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REFINERY TECHNOLOGICAL PROCESSES INTEGRATION. PROPYLENE PRODUCTION ON FCC UNIT

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It is written about factors influencing the selection of FCC propylene yield design points and how refiners can leverage existing assets to close the market gap for propylene production.

Keywords: *catalytic cracking process, ethylene, propylene, light olefins, FCC propylene production, propylene recovery, revamp unit design.*

Today both the petrochemical and refining industries are becoming increasingly aware of potential to link their existing facilities. The refinery can produce increasing quantities of propylene, and in conjunction with this trend, will also produce a viable quantity of ethylene. Before propylene has often been considered as "the other olefin", implying a relative unimportance compared to ethylene.

The supply and demand balance is tightening, as propylene demand growth is forecast by SRI Consulting to exceed 4.5-5.0 % per year over the next four years, led by Asia with even stronger growth at nearly 6 % per year. This exceeds the forecast growth rate of ethylene by about 0.5 %. The consequence of these different growth rates is that by 2015 propylene will form 40 % of the total olefin demand. On the supply side of the balance, propylene is a by-product of ethylene plants and refineries. Currently, about 61 % is produced in ethylene plants, 34 % in petroleum refineries and less than 3 % in on-purpose propylene-only production plants [2].

Ethylene plants, however, have very limited flexibility for increasing the relative yield of propylene. Table 1 shows that feedstock selection essentially determines the yield ratio, and even the heaviest gas-oil feeds will only produce about 37.5 % propylene [1].

Table 1

Steam cracker production ratio

Feed	Propylene/ethylene	% propylene
Ethane	< 1	< 1
LPG	0,33-0,46	25-32
Naphtha	0,40-0,57	29-36
Gas oil	0,53-0,62	35-38

The key refining technology which can provide petrochemical advantages is the FCC and its related derivatives. In refineries, while cokers and visbreakers produce some propylene, the majority comes from FCC units. It is only in refineries with FCCUs that the scale of production supports the investment in recovery of propylene as a separate product. Propylene production in refineries is also increasing as refiners struggle to blend FCCU naphtha and propylene polymer gasoline into the gasoline pool due to increasingly restrictive product specifications. The major advantage the FCCU has over steam crackers is its high degree of flexibility in low-cost feedstock selection and product yields. The FCCU operator can use a combination of operating conditions, catalyst selection and additives that can be adjusted to suit the current economics. All these factors combine to make propylene ever more important to refinery and FCCU economics.

The average propylene yield from the installed FCC base is around 5.0 wt% on fresh feed (wt% FF). Many of the new FCCUs that will come online over the next ten years will produce even higher propylene yields, some with design points as high as approximately 20 wt% FF. With the strong market demand for propylene and the capability to achieve elevated propylene yields with an FCCU, there is a possibility to maximize propylene yields from new FCCUs. However, there are competing economic forces suggesting that the optimal propylene yield from an FCCU is 10-11 wt% FF, which is substantially lower than the current technology can produce [3].

While propylene generation from an FCCU certainly varies with feedstock, it is primarily a function of reactor temperature, partial pressure, catalyst-to-oil ratio and total pressure. For propylene maximization, the reactor/regenerator design objectives should be a high cat-to-oil ratio and high riser temperature to give a high conversion, and short contact time for selective cracking. Good catalyst activity maintenance is also important, since it increases conversion and improves selectivity, while allowing greater flexibility in catalyst design.

With a full-range hydrotreated VGO, the technology exists to operate over a range of about 5.0-20 wt% propylene on feed. Higher propylene production comes at expense of gasoline. In working with refiners to meet their processing objectives, three design envelopes emerge: maximum gasoline; gasoline + LPG; propylene + aromatics. Table 2 provides the yields for three modes of operation for an FCCU processing a typical 24° API full-ranged hydrotreated VGO feedstock [3].

