CHEMSYSTEMS
PERP PROGRAM

Olefins via Enhanced FCC

Process Technology, (Propylene/Ethylene), Production Costs (including Economic Comparison of High Severity and Conventional FCC, ZSM-5 Additive/Conventional Naphtha Steam Cracking Routes), and Regional Supply/Demand Forecasts.

PERP07/08S5

Report Abstract

March 2009

Nexant

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INTRODUCTION

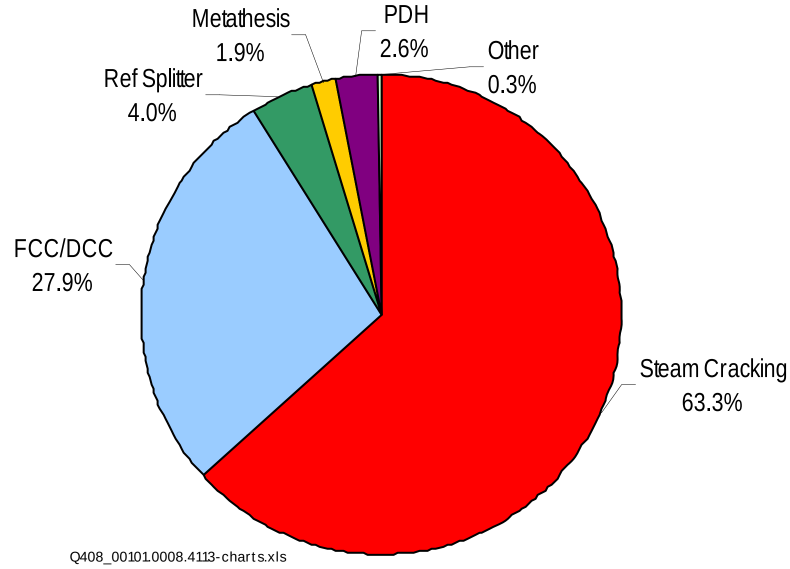
Fluid catalytic cracking (FCC) has been an integral part of oil refineries since 1942, when it was introduced in the United States by Exxon Corporation in response to a growing wartime need for hydrocarbon based fuels. Catalytic cracking has emerged as the most widely used refining process in the world today. Two major factors that have increased the need for cracking are the depletion of light crude oils and the increasing demand for gasoline. Over the years, demand for gasoline has increased in contrast with its availability. The FCC unit is used for gasoline production. Production of gasoline as well as other important products depends to a large extent on the performance of the FCC unit.

The gasoline produced in the FCC unit has an elevated octane rating but is less chemically stable compared to other gasoline components due to its olefinic profile. Olefins in gasoline are responsible for the formation of polymeric deposits in storage tanks, fuel ducts and injectors. The LPG produced in the FCC is an important source of C_3-C_4 olefins and isobutane that are essential feeds for the alkylation process and the production of polymers such as polypropylene.

Traditionally, the FCC units have been operated on either the maximum gasoline mode or the maximum distillate mode, dependent largely on the seasonal product demand pattern. Of late, a third mode is gaining importance, that of a maximum olefin mode which maximizes LPG, propylene and butylenes. This is referred to as enhanced FCC, high severity FCC, high propylene FCC or high olefin FCC.

Propylene growth rate continues to outpace ethylene growth rate, and this will continue to put stress on traditional propylene sources, in particular steam crackers. Historically, propylene has been considered a by-product of ethylene production via steam cracking, as can be seen from the figure below.

Global Propylene Capacity, 2007



FCC units typically produce around 3-5 weight percent propylene, depending on feed type, operating conditions (reactor temperature, partial pressure, catalyst-to-oil ratio, and total pressure) and the nature of the FCC catalyst. This important source of propylene currently accounts for 28 percent of the worldwide propylene (see Figure above) and this proportion will continue to increase as the percentage of propylene supplied from steam crackers decreases as a result of an increase in ethane-based cracking. While propylene is a normal product of the FCC process, conventional FCC operation does not maximize propylene production. In the gasoline mode, a typical FCC contributes 35 percent of the gasoline pool volume. (Reforming adds another 30 percent, alkylation 20 percent, and isomerization 15 percent).

One cost effective way to increase the propylene yield from the FCC unit is the use of specialized catalysts that contain ZSM-5 zeolite. ZSM-5 is a pentasil zeolite concentrate which typically incorporates up to 25 percent to 40 percent pentasil. Within the FCC, increased operating severity and the use of ZSM-5 catalyst additives are employed to increase the LPG olefin yield (mainly propylene) at the expense of gasoline.

