# Fluid Catalytic Cracking Handbook

## Design, Operation, and Troubleshooting of FCC Facilities

Reza Sadeghbeigi

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# Fluid Catalytic Cracking Handbook

To my wife Connie
and our children Jessica and Jason
for their understanding and support.

# Preface

Fluid Catalytic Cracking, better known as FCC, is one of the most important and complicated processes in petroleum refining. Since its first commercial start-up in 1942, thousands of articles have been written covering different aspects of this technology. However, my search of literature shows that there is no single book which discusses all the pertinent areas of FCC in a language that is clear, practical, and directed to the refinery process engineer.

My main objective is to share with readers the knowledge I have gained through 18 years of hands-on experience working in refineries and my continual analysis of cat cracking literature. This book is intended to provide readers with practical information covering all the key areas of FCC in a language that is clear to both the specialist and nonspecialist. The book will be used by engineers who are responsible for troubleshooting FCC units. It will be used by refinery management for the training of operating and technical personnel. It will become a key resource to research and development personnel, corporate planners, and companies servicing FCC facilities—that is, anyone having a vested interest in understanding and optimizing the FCC process.

For a process that is over 50 years old, one would think that FCC is a mature technology, but it is far from it. Cat cracking is an evolving technology that has been adapting to the changes in market and environmental demands. For instance:

- In the mid-1960s, there was a significant change in catalyst formulation that greatly improved product selectivity, resulting in higher gasoline yields and indirectly allowing refiners to process more feed in the unit.
- Further changes in the catalyst and hardware allowed processing of lower quality feeds in the FCC unit.
- With the governmental imposition of lead phase-down in motor gasoline in 1983, it was largely changes in catalyst, process, and hardware that resulted in meeting the octane requirements and

even exceeding them, as evidenced by the introduction of super-unleaded gasoline.

It is expected that FCC units will be playing an increasingly important role in meeting many challenges facing refiners. The passage of the Clean Air Act Amendment (CAAA) in 1990 affecting gasoline and diesel qualities and the implementation of Process Safety Management (PSM) are just two of the hot issues that the FCC technologist will be helping refinery management tackle in coming years.

One of the first things that new graduate refinery engineers recognize is that the refinery's operation can be more of an art than a science. This is particularly true when dealing with FCC. In my experience, if you put two cat cracker "experts" in a room, they will hardly ever agree. Just about all of the so-called FCC experts have some theories and hypotheses, but no one is totally sure what really takes place when the feed comes in contact with a 1300°F catalyst. One reason for the difficulty in understanding this process is that the interpretation of cause and effect is often subjective. Many improvements, such as feed and air injection devices, have been developed simply through trial-and-error approaches.

The goal of this book is to provide a straightforward yet thorough analysis of the fundamental issues affecting fluid catalytic cracking operations. The book would not have been possible without the support and feedback of my friends and colleagues. I express my sincere appreciation for their contributions.

*Reza Sadeghbeigi*

# Fluid Catalytic Cracking Handbook

# Contents

CHAPTER 1

# Process Flow Description

Fluid catalytic cracking (FCC) is considered the primary conversion process in an integrated refinery. For many refiners, the cat cracker is the key to profitability in that the successful operation of the unit can determine whether or not a refiner can stay in business and remain competitive in today's market.

There are approximately 400 cat crackers operating worldwide, with a total processing capacity of over 12 million barrels per day [1]. Several oil companies, such as Exxon, Shell, and TOTAL, have their own designs; however, most of the current operating units have been designed or revamped by three engineering companies: UOP, M.W. Kellogg, and Stone & Webster. Although the mechanical configuration of individual FCC units may be arranged differently, their common objectives are to upgrade low-value feedstocks to more valuable products. It is important to note that, worldwide, about 45% of all gasoline produced comes from the FCC and ancillary units, such as the alkylation unit.

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. FCC has a remarkable history of adapting to continual changes in market demands. Table 1-1 shows major developments in the cat cracking process.

The FCC unit utilizes a microspherodial catalyst which fluidizes when properly aerated. The main purpose of the unit is to convert high-boiling petroleum fractions called *gas oil* to high-value, high-octane gasoline and heating oil. Gas oil is the portion of crude oil that boils in the 650°–1050°+F (330°–550°C) range and contains a diversified mixture of paraffins, naphthenes, aromatics, and olefins (described in Chapter 2).

