

3RD EDITION

# FLUID CATALYTIC CRACKING HANDBOOK

An Expert Guide to the Practical Operation,  
Design, and Optimization of FCC Units



REZA SADEGHBEIGI



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# **Fluid Catalytic Cracking Handbook**

## ***Dedication***

*To my family and the great friends I have made over the years.*



## *Preface to the Third Edition*

Coming from Iran, I have been extremely blessed and fortunate in being educated and working in the United States of America. From my days of working as roustabout and roughneck on offshore drilling rigs in the early 1970s, to nearly 40 years later, my goal has been to share my hard-learned experience and knowledge with others. I have accomplished this through publishing technical articles and books, conducting seminars, and providing customized training. *My main objective of writing this book is simply to give back a fraction of the good will that so many great folks have provided to me throughout my professional journey.*

The refining industry has been downsizing in the United States for many years. The crop of aging refinery technical experts is fast disappearing, with no “farm system” to replace them. Attending annual conferences used to be beneficial in providing this technology transfer. In the past 10 years, these conferences are becoming restrained by political correctness and influenced by commercial interests. In many cases, the speakers/presenters have limited knowledge for offering practical “lessons learned” on the spot. Furthermore, many attendees are reluctant to challenge the status quo or raise new ideas in a public forum.

This third edition truly provides a transfer of my 35 years of experience in the cat cracking process. There are no other publications available that deliver comprehensive discussions of the cat cracking field without any commercial interest interference, while at the same time offering tangible and practical information that can be used in making the “right” decisions in an ever-challenged industry. Examples of these decisions would be processing suitable feedstock, purchasing appropriate fresh catalyst and/or additive, designing or ensuring that FCC equipment is designed appropriately, and being able to troubleshoot/optimize the operations of the unit effectively.

Several new chapters have been added since the second edition, and the original chapters have been extensively updated. The new chapter on *refractory lining* contains a great deal of practical information that is essential to enhancing the long-term mechanical reliability of the FCC components. The new chapter on *residue cracking* provides insights into achieving optimum yields, while sustaining long-term unit run length. The new chapter on *flue gas emissions* provides various effective options to better comply with emission requirements, without going overboard.

I am proud of this third edition. For one, I received input/feedback from our valued clients, industry “experts,” as well as my colleagues at RMS Engineering, Inc. Each chapter was reviewed carefully for accuracy and completeness. The emphasis has been on providing tools to maximize the profitability and reliability of existing operations without major capital project expenditures. I hope this book will serve as a handy reference resource for anyone associated with the fluid catalytic cracking process.

I plan to continue sharing my technical expertise and know-how for the next few years.

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## ***Acknowledgments***

I am grateful to the following individuals who played key roles in this book’s completion:

My colleagues at RMS Engineering, Inc., *Shari Glazier*, *Lee Kittleson*, and *Larry Gammon*, who went the “extra mile” to ensure the book flows well. I would also like to thank Doug Hogue, Refractory Consultant of HRCI, for his major contribution to the chapter on refractory.

## *About the Author*

Mr. Reza Sadeghbeigi has extensive experience with fluid cat crackers, having worked with more than 100 FCC units since 1977. Reza received his BS in chemical engineering from Iowa State University and his MS from Oklahoma State University. He is a registered professional engineer in Texas and Louisiana.

Reza established RMS Engineering, Inc. (RMS) in January 1995 to provide independent engineering services to the refining industry in the area of fluid catalytic cracking. RMS provides expertise and know-how in delivering services such as FCC equipment design, troubleshooting, unit optimization, and customized operator/engineer training.

Should you have any questions or comments on this book, or if you would like to tap into our services, please feel free to contact Reza at (281) 333-0464 (US) or by e-mail ([reza@rmsfcc.com](mailto:reza@rmsfcc.com)).



