

Abstract
Process Economics Program Report No. 211
HYDROCRACKING
(April 1994)

The hydrocracking unit is the most versatile of refinery conversion units. It can process a wide range of feedstocks from naphtha to asphalt to yield any desired product with a molecular weight lower than that of the feedstock. In the 1960s hydrocracking was widely used to produce gasoline in the United States. Since the 1970s it has also gained worldwide recognition for its high quality distillate products. In the environmentally conscious 1990s, hydrocracking may be the best source of low sulfur and low aromatics diesel fuel as well as high smoke point jet fuel.

This report reviews the technology and economics of high pressure and moderate pressure hydrocracking. We evaluate the flexibility of the hydrocracking process for the production of middle distillate and low sulfur fuel oil from vacuum gas oil feedstock, and the production of naphtha from a mixed feed of fluid catalytic cracking light cycle oil and straight run distillate. These three case studies illustrate refiners' options to increase their conversion capacity.

We discuss the world hydrocracking processing trends and include a detailed listing of operating units. Announced new hydrocracking capacity is also listed. This information will be useful for refiners, hydrogen suppliers, and catalyst vendors in identifying future needs and new opportunities.

CONTENTS

1 INTRODUCTION	1-1
2 SUMMARY	2-1
GENERAL ASPECTS	2-1
TECHNICAL ASPECTS	2-1
ECONOMIC ASPECTS	2-3
3 INDUSTRY STATUS	3-1
GENERAL	3-1
TRENDS IN TRANSPORTATION FUEL DEMAND	3-1
Reformulated Gasoline	3-2
Diesel Regulations	3-2
INSTALLED CAPACITIES	3-3
Worldwide Summary	3-4
United States and Canada	3-5
Europe	3-13
Asia-Pacific Region	3-13
Latin America and Caribbean	3-13
Middle East, India, and Africa	3-13
NEW HYDROCRACKING CAPACITY	3-24
4 ROLE OF HYDROCRACKING IN THE REFINERY	4-1
FUELS REFINERY OVERVIEW	4-1
HYDROSKIMMING REFINERY CONFIGURATION	4-3
CONVERSION REFINERY CONFIGURATIONS	4-3
FCC-Hydrocracking Refinery	4-4
Hydrocracking Refinery	4-5
HYDROCRACKING FEEDSTOCKS	4-5
HYDROCRACKING PRODUCTS	4-5
Gasoline	4-6
Distillate Fuels	4-6
Jet Fuels	4-6
Diesel Fuels	4-7
Fuel Oil	4-7
Unconverted Bottoms	4-8

CONTENTS (Continued)

5 HYDROCRACKING TECHNICAL REVIEW	5-1
CHEMISTRY OF HYDROCRACKING	5-1
Hydrotreating	5-1
Desulfurization	5-1
Denitrogenation	5-1
Hydrocracking	5-2
Reactions of Paraffins	5-2
Reactions of Cycloparaffins	5-3
Reactions of Alkyl Aromatics	5-3
Hydrocracking of Cycloparaffins versus Alkylbenzene	5-6
Reactions of Polynuclear Aromatics	5-6
Hydrocracking Thermodynamics	5-6
PROCESS VARIABLES	5-8
Reaction Temperature	5-8
Reactor Pressure	5-8
Space Velocity	5-8
Nitrogen Content	5-8
Hydrogen Sulfide	5-9
REACTION PROCESS REVIEW	5-9
Multi-Stage Hydrocracking	5-9
Two-Stage Hydrocracking	5-10
Three-Stage Hydrocracking	5-12
Single-Stage Hydrocracking	5-12
Single-Stage Series Flow Hydrocracking	5-12
Single-Stage Single-Reactor Hydrocracking	5-12
Single-Stage Once-Through Hydrocracking	5-15
Two-Stage Versus Single-Stage Hydrocracking	5-15
High Pressure and Moderate Pressure Hydrocracking	5-15
HYDROCRACKING CATALYSTS	5-16
Catalyst Metal Function	5-17
Catalyst Supports	5-17
Amorphous Catalysts	5-18
Zeolite Catalyst	5-18
Hydrocracking Catalyst Market	5-18
POLYNUCLEAR AROMATICS MANAGEMENT	5-19