Table 2

FCC product yield comparisons across operating modes

Mode	wt% yield on fresh feed		
	Gasoline	Gasoline + LPG	Propylene
Ethylene	0,83	1,42	7,10
Ethane	0,90	0,94	1,21
Propylene	4,76	10,03	18,10
Propane	1,84	3,52	2,18
Butylenes	6,62	9,62	9,83
i-Butane	3,92	4,87	2,98
n-Butane	1,21	1,51	0,82
Gasoline	54,36	43,94	35,21
LCO	11,57	10,10	8,32
Mode	wt% yield on fresh feed		
	Gasoline	Gasoline + LPG	Propylene
Clarified oil	7,93	6,89	5,59
Naphtha composition			
Aromatics	34,70	44,00	54,70
Benzene in gasoline	0,46	0,59	1,29

Yield comparison

As the operation of the FCCU is shifted towards the higher propylene production, there is a coincident increase in ethylene and butylene. Along with this shift towards light products, there is also a decrease in gasoline yield and a change in the gasoline composition. Important to note that gasoline quality is progressively reduced at higher unit operating severity. This is due to existing aromatics being concentrated in less gasoline, as well as the production of additional aromatics. In this case, total aromatics increased by 58 %, and benzene increased by 180 %. With gasoline benzene limits already in force, the high benzene content of the propylene mode is often not suitable for gasoline blending without either extraction or saturation.

For most refiners, maximum propylene operation reduces gasoline quality and devalues the product. Refiners that practice propylene mode operation typically process the FCC naphtha through a naphtha hydrotreater and a platforming unit as feed preparation upstream from a petrochemical complex for the production of benzene, toluene and xylene (BTX). However, high-severity FCC operation actually reduces the overall aromatics production by reducing precursors that would be more selectively converted to BTX in the platforming unit. Optimising the overall complex LP is critical to defining the proper FCCU operating envelope. In addition to high aromatics and benzene issues, the operating severity required to maximize propylene production results in nearly a fivefold increase in dry gas production with high selectivity for ethylene [1].

The gasoline + LPG mode appears to be a reasonable balance between the need for higher propylene production and the need to maintain acceptable gasoline blendstock quality. In the gasoline + LPG mode, it is possible to obtain a 110 % increase in propylene production with only a 28 % increase in the benzene content of the gasoline. Although the benzene content increases, more than 80 % of this increase is due to the concentration of existing benzene production in the gasoline as a result of selectively cracking olefinic naphtha to LPG with the use of ZSM-5 additives [4]. It is also important to note that butylene production hits a plateau around medium severity; so if the FCCU is being operated to produce alkylation feedstock, medium severity operation is good enough.

Production targets

Over the past two years UOP company finished seven new FCC projects. At the beginning refiners quoted objectives to push propylene yields towards the upper limits of what the equipment, catalyst and feedstock can produce, but in the final design basis propylene yields were for the gasoline + LPG mode rather than towards the maximum propylene production desired at the start [3] (see table 3).

The optimum cash cost of propylene production from an FCCU is an intricate balance of capital, throughput, operating severity and overall product values.

Table 3

Initial propylene request vs final design point

	Initial request (C_3= yield, wt%)	Final design (C_3= yield, wt%)
Unit “A”	-	10,5
Unit “E”	20,0	8,0
Unit “J”	20,0	10,5
Unit “P”	18,0	15,1
Unit “R”	21,0	11,3
Unit “S”	15,0	11,1

Refiners optimise their FCCU by maximising converted barrels (throughput), minimising their operating and capital costs, and producing a flexible product slate. The main problem with pushing the limits of propylene production from an FCCU is that all of these optimization factors are negatively impacted. The operating conditions needed to maximise propylene yield as a weight percentage of fresh feed require significantly larger equipment per barrel processed, resulting in a higher capital cost. To move the operation from gasoline to propylene mode derates the operating capacity by approximately 50 %. In other words, if a unit is designed for a gasoline mode throughput of 50 000 bpd, to maximise severity to propylene mode operation in the same equipment the feed rate would need to be reduced to approximately 25 000 bpd [6].