# Contents

<i>Preface and Acknowledgments</i> .....	<i>xi</i>
<i>About the Author</i> .....	<i>xiii</i>
<b><i>Chapter 1: Process Description</i></b> .....	<b><i>1</i></b>
Feed Preheat .....	14
Feed Nozzles—Riser .....	15
Catalyst Separation .....	17
Stripping Section .....	20
Regenerator—Heat/Catalyst Recovery .....	23
Partial Versus Complete Combustion .....	24
Regenerated Catalyst Standpipe/Slide Valve .....	25
Flue Gas Heat and Pressure Recovery Schemes .....	26
Catalyst Handling Facilities .....	28
Main Fractionator .....	28
Gas Plant .....	31
Treating Facilities .....	37
Summary .....	40
References .....	42
<b><i>Chapter 2: Process Control Instrumentation</i></b> .....	<b><i>43</i></b>
Operating Variables .....	44
Process Control Instrumentation .....	44
Summary .....	49
<b><i>Chapter 3: FCC Feed Characterization</i></b> .....	<b><i>51</i></b>
Hydrocarbon Classification .....	52
Feedstock Physical Properties .....	55
Impurities .....	63
Empirical Correlations .....	74

Benefits of Hydroprocessing .....	85
Summary .....	86
References .....	86
<b>Chapter 4: FCC Catalysts .....</b>	<b>87</b>
Catalyst Components .....	87
Catalyst Manufacturing Techniques .....	96
Fresh Catalyst Properties .....	99
E-Cat Analysis .....	101
Catalyst Management .....	109
Catalyst Evaluation .....	113
Summary .....	115
References .....	115
<b>Chapter 5: Catalyst and Feed Additives .....</b>	<b>117</b>
CO Combustion Promoter .....	117
SO <sub>x</sub> Additive .....	118
NO <sub>x</sub> Additive .....	119
ZSM-5 Additive .....	120
Metal Passivation .....	122
Bottoms-Cracking Additive .....	123
Summary .....	123
References .....	123
<b>Chapter 6: Chemistry of FCC Reactions .....</b>	<b>125</b>
Thermal Cracking .....	126
Catalytic Cracking .....	128
Thermodynamic Aspects .....	133
Summary .....	134
References .....	135
<b>Chapter 7: Unit Monitoring and Control .....</b>	<b>137</b>
Material Balance .....	138
Heat Balance .....	152
Pressure Balance .....	159
Summary .....	167
Reference .....	167
<b>Chapter 8: Products and Economics .....</b>	<b>169</b>
FCC Products .....	169
FCC Economics .....	187
Summary .....	189
References .....	189

---

<b>Chapter 9: Effective Project Execution and Management .....</b>	<b>191</b>
Project Management .....	191
<b>Chapter 10: Refractory Lining Systems .....</b>	<b>197</b>
Materials/Manufacture .....	197
Stainless Steel Fibers in Refractory .....	198
Types of Refractory .....	198
Castables—Product Categories .....	199
Physical Properties .....	202
Anchors .....	204
Designing Refractory Lining Systems .....	212
Application Techniques .....	213
Dryout of Refractory Linings .....	218
Initial Heating of Refractory Linings .....	219
Dryout of Refractory Linings During Start-up of Equipment .....	219
Subsequent Heating of Refractory Lining Systems .....	220
Examples of Refractory Systems in FCC Units .....	220
Summary .....	222
Acknowledgment .....	222
<b>Chapter 11: Process and Mechanical Design Guidelines for FCC Equipment .....</b>	<b>223</b>
FCC Catalyst Quality .....	223
Higher Temperature Operation .....	223
Refractory Quality .....	223
More Competitive Refining Industry .....	224
Summary .....	240
<b>Chapter 12: Troubleshooting .....</b>	<b>241</b>
Several General Guidelines for Effective Troubleshooting .....	242
Key Aspects of FCC Catalyst Physical Properties .....	243
Fundamentals of Catalyst Circulation .....	244
Catalyst Losses .....	249
Coking/Fouling .....	251
Increase in Afterburn .....	252
Hot Gas Expanders .....	254
Flow Reversal .....	256
Summary .....	263
<b>Chapter 13: Optimization and Debottlenecking .....</b>	<b>265</b>
Introduction .....	265
Approach to Optimization .....	266
Improving FCC Profitability Through Proven Technologies .....	267

