and to this book. Heartfelt thanks are due to all of my friends who helped me in so many ways throughout my life. I am very thankful to the many professional associates and leaders of the process systems engineering community whose contributions have impacted my technical interests and development. I am particularly grateful to Dr. Dennis Spriggs (President of Matrix Process Integration) who has significantly impacted my career through enjoyable collaborations and industrial projects that introduced me to many process-integration approaches and practices.

I am indebted to my colleagues at Texas A&M University. Many thanks are due to Dr. John Baldwin. I have learned a great deal from him while co-teaching the notorious design classes. I am also thankful to Drs. Juergen Hahn, Ken Hall, and Sam Mannan for the enriching collaboration, insightful discussions, and continuous support.

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Mahmoud M. El-Halwagi

CONTENTS

Preface vii

1 Introduction to Process Integration

1.1 Generating Alternatives for Debottlenecking and Water Reduction in Acrylonitrile Process 2
1.2 Traditional Approaches to Process Development and Improvement 9
1.3 What is Process Synthesis? 11
1.4 What is Process Analysis? 11
1.5 Why Integration? 12
1.6 What is Process Integration? 15
1.7 Categories of Process Integration 18
1.8 Structure of the Book 18
1.9 References 19

2 Overall Mass Targeting

2.1 Targeting for Minimum Discharge of Waste 21
2.2 Targeting for Minimum Purchase of Fresh Material Utilities 25
2.3 Mass-Integration Strategies for Attaining Targets 26

2.4 Problems 33
2.5 References 36

3 Graphical Techniques for Direct-Recycle Strategies

3.1 Problem Statement 40
3.2 Source–Sink Mapping Diagram and Lever-Arm Rules 40
3.3 Selection of Sources, Sinks, and Recycle Routes 47
3.4 Direct-Recycle Targets Through Material Recycle Pinch Diagram 62
3.5 Design Rules from the Material Recycle Pinch Diagram 65
3.6 Multicomponent Source–Sink Mapping Diagram 78
3.7 Additional Readings 81
3.8 Problems 81
3.9 References 85

4 Synthesis of Mass Exchange Networks: A Graphical Approach

4.1 Design of Individual Mass Exchangers 88
4.2 Cost Optimization of Mass Exchangers 92
4.3 Problem Statement for Synthesis of Mass Exchange Networks 101
4.4 Mass Exchange Pinch Diagram 104
4.5 Screening of Multiple External MSAs and Constructing the Pinch Diagram without Process MSAs 117
4.6 Example - Wastewater Treatment 121
4.7 Additional Readings 123
4.8 Problems 123
4.9 Symbols 132
4.10 References 133

5 Visualization Techniques for the Development of Detailed Mass-Integration Strategies

5.1 Low/No Cost Strategies 139
5.2 Modest Changes in Process Variables and Operating Conditions 140
5.3 Medium-Cost Strategies and Main Technology Changes 140
5.4 Problems 157
5.5 References 160

6 Algebraic Approach to Targeting Direct Recycle

6.1 Problem Statement 162
6.2 Algebraic Targeting Approach 162
6.3 Algebraic Targeting Procedure 168
6.4 Case Study: Targeting for Acetic Acid Usage in a Vinyl Acetate Plant 170
6.5 Problems 171
6.6 Symbols 171
6.7 References 172

7 An Algebraic Approach to the Targeting of Mass Exchange Networks

7.1 The Composition-Interval Diagram 174
7.2 Table of Exchangeable Loads 175
7.3 Mass Exchange Cascade Diagram 175
7.4 Example on Cleaning of Aqueous Wastes 176
7.5 Problems 179
7.6 Symbols 181
7.7 References 182

8 Recycle Strategies Using Property Integration

8.1 Property-Based Material Recycle Pinch Diagram 184
8.2 Process Modification Based on Property-Based Pinch Diagram 189
8.3 Example on Solvent Recycle in Metal Degreasing 191
8.4 Clustering Techniques for Multiple Properties 195
8.5 Cluster-Based Source–Sink Mapping Diagram for Property-Based Recycle and Interception 200
8.6 Property-Based Design Rules for Recycle and Interception 202
8.7 Dealing with Multiplicity of Cluster-to-Property Mapping 205
8.8 Papermaking and Fiber Recycle Example 209
8.9 Relationship between Clusters and Mass Fractions 220
8.10 Additional Readings 222
8.11 Problems 222
8.12 Symbols 227
8.13 References 228

9 Heat Integration

9.1 Synthesis of Heat Exchange Networks (HENs) 231
9.2 Heat Exchange Pinch Diagram 233
9.3 Minimum Utility Targeting Through an Algebraic Procedure 244
9.4 Case Study Revisited Using the Algebraic Procedure 245
9.5 Screening of Multiple Utilities Using the Grand Composite Representation 248
9.6 Problems 252
9.7 Symbols 256
9.8 References 256

10 Combined Heat and Power Integration

10.1 Heat Engines 259
10.2 Heat Pumps 262
10.3 Heat Engines and Thermal Pinch Diagram 266
10.4 Heat Pumps and Thermal Pinch Diagram 272
10.5 Cogeneration Targeting 273
10.6 Additional Readings 282
10.7 Problems 282
10.8 References 282