The operating costs associated with maximum propylene production are higher than for gasoline mode operation. Lower hydrocarbon partial pressure to maximise propylene selectivity requires additional steam use, and maximising propylene (C_3=) over butylenes (C_4=) requires lower absolute operating pressure, both contributing to larger vessel requirements per barrel throughput. The catalyst systems for maximum propylene production command a premium. Increased LPG production and the net lower molecular weight of the reaction products increases the overall compression costs for product recovery.

As a net result of detailed Capex, Opex and product value evaluations, shows that the market selecting an optimal propylene production that is far less than theoretical limits. The ideal balance point across a variety of feedstocks and market regions appears to be around 11 wt% FF propylene yield, as previously mentioned.

FCC propylene production

There are two ways to increase propylene production from existing FCCUs: first, improve the recovery capability of the existing gas concentration unit (gas con), and second, increase the quantity of propylene produced in the FCC reactor (was discussed above).

CMAI estimates that on average the recovery of polymer-grade propylene from FCCUs across the world is approximately 67 %. Irrespective of where the propylene product is sent, the economic incentives to improve recovery have increased dramatically over the past few years [5].

Revamp unit designs

Operating variables in the gas con section that have a significant effect on propylene recovery are pressure, cooling temperature, absorber lean oil circulation and absorber efficiency. These variables can be optimised across a broad shift in product slate to maintain high product recoveries up to 98 - 99 %. Balancing the target propylene generation, percentage recovery and the cost of modifications to achieve the refiner's objectives is an important part of every revamp study.

There are some typical capacity constraints that require revamping to enable higher severity or higher throughput operation of the gas con unit, including [6]:

- *Wet gas compressor capacity***.** The increase in light ends and LPG make will increase the load in the wet gas compressor. However, for most revamps, the reactor pressure is normally increased to accommodate the reactor cyclone design within the existing reactor shell constraints. Increasing the reactor pressure results in an increase in the compressor suction pressure, which often offsets the decrease in molecular weight to the compressor. Due to the high cost of wet gas compressor replacement, in many cases the operating conditions for the revamp are set within the maximum capacity of the existing compressor casing.

- *Fractionators/absorbers capacity.* In most revamps, the capacity constraints of trayed columns can be overcome with the use of high-capacity trays or packing. The typical limiting areas are the HCO section of the main fractionator, top section of the debutaniser, the stripper and the absorber.

- *Cooling temperature and absorber lean oil circulation.* For propylene yields less than 12 wt% FF, a traditional cooling water heat-removal system is generally sufficient to meet the desired propylene recovery. A chilled water system can be applied if the unit has other constraints that cannot be overcome. However, this is not typically required. Absorber lean oil circulation is normally the primary variable that can be adjusted for a revamped unit to achieve a higher propylene recovery.

- *Heat integration with the FCC main fractionators.* Proper design of the main fractionator's heat integration with the gas con is typically the most complex part of most revamps. Different scenarios of heat exchange with the main fractionator are normally identified to stay within the main fractionator's limitations and reduce equipment modifications.

Conclusions

Global propylene demand trends remain strong, and with the change towards lighter feedstocks in new steam crackers there will be a growing reliance on FCCUs to balance the supply side of the propylene equation. The technology exists today to help make this happen. FCC process is flexible enough to meet the challenge associated with closing the global market gap for propylene. This will happen through a combination of new units designed for elevated propylene yields and revamps of existing facilities to increase propylene yield and recovery within logical equipment constraints.

Competing economic forces and real market data that suggests the optimal yield of propylene from a FCCU is 10-12 wt% FF, which is substantially lower than the theoretical limits associated with most feeds and operating systems. The premium propylene and butylene command over other products, such as gasoline, is enough to give many refiners the incentive to invest in their existing assets.

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