CONTENTS (Continued)

6 HYDROCRACKING FOR MIDDLE DISTILLATE	6-1
PROCESS DESCRIPTION	6-1
Reaction (Section 100)	6-4
Vapor Recovery (Section 200)	6-4
Product Recovery (Section 300)	6-4
Make-Up Gas Compression (Section 400)	6-5
PROCESS DISCUSSION	6-11
Feedstock	6-11
Operating Conditions	6-11
Hydrocracking Catalyst	6-11
Conversion	6-12
Hydrogen Requirement	6-13
Equipment	6-14
Heater	6-14
Make-up Gas Compressor	6-14
Materials of Construction	6-14
Storage Requirements	6-15
Product Quality	6-15
Waste Treatment	6-15
Spent Catalyst	6-15
COST ESTIMATES	6-15
Investment Costs	6-15
Production Costs	6-16
7 HYDROCRACKING FOR NAPHTHA	7-1
PROCESS DESCRIPTION	7-1
PROCESS DISCUSSION	7-10
Process Configuration	7-10
Catalysts	7-10
Feedstock	7-10
Product Quality	7-11
Materials of Construction	7-11
Storage Requirements	7-11
Waste Treatment	7-11
Spent Catalyst	7-11

CONTENTS (Concluded)

7 HYDROCRACKING FOR NAPHTHA (Concluded)	
COST ESTIMATES	7-12
Investment Costs	7-12
Product Costs	7-12
Profitability	7-13
8 MODERATE PRESSURE HYDROCRACKING	8-1
PROCESS DESCRIPTION	8-1
Reaction (Section 100)	8-1
Product Recovery (Section 200)	8-1
PROCESS DISCUSSION	8-9
Operating Conditions	8-9
Product Quality	8-10
Product Recovery	8-10
Material of Construction	8-11
Storage Requirements	8-11
COST ESTIMATES	8-11
Investment Costs	8-11
Production Costs	8-11
ECONOMICS OF MPHC AND VGO DESULFURIZATION	8-18
Assumptions	8-18
Profitability	8-18
APPENDIX A: PATENT SUMMARY TABLES	A-1
APPENDIX B: DESIGN AND COST BASES	B-1
APPENDIX C: CITED REFERENCES	C-1
APPENDIX D: PATENT REFERENCES BY COMPANY	D-1
APPENDIX E: PROCESS FLOW DIAGRAMS	E-1

ILLUSTRATIONS

3.1	U.S. Petroleum Administration for Defense (PAD) Districts	3-6
4.1	Refinery Block Flow Diagram	4-2
5.1	Reactions of Cycloparaffins	5-4
5.2	Reactions of Alkyl Aromatics	5-5
5.3	Reactions of Polycyclic Aromatics	5-7
5.4	Simplified Flow Diagram of Two-Stage Hydrocracking	5-11
5.5	Simplified Flow Diagram of Single-Stage Series Flow Hydrocracking	5-13
5.6	Simplified Flow Diagram of Single-Stage Hydrocracking	5-14
6.1	Hydrocracking for Middle Distillate Process Flow Diagram	E-3
6.2	Hydrocracking for Middle Distillate Vacuum Gas Oil Valuation	6-22
7.1	Hydrocracking for Naphtha Process Flow Diagram	E-5
8.1	Moderate Pressure Hydrocracking Process Flow Diagram	E-7
8.2	Naphtha Price (Singapore) versus Crude Oil Price: 1978-1992	8-20
8.3	Gas Oil Price (Singapore) versus Crude Oil Price: 1978-1992	8-21
8.4	0.3% S Residual Fuel Oil Price (Singapore) versus Crude Oil Price: 1978-1992	8-22