Yields of olefins from Enhanced FCC are significantly higher compared with typical yields for conventional FCC. It is important to note that higher olefin (i.e., ethylene, propylene, and butylenes) production comes at the expense of gasoline production, as well as a change in gasoline composition. While an Enhanced FCC operation can double or triple the production of propylene, at the same time, gasoline production is reduced by 25-35 percent. In addition, the concentration of aromatics is 2-3 times what is found in traditional FCC gasoline and more similar to that of reformate. The high benzene content may make the gasoline unsuitable for gasoline blending without either extraction or saturation and opens up the opportunity for integrating an Enhanced FCC unit with an aromatics complex, as well as a steam cracker.

TECHNICAL ANALYSIS

In the next few years, operators of FCC units will look increasingly to the petrochemicals market to boost their revenues by taking advantage of economic opportunities that arise in the propylene market. This section includes a review of FCC technology and examines the various Enhanced FCC technologies that are either already commercial or that are being developed. Section 3 investigates the economics of producing propylene via high severity FCC and its sensitivities. Finally, the commercial aspects of propylene are analyzed in Section 4.

Fluidized Catalytic Cracking Process Characteristics

The catalyst is a fine powder with an average particle size of 50-60 microns. The catalyst, although a solid, is maintained in suspension, or “fluidized” by the reaction products, steam or air in the vessels and catalyst transfer lines. In this state, the catalyst behaves much like a fluid and flows back and forth between the reactor and regenerator.

In addition, to catalyst and chemistry, brief descriptions of the following are given in this section: process; feeds; products; operating conditions; process variables, yields, and severity (temperature, catalyst/oil ratio, catalyst activity, pressure, space velocity); FCC reactor section (reactor, regenerator); and revamping an existing FCC unit for olefin production.

Enhanced FCC Technologies

Many companies now market or have developed high severity or enhanced FCC-type processes for the purpose of increasing propylene yields.

Central to these processes are modifications to different zeolite catalyst formulations accompanied by innovation in the FCC hardware, and some changes in the operating parameters. The following technologies being developed and licensed are discussed in the report:

- Shaw Stone & Webster/SINOPEC - Shaw Stone & Webster (SS&W) have an exclusive agreement with the Research Institute of Petroleum Processing (RIPP) and Sinopec International, both located in the People's Republic of China, with respect to licensing Deep Catalytic Cracking (DCC) technology outside of China.
- UOP – PetroFCC™ - UOP has leveraged its FCC experience and know-how to develop and license a new type of cracking process. PetroFCC™ is an FCC process that targets the production of petrochemical feedstocks rather than fuel products. The new process, which utilizes a uniquely designed FCC unit, can produce very high yields of light olefins and aromatics when coupled with an aromatics complex.
- Indian Oil Corp./Lummus Technology Inc. – INDMAX FCC (I-FCC™) - The Indane Maximization (Indmax™) technology (developed by Indian Oil Corp. Ltd. (IOCL) and licensed by Lummus Technology Inc., a CB&I Company (formerly ABB Lummus Global)) employs a circulating fluidized catalyst, riser reactor system along with catalyst stripper and catalyst regenerator similar to that of a conventional Fluid Catalytic Cracking (FCC) unit.
- Kellogg, Brown and Root LLC - Kellogg, Brown and Root LLC (KBR) offers three enhanced FCC processes for license depending on the available feed. The Advanced Catalytic Olefins (ACO™) process employs straight run paraffinic feeds and cracks them to produce more total olefins than pyrolysis (i.e., steam cracking). Superflex™ uses olefinic feeds and produces 50-60 percent total olefins. Maxofin™ uses typical FCC feeds (gas oils and resides) and increases propylene yield from about fourfold relative to a typical refinery operation.

