CHAPTER 1
INTRODUCTION

Fluid Catalytic Cracking (FCC) is one of the most efficient secondary processes to increase gross refinery margin (GRM). This process offers the greatest potential for increasing profitability in the entire refinery. FCC converts low-priced heavy feedstock into lighter, more valuable hydrocarbons such as liquefied petroleum gas (LPG) and gasoline. Coke is formed as a byproduct during the process along with dry gas, both of which are undesirable. The conversion and yield pattern strongly depend on the feedstock quality, operating conditions of the riser reactor-regenerator sections and the type of catalyst. The FCC process is very complex due to complicated hydrodynamics, heat transfer and mass transfer effects and complex cracking kinetics. These complex interactions coupled with economic importance of the unit have prompted many researchers to put their efforts on the modelling of FCC processes. Transport phenomena based mathematical models are the most popular because of their analytical description of the process in detail. Modeling is an iterative process and, therefore, leads to deeper understanding of the physics involved in the FCC process. Parametric sensitivity study helps in designing better control. Process optimization, which can be subsequently carried out, can lead to improved productivity by maximizing throughput and choosing optimal operating conditions. Optimizing online can help maximize long-term profits. Additionally, running a model simultaneously in parallel with the plant operation can help in monitoring the plant and its health.

1.1 FLUID CATALYTIC CRACKING UNIT

FCC units operate at high temperature and moderate pressure with finely divided silica/alumina based catalyst. One of the important advantages of FCC is the
ability of the catalyst to flow easily between the reactor and regenerator when fluidized with reaction mixture in vapor phase. Due to this fluidization of the catalyst, there is intimate interaction between the catalyst and hydrocarbons leading to more cracking reactions. The main components of FCCU are riser reactor and regenerator. The partially vaporized raw oil charge meets a stream of regenerated hot catalyst at the base of riser. The liquid droplets of the feed receive heat from the hot catalyst particles and almost instantaneously vaporize. As the vapors and catalyst particles move up the riser, the cracking reactions take place. Carbon generated during cracking reactions gets deposited on the catalyst surface and cracking activity progressively decreases. At the exit of the reactor, catalyst is separated from the reaction mass, adsorbed hydrocarbons stripped off in a stripper with the help of steam and the spent catalyst sent to regenerator. In the regenerator, the catalyst is continuously regenerated by burning off the coke deposited during the cracking reaction. Other auxiliary units such as feed preheat, air and flue gas systems are required for control and optimal operation of this unit for regenerating the catalyst.

1.1.1 FCC Feed

FCC processes the feedstock, which is obtained either from a refinery atmospheric distillation unit or vacuum distillation unit and normally has the boiling range from 650 0F (350 0C) to 1000+ 0F (550+ 0C). In addition, FCCU may also process heavy fractions from other conversion units (coker gas oil and hydrocracker fractionator bottoms) as part of the FCC feed blend. The feed is normally, heated to the desired reactor inlet temperature of 500 0F (260 0C to 700 0F (370 0C). The main fractionator bottoms pumparound and /or fired heaters are usual sources of heat. The main feedstocks for FCC unit are as follows

- Straight- Run Feedstocks
In addition to fresh feed streams, FCCU may also recycle certain product streams, such as heavy cycle oil (HCO) and slurry settler. All these feedstocks and recycle streams will have different properties and will therefore also have a different cracking behaviour in the FCCU.

1.1.2 Reactor-Regenerator Section

FCC feed enters at the bottom of the riser reactor through feed nozzle system as a mixture of vapors and liquid drops and makes contact with hot catalyst particles coming from the regenerator. Figure 1.1 shows a schematic of the FCC riser reactor and regenerator. Heat from the catalyst vaporizes the gas oil droplets and the cracking process, which occurs only in vapor phase at the catalyst surface. As a heavy molecule of gas oil cracks into several smaller hydrocarbon molecules, the vapor volume expands as it moves up the riser. These vapors carry the catalyst particles along with them at about the same velocity. The rate of vaporization of feed in the entry zone of the riser/reactor affects the cracking performance of the feed to a great
extant. The rate of cracking and yield of products are strongly dependent on the temperature and amount of catalyst.

The cracking process terminates in the riser reactor because of the deactivation of the catalyst due to the coke deposition on the catalyst surface as well as the short contact time between catalyst and vapor hydrocarbons in the riser reactor. The cracked hydrocarbons are separated from the catalyst in the cyclones which are located at the upper part of the reactor to prevent the catalyst particles from going along with the product stream. Finally, the cracked hydrocarbons, separated from the catalyst in the reactor and move overhead to the main fractionation column and gas plant. The main fractionator recovers the heavier products such as light cycle and decanted oil, from the gasoline and lighter products. The gas plant separates the main fractionator overhead vapors into gasoline, C3’s, C4’s and fuel gas.

**Figure 1.1: Schematic of riser reactor - regenerator**

The catalyst falls down into the stripping section. Steam is used to strip the catalyst particles of the adsorbed hydrocarbons and the catalyst then flows down a
standpipe to the regenerator. A standpipe carries spent catalyst from reactor to mix with air at the base of the regenerator. The deposited coke on catalyst surface is burned in presence of air, which restores the catalyst activity. The flue gases are released in atmosphere after burning CO to CO2 in CO-boiler and removing catalyst particles in cyclones and scrubber unit. The regenerated catalyst flows down a standpipe to the reactor to meet the raw oil charge, and used as a heat carrier, provides heat required for endothermic cracking reactions and feed vaporization. This is the continuous cyclic process between regenerator and reactor.