---

Apparent Operating Constraints .....	267
Debottlenecking .....	267
Feed Circuit Hydraulics .....	268
Reactor/Regenerator Structure .....	270
Air and Spent Catalyst Distribution System .....	282
Debottlenecking Catalyst Circulation .....	283
Debottlenecking Combustion Air .....	284
Regeneration .....	285
Flue Gas System .....	285
FCC Catalyst .....	286
Debottlenecking Main Fractionator and Gas Plant .....	286
Debottlenecking the Wet Gas Compressor (WGC).....	288
Improving Performance of Absorber and Stripper Columns .....	289
Debottlenecking Debutanizer Operation .....	290
Instrumentation .....	292
Utilities/Off-sites .....	292
Summary .....	293
<b>Chapter 14: Emissions .....</b>	<b>295</b>
New Source Performance Standards .....	295
Maximum Achievable Control Technology (MACT II) .....	296
EPA Consent Decrees .....	297
Control Options .....	297
Particulate Matter .....	301
Sintered Metal Pulse-Jet Filtration.....	304
NO <sub>x</sub> .....	306
LoTOx™ Technology .....	309
Summary .....	310
<b>Chapter 15: Residue and Deep Hydrotreated Feedstock Processing.....</b>	<b>311</b>
Residue Cracking.....	311
RFCC Technology Offerings .....	316
Operational and Mechanical Reliability .....	321
Operational Impacts of Residue Feedstocks .....	321
Processing “Deep” Hydrotreated Feedstock .....	322
Summary .....	323
<b>Appendix 1: Temperature Variation of Liquid Viscosity .....</b>	<b>325</b>
<b>Appendix 2: Correction to Volumetric Average Boiling Point .....</b>	<b>326</b>
<b>Appendix 3: TOTAL Correlations .....</b>	<b>327</b>
<b>Appendix 4: <math>n-d-M</math> Correlations.....</b>	<b>328</b>

---

<i>Appendix 5: Estimation of Molecular Weight of Petroleum Oils from Viscosity Measurements .....</i>	<i>329</i>
<i>Appendix 6: Kinematic Viscosity to Saybolt Universal Viscosity.....</i>	<i>331</i>
<i>Appendix 7: API Correlations .....</i>	<i>332</i>
<i>Appendix 8: Definitions of Fluidization Terms .....</i>	<i>334</i>
<i>Appendix 9: Conversion of ASTM 50% Point to TBP 50% Point Temperature.....</i>	<i>337</i>
<i>Appendix 10: Determination of TBP Cut Points from ASTM D86 .....</i>	<i>338</i>
<i>Appendix 11: Nominal Pipe Sizes .....</i>	<i>339</i>
<i>Appendix 12: Conversion Factors .....</i>	<i>342</i>
<i>Glossary .....</i>	<i>345</i>
<i>Index.....</i>	<i>355</i>

## *Process Description*

Global demand for transportation fuels will continue to grow and this demand will be met largely by gasoline and diesel fuels. The fluid catalytic cracking (FCC) process continues to play a key role in an integrated refinery as the primary conversion process of crude oil to lighter products. In the next two decades, the FCC process will be likely used for biofuels and possibly for reducing CO<sub>2</sub> emissions. For many refiners, the cat cracker is the key to profitability because the successful operation of the unit determines whether or not the refiner can remain competitive in today's market.

Since the start-up of the first commercial FCC unit in 1942, many improvements have been made to enhance the unit's mechanical reliability and its ability to crack heavier, lower value feedstocks. The FCC has a remarkable history of adapting to continual changes in market demands. Tables 1.1 and 1.1A highlight some of the major developments in the history of the FCC process.

The FCC unit uses a “microspherical” catalyst that behaves like a liquid when it is properly fluidized. The main purpose of the FCC unit is to convert high-boiling petroleum fractions called *gas oil* to high-value transportation fuels (gasoline, jet fuel, and diesel). FCC feedstock is often the gas oil portion of crude oil that commonly boils in the 650°F+ to 1,050°F+ (330–550°C) range. Feedstock properties are discussed in Chapter 3.

Approximately 350 cat crackers are operating worldwide (102 in the United States), with a total processing capacity of over 14.7 million barrels per day [1]. Most of the existing FCC units have been designed or modified by six major technology licensors:

1. UOP (Universal Oil Products)
2. Kellogg Brown & Root—KBR (formerly The M.W. Kellogg Company)
3. ExxonMobil Research and Engineering (EMRE)
4. The Shaw Group Inc.
5. CB&I Lummus
6. Shell Global Solutions International.