Brief descriptions of the following technologies being developed and licensed are also provided:

- Japan Petroleum Energy Center – HS-FCC - The Japan Petroleum Energy Center’s (JPEC) high severity fluid catalytic cracking (HS-FCC) process employs a down-flow type reactor as opposed to a conventional riser type reactor.
- NExCC™ (Fortum Oy) - The key element of the NExCC™ process is a completely novel reactor design that makes it possible to construct large-scale equipment with a small height-to-diameter ratio.
- Resid Fluid Catalytic Cracking PetroRiser^{SM} (Axens) - Axens’ new, flexible FCC process configuration is able to maximize propylene and petrochemical production upon demand.
- Middle Distillates and Lower Olefins Selective Process (Shell Global Services) - The Middle Distillates and Lower Olefins Selective (MILOS) process was developed by Shell Global Services (SGS) to facilitate the conversion of low-quality oil into high-end

petroleum products. MILOS is a FCC process which provides refiners with the flexibility to obtain optimal yields of diesel and propylene without increasing the cost from using an expensive special catalyst.

- High-Olefins FCC (Petrobras) - Petrobras has investigated the flexibility that results from adding a second, external parallel riser to an existing FCC unit.
- SINOPEC - In addition to their work on DCC and CPP technologies, SINOPEC has filed two patent applications recently that deal with inventions for producing light olefins employing FCC units by cracking either naphtha or C_4 and higher olefins.

ECONOMIC ANALYSIS

The cost of production for a conventional FCC employing ZSM-5 additive producing propylene has been carried out.

- Polymer Grade Propylene via Conventional FCC Process with ZSM-5 additive Cost of Production Estimate

In addition, the cost of production for a generic high severity FCC process producing propylene with and without ethylene recovery is given. The recovery of ethylene is highly dependent on the plant location.

- Polymer Grade Propylene via Enhanced FCC Process Cost of Production Estimate
- Polymer Grade Propylene via Enhanced FCC Process with Recovery of Ethylene Cost of Production Estimate

The cost of production estimate for producing olefins (ethylene plus propylene) via steam cracking of light naphtha under moderate severity conditions and employing the Advanced Catalytic Olefins (ACO™) technology with a naphtha feed is given.

- Olefins via Steam Cracking of Light Naphtha Process Cost of Production Estimate
- Olefins via Advanced Catalytic Olefins Process Cost of Production Estimate

Various sensitivity analyses have been evaluated as indicated below:

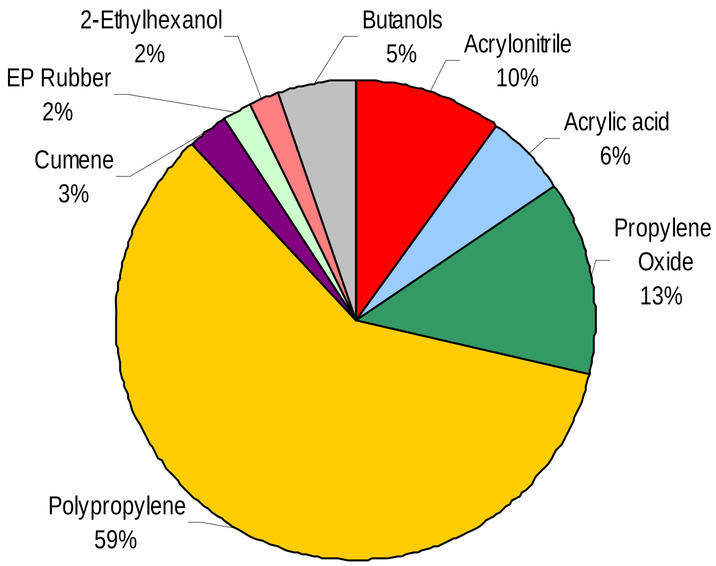
- Sensitivity of Propylene Economics based on Enhanced FCC to Operational Severity
- Sensitivity of Propylene Economics based on Enhanced FCC to Economy of Scale
- Sensitivity of the Enhanced FCC operation to the price of feedstock and the price of the by-products (gasoline and ethylene)
- Sensitivity of the propylene cost of production to the return on capital employed
- The economics have been evaluated for the sensitivity to capital investment

COMMERCIAL ANALYSIS

Propylene demand is approximately one-half the size of ethylene demand. Propylene is the second most important olefin product and like ethylene, it is a primary petrochemical precursor. In each region, polypropylene is the largest propylene derivative.

The major end-uses for Propylene are demonstrated by the chart below showing propylene end-use demand for the United States in 2007.

U.S. Propylene End-Use Pattern, 2007



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- Supply, Demand and Trade data are given for the U.S., Western Europe and Asia Pacific
- Specific Propylene capacity for individual plants citing location, operating company, and process of production are given for each of the regions discussed (i.e. U.S., Western Europe and Asia Pacific)

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