1.2 MODELING OF FCC UNIT

The performance of the FCC units plays a major role in the overall economics of refinery plants. A small improvement in the operation or control of an FCC unit can result in impressive economic benefits. However, these can be achieved only if a satisfactory mathematical model is available which is analytical so that its optimization can lead to optimal operating conditions. A large number of researchers have examined this problem but because of the complexities involved, a completely satisfactory model has eluded each one so far. Because of a large number of components present in the FCC feed, a rigorous kinetic model is not possible. Therefore, the description of these complex reactions has been studied by lumping together a large number of chemical compounds. Modeling of FCC riser reactor is based on a specified number of lumps for feedstock and product yields rather than for individual molecules. These lumps are considered either on the basis of boiling range of the feedstock and corresponding products in the reaction system or based on type of hydrocarbon groups. Each type of hydrocarbons is assumed as one lump and the products are considered by different lumps according to their boiling range. Larger the number of lumps, more accurate will be the result but that requires still larger
number of rate parameters to be determined. This is seldom possible because of the
cost associated with obtaining experimental data. Besides difficulties in developing a
detailed kinetic model, other problems arise from the hydrodynamics which is no less
complex. The partially vaporized feed enters the riser reactor through a system of
pipes or nozzles which decide the liquid droplet sizes. These, in turn, decide the
length of the riser required to completely vaporize the feed, which has profound
influence on the reactor performance. Also, because of wall effect, the flow of vapors
and catalyst particles is never plug flow type. Small catalyst particles may form loose
agglomerates complicating heat and mass transfer. The slip between vapor and solid
particles also completes the hydrodynamics. In view of these, the resultant
hydrodynamics coupled with heat and mass transfer effects is very complex and no
satisfactory hydrodynamic model is available.

1.3 SCOPE OF PRESENT WORK AND THESIS ORGANIZATION

As discussed above, a finite number of kinetic lumps are used to describe the
reactions taking place in the FCC riser reactor. Two to six lump models considered
feed as a single lump, which is too gross, and hence less than satisfactory. The ten or
twelve lump kinetic models used by some researchers are quite elaborate and
characterizes the feed not by a single lump but 6 to 8 lumps in terms of different
hydrocarbon groups. However, the limitation of single lump representing feed is that
the kinetics is valid only for the particular VGO with which the model parameters
were estimated and is generally not applicable to other feeds especially if the
composition is significantly different. Hence, a more realistic, a new ten lump kinetic
model has been developed which is more general and applicable for various VGO
with different properties. Moreover, the new ten lump kinetic model uses 6 lumps to
describe the feed gas oil namely heavy and light paraffins, heavy and light naphthenes
and heavy and light aromatics. However, in day to day refinery operations, it is not possible to analyze every VGO stream in terms of these lumps before using in the FCC model. In the present work, an ANN model was sought to be developed, which relates the easily measurable properties of gas oil such as specific gravity, Conradson carbon residue (CCR), total sulfur, nitrogen and ASTM distillation temperatures to these kinetic lumps.

The main objectives have been identified that lead to a logical progression through the research:

I. Development of an Artificial Neural Network (ANN) model, which relates the simple feed properties such as specific gravity, CCR, total sulfur, nitrogen and ASTM distillation temperatures to the detailed composition of feed in terms of paraffins, naphthenes and aromatics.

II. Development of a new ten lump kinetic model for the riser reactor including estimation of kinetic parameters which when coupled with a regenerator model can simulate the behaviour of the FCC unit.

III. Combining the ANN model with the ten lump kinetic model along with a solution procedure into a simulation package for the prediction of FCC product yields from simple feed properties. This model should be feed composition invariant and be applicable to a variety of heavy gas oils.

IV. Comparison of present development with conventional five lump model results. Parametric sensitivity study with respect to operating conditions is desirable.

The research work done in this study has been organized into eight chapters. An outline of these chapters is as follows:

**Chapter 1** provides an introduction to fluid catalytic cracking (FCC) with scope of present study and thesis organization.

**Chapter 2** provides the literature review on modeling of FCC unit

**Chapter 3** presents simulation of integrated five lump kinetic model for riser with a regenerator model. Also included is the parametric sensitivity study with respect to operating conditions of FCC unit.
Chapter 4 presents the experimental work required for ANN modeling. Also included are FCC yield data from an operating plant as well as from ASPEN FCC Simulator for kinetic modeling.

Chapter 5 includes the development of an artificial neural network model for predicting the FCC feed composition. The ANN model validation is also included in this chapter.

Chapter 6 presents the development of a new ten lump kinetic model with associated kinetic parameters estimation. A sensitivity study with respect to kinetic parameters is also included in this chapter.

Chapter 7 In this chapter, a simulator development based on the ten lump kinetics is discussed. The simulator predicted results are compared with plant experimental data for validation of the kinetic model. Also included in this chapter is a comparison of 10- lump model with 5 – lump model results.

Chapter 8 includes the conclusions drawn from the present study together with the recommendations for future work.