TABLES

2.1	Middle Distillate Hydrocracking Kerosene Production Summary of Cost Estimates	2-5
2.2	Naphtha Hydrocracking Naphtha Production Summary of Cost Estimates	2-6
2.3	Moderate Pressure Hydrocracking Low Sulfur Fuel Oil Production Summary of Cost Estimates	2-7
3.1	Percentage of Refinery Fuels Consumption	3-2
3.2	Diesel Fuel Specifications	3-3
3.3	Worldwide Conversion Refinery Capacity Summary-January 1994	3-4
3.4	United States and Canada Refinery Conversion Refining Capacity Summary-January 1994	3-7
3.5	Installed Conversion Refinery Capacity United States and Canada-January 1994	3-8
3.6	Installed Conversion Refinery Capacity Europe-January 1994	3-14
3.7	Installed Conversion Refinery Capacity Asia-Pacific-January 1994	3-18
3.8	Installed Conversion Refinery Capacity Latin America and the Caribbean-January 1994	3-20
3.9	Installed Conversion Refinery Capacity The Middle East, India, and Africa-January 1994	3-22
3.10	New Hydrocracking Constructions	3-24
4.1	Properties of Aviation Fuels	4-6
4.2	Properties of Diesel Fuels	4-7
4.3	Properties of Fuel Oils	4-8
5.1	Hydrocracking Patent Summary	A-3

TABLES (Continued)

5.2	Conventional High Pressure and Moderate Pressure Hydrocracking Operating Conditions	5-16
5.3	Hydrocracking Catalyst Vendors	5-19
6.1	Hydrocracking for Middle Distillate Design Bases and Assumptions	6-2
6.2	Hydrocracking for Middle Distillate Feed Properties	6-2
6.3	Hydrocracking for Middle Distillate Product Yields and Properties	6-3
6.4	Hydrocracking for Middle Distillate Stream Flows	6-6
6.5	Hydrocracking for Middle Distillate Major Equipment	6-8
6.6	Hydrocracking for Middle Distillate Utilities Summary	6-10
6.7	Hydrocracking for Middle Distillate Comparison of Product Yields	6-12
6.8	Hydrocracking for Middle Distillate Total Capital Investment	6-17
6.9	Hydrocracking for Middle Distillate Capital Investment by Section	6-18
6.10	Hydrocracking for Middle Distillate Production Costs	6-20
7.1	Hydrocracking for Naphtha Design Bases and Assumptions	7-2
7.2	Hydrocracking for Naphtha Feed Properties	7-3
7.3	Hydrocracking for Naphtha Product Properties	7-4
7.4	Hydrocracking for Naphtha Stream Flows	7-5
7.5	Hydrocracking for Naphtha Major Equipment	7-7

TABLES (Continued)

7.6	Hydrocracking for Naphtha Utilities Summary	7-9
7.7	Hydrocracking for Naphtha Total Capital Investment	7-14
7.8	Hydrocracking for Naphtha Capital Investment by Section	7-15
7.9	Hydrocracking for Naphtha Production Costs	7-17
7.10	Average Refinery Product Slate in 1990	7-19
8.1	Moderate Pressure Hydrocracking Design Bases and Assumptions	8-2
8.2	Moderate Pressure Hydrocracking Product Yields and Properties	8-3
8.3	Moderate Pressure Hydrocracking Stream Flows	8-4
8.4	Moderate Pressure Hydrocracking Major Equipment	8-6
8.5	Moderate Pressure Hydrocracking Utilities Summary	8-8
8.6	Moderate Pressure Hydrocracking Total Capital Investment	8-12
8.7	Moderate Pressure Hydrocracking Capital Investment by Section	8-13
8.8	Moderate Pressure Hydrocracking Production Costs	8-14
8.9	Moderate Pressure Hydrocracking Production Economics Vaccum Gas Oil on the U.S. Gulf Coast	8-16
8.10	Comparison of Moderate Pressure Hydrocracking (MPHC) and VGO Hydrodesulfurization (HDS) in the Asia-Pacific Region Process Conditions and Product Yields	8-23
8.11	Comparison of Moderate Pressure Hydrocracking (MPHC) and VGO Desulfurization (HDS) in the Asia-Pacific Region Process Economics	8-24