**Table 1-1**
**The Evolution of FCC**

| | |
|---|---|
| 1915 | McAfee of Gulf Refining Co. discovered that a Friedel-Crafts aluminum chloride catalyst could catalytically crack heavy oil. |
| 1936 | Use of natural clays as catalyst greatly improved cracking efficiency. |
| 1938 | Standard of New Jersey, Kellogg, I.G. Farben, and Standard of Indiana formed a consortium to develop catalytic cracking. |
| 1942 | First commercial FCC unit (Model I) started up at Standard of New Jersey's Baton Rouge, La., refinery. |
| 1947 | First UOP stacked FCC unit was built. Kellogg introduced the Model III FCC unit. |
| 1948 | Davison Division of W.R. Grace & Co. developed microspherodial FCC catalyst. |
| 1950s | Evolution of bed cracking process designs. |
| 1956 | Shell invented riser cracking. |
| 1961 | Kellogg and Phillips developed and put the first resid cracker onstream at Borger, Texas. |
| 1964 | Mobil Oil developed USY and ReY FCC catalysts. |
| 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. |

*Contributor: Richard Wrench of M.W. Kellogg, December 1994.*

Before proceeding, it is helpful to examine how a typical cat cracker fits into the refinery process. A petroleum refinery is composed of several processing units that are designed to convert raw crude oil into usable products such as gasoline, diesel, and jet fuel (Figure 1-1).

The crude unit is the first processing unit in the refining processes. Here, the raw crude is distilled into several intermediate products. The heavy portion of the crude oil that cannot be distilled in the atmospheric tower is heated and sent to the vacuum tower. The tar from

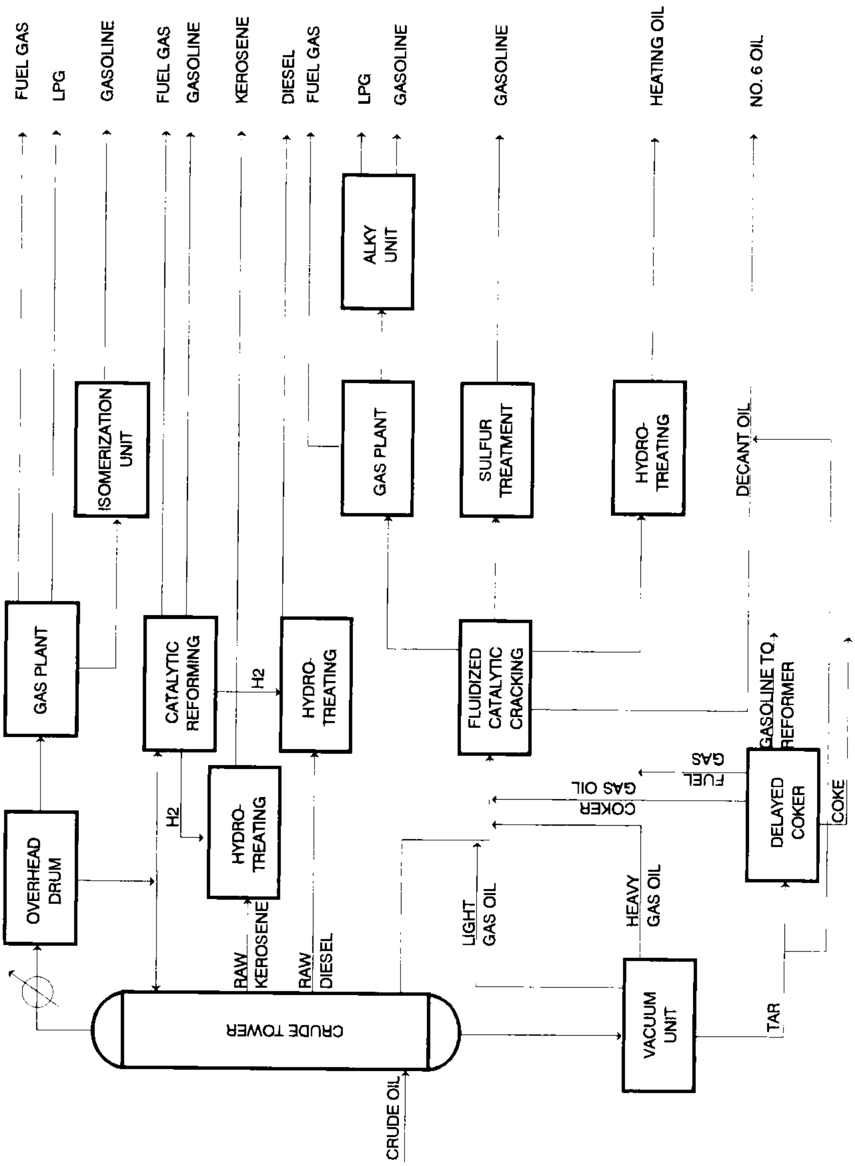


**Figure 1-1.** A typical high-conversion refinery.

the vacuum tower is sent to be processed further in a delayed coker, visbreaker, or other resid processing units.

The gas oil to a conventional cat cracker comes primarily from the atmospheric column, the vacuum tower, and the delayed coker unit. In addition, many refiners blend some atmospheric or vacuum residue with the cracker feedstocks to be processed in the FCC unit.