11 Overview of Optimization

11.1 Mathematical Programming 286
11.2 Classification of Optimization Programs 289
11.3 Formulation of Optimization Models 290
11.4 The Use of 0-1 Binary-Integer Variables 301
11.5 Enumerating Multiple Solutions Using Integer Cuts 304
11.6 Modeling Discontinuous Functions and What-If Scenarios Using Integer Variables 307
11.7 Problems 311
11.8 References 314

12 Mathematical Approach to Direct Recycle

12.1 Problem Statement 315
12.2 Problem Representation 316
12.3 Optimization Formulation 317
12.4 Interaction between Direct Recycle and the Process 324

12.5 Problems 333
12.6 Symbols 333
12.7 References 334

13 Mathematical Techniques for the Synthesis of Mass and Heat Exchange Networks

13.1 Synthesis of HENs 335
13.2 Synthesis of MENs 341
13.3 Problems 347
13.4 Symbols 347
13.5 References 348

14 Mathematical Techniques for Mass Integration

14.1 Source-Interception-Sink Representation 349
14.2 Incorporation of Process Model in Mass Integration 362
14.3 Problems 372
14.4 Symbols 375
14.5 References 375

15 Putting it Together: Initiatives and Applications

15.1 Are there Opportunities? 377
15.2 Starting and Sustaining PI Initiatives and Projects 378
15.3 Examples of Industrial Applications 380
15.4 References 384

Appendix I: Conversion Factors 385

Appendix II: Lingo Software 389

AII.1 Creating a New File 389
AII.2 Model Format 389
AII.3 Solving a Program 390
AII.4 Mathematical Functions 391
AII.5 Dual Prices and Sensitivity Analysis 391
AII.6 References 394

Index 395

1 INTRODUCTION TO PROCESS INTEGRATION

The process industries are among the most important manufacturing facilities. They span a wide range of industries including chemical, petroleum, gas, petrochemical, pharmaceutical, food, microelectronics, metal, textile, and forestry products. The performance of these industries is strongly dependent on their engineering and engineers. So, what are the primary responsibilities of process engineers in the process industries? Many process engineers would indicate that their role in the process industries is to design and operate industrial processes and make them work faster, better, cheaper, safer, and greener. All of these tasks lead to more competitive processes with desirable profit margins and market share. Specifically, these responsibilities may be expressed through the following specific objectives:

- Process innovation
- Profitability enhancement
- Yield improvement
- Capital-productivity increase
- Quality control, assurance, and enhancement
- Resource conservation
- Pollution prevention
- Safety
- Debottlenecking

These objectives are also closely related to the seven themes identified by Keller and Bryan (2000) as the key drivers for process-engineering research, development, and changes in the primary chemical process industries. These themes are:

- Reduction in raw-material cost
- Reduction in capital investment
- Reduction in energy use
- Increase in process flexibility and reduction in inventory
- Ever greater emphasis on process safety
- Increased attention to quality
- Better environmental performance

The question is how? What are the challenges, required methodologies, and enabling tools needed by engineers to carry out their responsibilities. In order to shed some light on these issues, let us consider the following motivating example.

1.1 GENERATING ALTERNATIVES FOR DEBOTTLENECKING AND WATER REDUCTION IN ACRYLONITRILE PROCESS

Consider the process shown in Figure 1-1a for the production of acrylonitrile (AN, C_3H_3N). The main reaction in the process involves the vapor phase

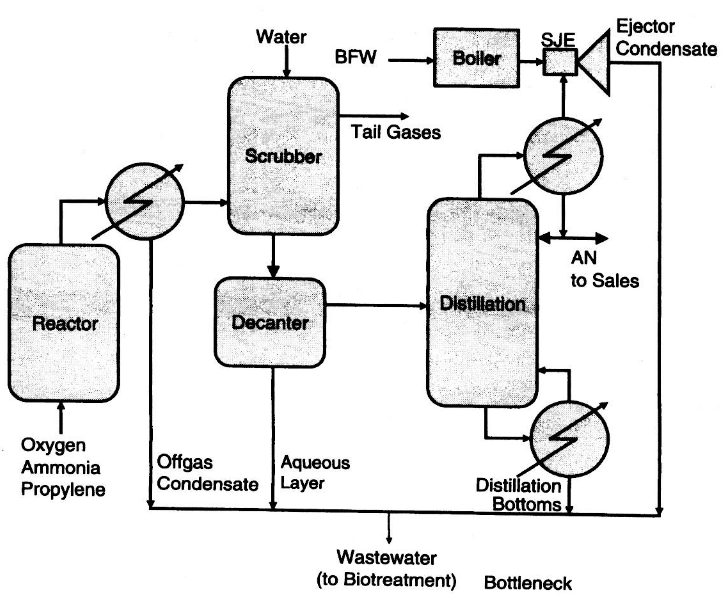

FIGURE 1-1a PROCESS FOR AN MANUFACTURE (EL-HALWAGI 1997)