**Table 1.1: The Evolution of Catalytic Cracking—Pre FCC Invention.**

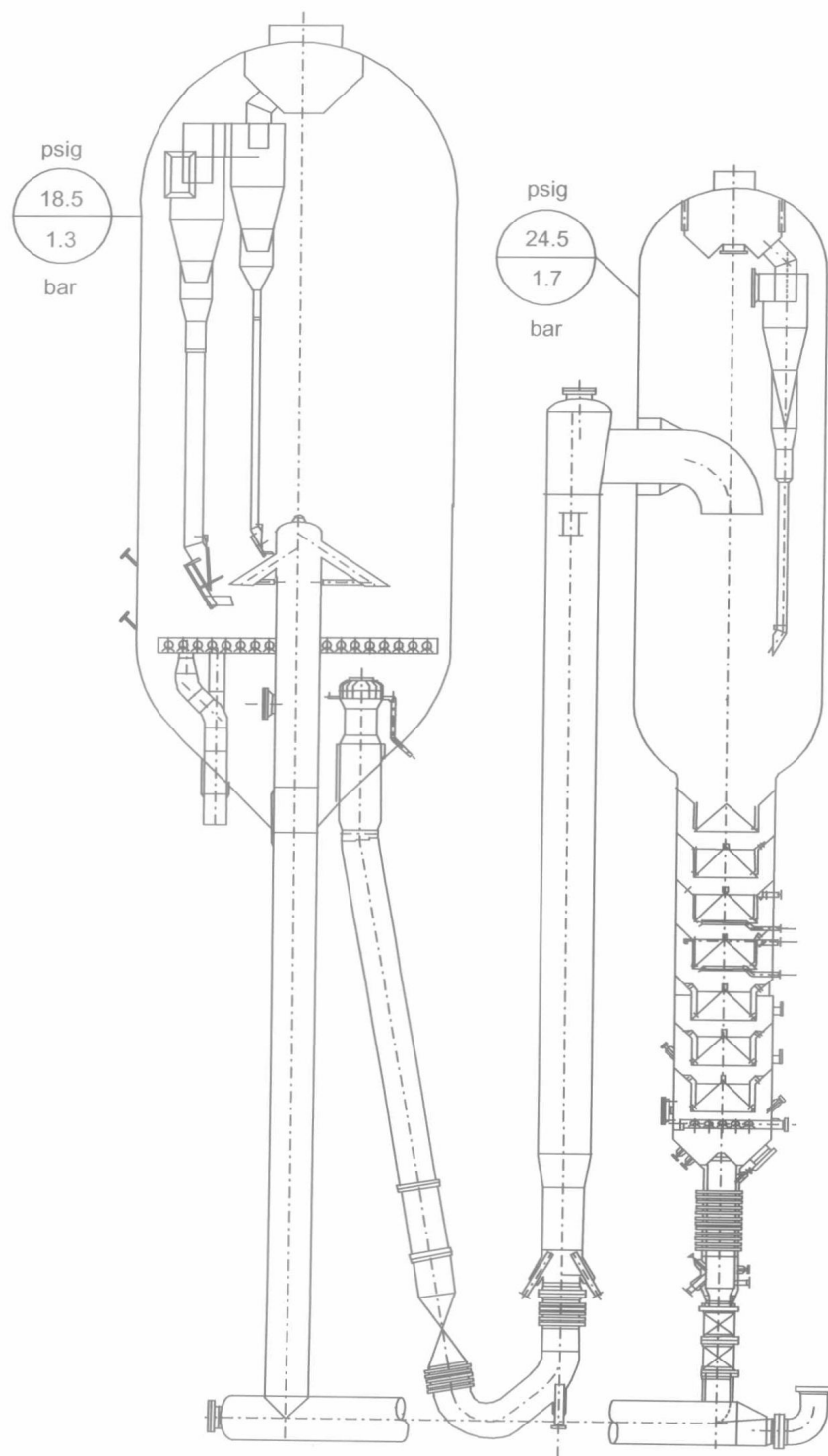
1915	Almer M. McAfee of Gulf Refining Co. discovered that a Friedel—Crafts aluminum chloride catalyst could catalytically crack heavy oil. However, the high cost of catalyst prevented the widespread use of McAfee's process.
1922	The French mechanical engineer named Eugene Jules Houdry and a French pharmacist named E.A. Prodhomme set up a laboratory to develop a catalytic process for conversion of lignite to gasoline. The demonstration plant in 1929 showed the process is not economical. Houdry had found that fuller's earth, a clay containing aluminosilicate ( $\text{Al}_2\text{SiO}_6$ ), could convert oil from lignite to gasoline.
1930	The Vacuum Oil Company invited Houdry to move his laboratory to Paulsboro, NJ.
1931	The Vacuum Oil Company merged with Standard Oil of New York (Socony) to form Socony-Vacuum Oil Company.
1933	A small Houdry unit processing 200 bpd of petroleum oil was commissioned because of the economic depression of the early 1930s. Socony-Vacuum could not support Houdry's work and granted him permission to seek help elsewhere. Sun Oil Company joined in developing Houdry's process.
1936	Socony-Vacuum converted an old thermal cracker to catalytically crack 2,000 bpd of petroleum oil using the Houdry process.
1936	Use of natural clays as catalyst greatly improved cracking efficiency.
1937	Sun Oil began operation of Houdry unit processing 12,000 bpd. The Houdry process used reactors with a fixed bed of catalyst and it was a semi-batch operation. Almost 50% of the cracked products were gasoline.
1938	With the commercial successes of the Houdry process, Standard Oil of New Jersey resumed research of the FCC process as part of the consortium that included five oil companies (Standard Oil of New Jersey, Standard Oil of Indiana, Anglo-Iranian Oil, Texas Oil, and Dutch Shell), two engineering construction companies (M.W. Kellogg and Universal Oil Products), and a German chemical company (I.G. Farben). This consortium was called Catalyst Research Associates (CRA), and its objective was to develop a catalytic cracking process that did not impinge on Houdry's patents. Two MIT professors (Warren K. Lewis and Edwin R. Gilliland) had suggested to CRA researchers that a low gas velocity through a powder might lift the powder enough to flow like liquid. Standard Oil of New Jersey developed and patented the first fluid catalyst cracking process.
1938— 1940	By 1938 Socony-Vacuum had 8 additional units under construction, and by 1940 there were 14 Houdry units in operation processing 140,000 bpd of oil. The next step was to develop a continuous process rather than Houdry's semi-batch operation. Thus came the advent of a moving-bed process known as thermofor catalytic cracking (TCC), which used a bucket conveyor elevator to move the catalyst from the regenerator kiln to the reactor.
1940	M.W. Kellogg designed and constructed a large pilot plant at the Standard Oil Baton Rouge, Louisiana, refinery.
1941	A small TCC demonstration unit was built at Socony-Vacuum's Paulsboro refinery.
1943	A 10,000 bpd TCC unit began operation at Magnolia Oil Company in Beaumont, TX (an affiliate of Socony-Vacuum's Paulsboro refinery).
1945	By the end of World War II, the processing capacity of the TCC units in operation was about 300,000 bpd.

