Khalid Y. Al-Qahtani and
Ali Elkamel

Planning and Integration of
Refinery and Petrochemical
Operations
Related Titles

Reniers, G. L. L.
Multi-Plant Safety and Security Management in the Chemical and Process Industries
2010
ISBN: 978-3-527-32551-1

Lieberman, N.
Troubleshooting Process Plant Control

Georgiadis, M., Kikkinides, E. S., Pistikopoulos, E. (eds.)
Process Systems Engineering Volume 5: Energy Systems Engineering
2008
ISBN: 978-3-527-31694-6

Elvers, B. (ed.)
Handbook of Fuels
Energy Sources for Transportation
2008
ISBN: 978-3-527-30740-1

Papageorgiou, L., Georgiadis, M. (eds.)
Process Systems Engineering Volume 4: Supply Chain Optimization
2008
ISBN: 978-3-527-31906-0

Wiley
Wiley Critical Content
Petroleum Technology, 2 Volume Set
ISBN: 978-0-470-13402-3

Bloch, H. P.
A Practical Guide to Compressor Technology
2006
ISBN: 978-0-471-72793-4

Ocic, O.
Oil Refineries in the 21st Century
Energy Efficient, Cost Effective, Environmentally Benign
2005
ISBN: 978-3-527-31194-1

Papageorgiou, L., Georgiadis, M. (eds.)
Process Systems Engineering Volume 3: Supply Chain Optimization
2008
ISBN: 978-3-527-31693-9
Planning and Integration of Refinery and Petrochemical Operations
Contents

Preface IX

Part One  Background 1

1 Petroleum Refining and Petrochemical Industry Overview 3
1.1 Refinery Overview 3
1.2 Mathematical Programming in Refining 5
1.3 Refinery Configuration 7
1.3.1 Distillation Processes 7
1.3.2 Coking and Thermal Processes 8
1.3.3 Catalytic Processes 9
1.3.3.1 Cracking Processes 9
1.3.3.2 Alteration Processes 9
1.3.4 Treatment Processes 10
1.3.5 Product Blending 10
1.4 Petrochemical Industry Overview 11
1.5 Petrochemical Feedstock 12
1.5.1 Aromatics 12
1.5.2 Olefins 13
1.5.3 Normal Paraffins and Cyclo-Paraffins 13
1.6 Refinery and Petrochemical Synergy Benefits 14
1.6.1 Process Integration 14
1.6.2 Utilities Integration 15
1.6.3 Fuel Gas Upgrade 16

References 16

Part Two  Deterministic Planning Models 19

2 Petroleum Refinery Planning 21
2.1 Production Planning and Scheduling 21
2.2 Operations Practices in the Past 23
3.6 Conclusion 75
References 77

4 Petrochemical Network Planning 81
4.1 Introduction 81
4.2 Literature Review 82
4.3 Model Formulation 83
4.4 Illustrative Case Study 84
4.5 Conclusion 87
References 88

5 Multisite Refinery and Petrochemical Network Integration 91
5.1 Introduction 91
5.2 Problem Statement 93
5.3 Model Formulation 95
5.4 Illustrative Case Study 99
5.5 Conclusion 105
References 106

Part Three Planning Under Uncertainty 109

6 Planning Under Uncertainty for a Single Refinery Plant 111
6.1 Introduction 111
6.2 Problem Definition 112
6.3 Deterministic Model Formulation 112
6.4 Stochastic Model Formulation 114
6.4.1 Approach 1: Risk Model I 114
6.4.1.1 Sampling Methodology 115
6.4.1.2 Objective Function Evaluation 115
6.4.1.3 Variance Calculation 116
6.4.2 Approach 2: Expectation Models I and II 117
6.4.2.1 Demand Uncertainty 117
6.4.2.2 Process Yield Uncertainty 118
6.4.3 Approach 3: Risk Model II 119
6.4.4 Approach 4: Risk Model III 120
6.5 Analysis Methodology 121
6.5.1 Model and Solution Robustness 121
6.5.2 Variation Coefficient 122
6.6 Illustrative Case Study 123
6.6.1 Approach 1: Risk Model I 124
6.6.2 Approach 2: Expectation Models I and II 125
6.6.3 Approach 3: Risk Model II 126
6.6.4 Approach 4: Risk Model III 133
6.7 General Remarks 133
References 137
Preface

Petroleum refining and the petrochemical industry account for a major share of the world energy and industrial market. In many situations, they represent the economic back-bone of industrial countries. Today, the volatile environment of the market and the continuous change in customer requirements lead to constant pressure to seek opportunities that properly align and coordinate the different components of the industry. In particular, petroleum refining and petrochemical industry coordination and integration is gaining a great deal of interest. Previous attempts in the field either studied the two systems in isolation or assumed limited interactions between them.