The FCC process is very complex. To provide a clear understanding of the unit operation, the process description has been broken down into six separate sections. These include the following:

- Feed Preheat
- Reactor
- Regenerator
- Main Fractionator
- Gas Plant
- Treating Facilities

## 1.1 FEED PREHEAT

Most refineries produce sufficient gas oil to meet the cat cracker's demand. However, in those refineries in which the gas oil produced does not meet the cat cracker capacity, it may be economical to supplement feed by purchasing FCC feedstocks or blending some residue. The refinery-produced gas oil and any supplemental feedstocks are generally combined and sent to a surge drum which provides a steady flow of feed to the FCC unit's charge pumps. This drum can also serve as a device to separate any water or vapor that may be inherent in the feedstocks.

From the surge drum, the feed is normally heated to a temperature of 550°–700°F (270°–357°C). The main fractionator bottoms pump-around and/or fired heaters are usually the sources of heat to preheat the feed. The feed preheater provides a tool to easily vary catalyst-to-oil ratio. In units where the air blower is the constraint, increasing preheat temperature allows increased throughput. The effects of feed preheat are discussed in Chapter 6.

## 1.2 REACTOR

The reactor-regenerator (Figure 1-2) is the heart of the FCC process. In a modern cat cracker, virtually all the reactions occur in the riser over a short period of two to four seconds before the catalyst and the

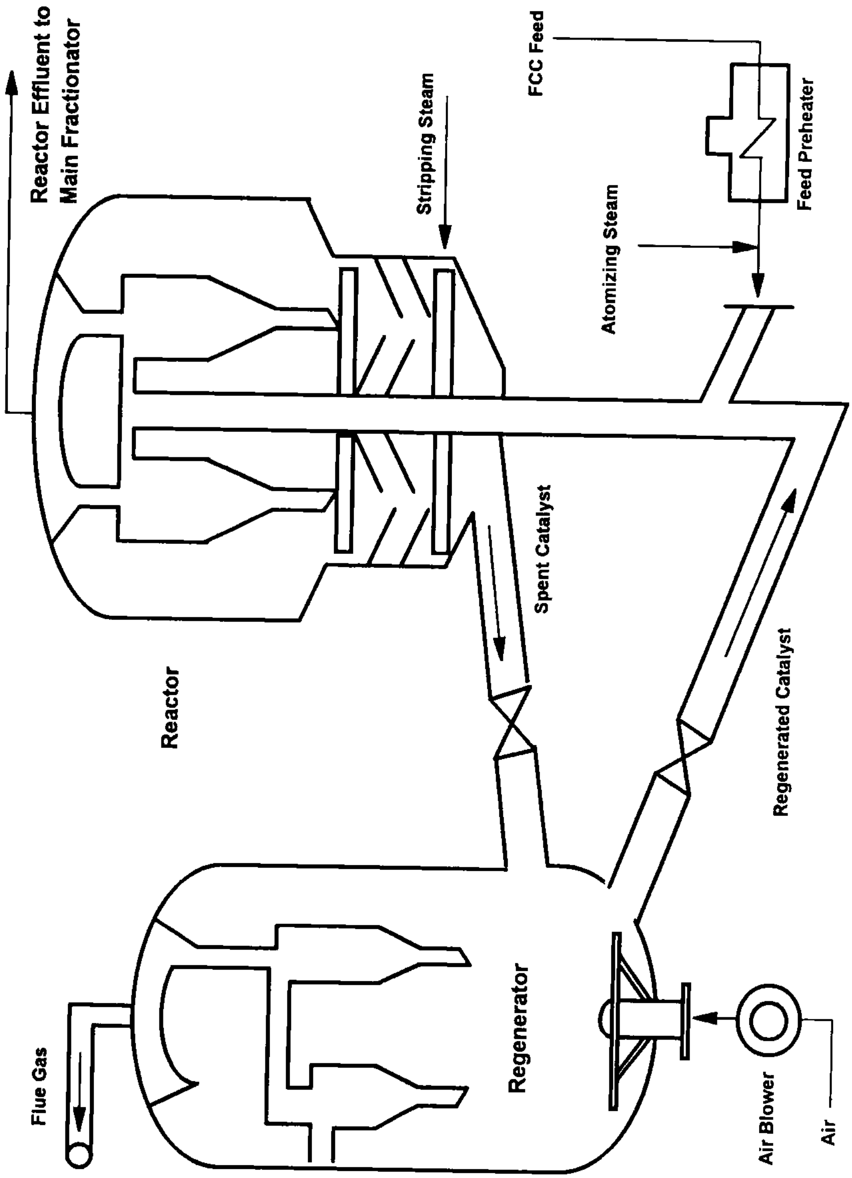


**Figure 1-2.** A typical FCC reactor-regenerator.