**Table 1.1A: The Evolution of the FCC Process.**

1942	The first commercial FCC unit (Model I upflow design) started up at the Standard of New Jersey Baton Rouge, Louisiana, refinery, processing 12,000 bpd.
1943	First down-flow design FCC unit was brought online. First TCC brought online.
1947	First Universal Oil Products (UOP)-stacked FCC unit was built. M.W. Kellogg introduced the Model III FCC unit.
1948	Davison Division of W.R. Grace & Co. developed microspheroidal FCC catalyst.
1950s	Evolution of bed cracking process designs.
1951	M.W. Kellogg introduced the Orthoflow design.
1952	Exxon introduced the Model IV.
1954	High alumina ( $\text{Al}_2\text{O}_3$ ) catalysts were introduced.
Mid-1950s	UOP introduces side-by-side design.
1956	Shell invented riser cracking.
1961	Kellogg and Phillips developed and put the first resid cracker onstream at the Borger, TX, refinery.
1963	The first Model I FCC unit was shut down after 22 years of operation.
1964	Mobil Oil developed ultrastable Y (USY) and rare earth exchanged ultrastable Y zeolite (ReY) FCC catalyst. Last TCC unit completed.
1972	Amoco Oil invented high-temperature regeneration.
1974	Mobil Oil introduced CO promoter.
1975	Phillips Petroleum developed antimony for nickel passivation.
1981	TOTAL invented two-stage regeneration for processing residue.
1983	Mobil reported first commercial use of ZSM-5 octane/olefins additive in FCC.
1985	Mobil started installing closed cyclone systems in its FCC units.
1994	Coastal Corporation conducted commercial test of ultrashort residence time, selective cracking (MSCC).
1996	ABB Lummus Global acquired Texaco FCC technologies.

Figures 1.1–1.9 contain sketches of typical unit configurations offered by the FCC technology licensors. Although the mechanical configuration of individual FCC units may differ, their common objective is to upgrade low-value feedstock to the more valuable products used for transportation and petrochemical industries. Worldwide, about 45% of all gasoline comes from FCC and ancillary units such as the alkylation unit.





**Figure 1.1:** Example of a Model II cat cracker with enhanced RMS design internals.