This book aims at providing the reader with a detailed understanding of the planning, integration and coordination of multisite refinery and petrochemical networks using proper deterministic and stochastic techniques. The book consists of three parts:

- **Part 1**: Background
- **Part 2**: Deterministic Planning Models
- **Part 3**: Planning under Uncertainty

Part 1, comprised of one chapter, introduces the reader to the configuration of petroleum refining and the petrochemical industry. It also discusses key classifications of petrochemical industry feedstock from petroleum products. The final part explains and proposes possible synergies between the petroleum refinery and the petrochemical industry.

Part 2, comprised of four chapters, focusses on the area of planning in petroleum refining and the petrochemical industry under deterministic conditions. Chapter 2 discusses the model classes used in process planning (i.e., empirical models, and first principle models) and provides a series of case studies to illustrate the concepts and impeding assumptions of the different modeling approaches. Chapter 3 tackles the integration and coordination of a multisite refinery network. It addresses the design and analysis of multisite integration and coordination strategies within a network of petroleum refineries through a mixed-integer linear programming (MILP) technique. Chapter 4 explains the general representation of a petrochemical planning model which selects the optimal network from the overall petrochemical superstructure. The system is modeled as a MILP problem and is illustrated via a
numerical example. Chapter 5 addresses the integration between the multisite refinery system and the petrochemical industry. The chapter develops a framework for the design and analysis of possible integration and coordination strategies of multisite refinery and petrochemical networks to satisfy given petroleum and chemical product demand. The main feature of the proposed approach is the development of a methodology for the simultaneous analysis of process network integration within a multisite refinery and petrochemical system. Part 2 of this book serves as a foundation for the reader of Part 3.

Part 3, comprised of four chapters, tackles the area of planning in the petroleum refinery and the petrochemical industry under uncertainty. Chapter 6 explains the use of two-stage stochastic programming and the incorporation of risk management for a single site refinery plant. The example used in this chapter is simple enough for the reader to grasp the concept of two-stage stochastic programming and risk management and to be prepared for the larger scale systems in the remaining chapters. Chapter 7 extends the proposed model in Chapter 3 to account for model uncertainty by means of two-stage stochastic programming. Parameter uncertainty was considered and included coefficients of the objective function and right-hand-side parameters in the inequality constraints. Robustness is analyzed based on both model robustness and solution robustness, where each measure is assigned a scaling factor to analyze the sensitivity of the refinery plan and the integration network due to variations. The proposed technique makes use of the sample average approximation (SAA) method with statistical bounding techniques to give an insight on the sample size required to give adequate approximation of the problem. Chapter 8 addresses the planning, design and optimization of a network of petrochemical processes under uncertainty and robust considerations. Similar to the previous chapter, robustness is analyzed based on both model robustness and solution robustness. Parameter uncertainty considered in this part includes process yield, raw material and product prices, and lower product market demand. The expected value of perfect information (EVPI) and the value of the stochastic solution (VSS) are also investigated to illustrate numerically the value of including the randomness of the different model parameters. Chapter 9 extends the petroleum refinery and petrochemical industry integration problem, explained in Chapter 5, to consider different sources of uncertainties in model parameters. Parameter uncertainty considered includes imported crude oil price, refinery product price, petrochemical product price, refinery market demand, and petrochemical lower level product demand. The sample average approximation (SAA) method is within an iterative scheme to generate the required scenarios and provide solution quality by measuring the optimality gap of the final solution.

All chapters are equipped with clear figures and tables to help the reader understand the included topics. Furthermore, several appendices are included to explain the general background in the area of stochastic programming, chance constraint programming and robust optimization.
Part One
Background
1 Petroleum Refining and Petrochemical Industry Overview

Petroleum refining and the petrochemical industry account for a major share in the world energy and industrial market. In many situations, they represent the economic backbone of industrial countries. Today, the volatile environment of the market and the continuous change in customer requirements lead to constant pressure to seek opportunities that properly align and coordinate the different components of the industry. In particular, petroleum refining and petrochemical industry coordination and integration is gaining a great deal of interest.

In this chapter, we will give an overview of the process configurations of petroleum refining and the petrochemical industry. We will also discuss the key classifications of petrochemical industry feedstock from petroleum products and explain and propose possible synergies between the petroleum refinery and the petrochemical industry.

1.1 Refinery Overview

The first refinery was built in Titusville, Pennsylvania in 1860 at a cost of $15,000 (Nelson, 1958). This refinery and other refineries at that time only used batch distillation to separate kerosene and heating oil from other crude fractions. During the early years, refining separation was performed using batch processing. However, with the increase in demand for petroleum products, continuous refining became a necessity. The first widely recognized continuous refinery plants emerged around 1912 (Nelson, 1958). With the diversity and complexity of the demand for petroleum products, the refining industry has developed from a few simple processing units to very complex production systems. A simplified process flow diagram of a typical modern refinery is shown in Figure 1.1. For a detailed history of the evolution of refining technologies, we refer the reader to Nelson (1958) and Wilson (1997).

Typically, a refinery is made up of several distinct components that constitute a total production system, as shown in Figure 1.2. These components include: