THE FUTURE OF FCC

Christian Vaccese and Victor Scalco, General Atomics Electromagnetic Systems, USA, argue that the future of catalytic cracking is tied to a better bottom line.

Increasing profits and maintaining a positive bottom line is critical for complex refineries. By 2021, the refining sector will be comprised of approximately 735 petroleum refineries worldwide. Over half of these refineries will utilise severe catalytic cracking technology to increase profits and take advantage of the existing crack spreads. Approximately 18 million bbl of crude oil are processed daily through a fluidised catalytic cracking (FCC) system, along with three quarters of the worldwide gasoline demand. The FCC is one of the most productive and profitable technologies among the refining processes. Any downtime in this unit would cause a refiner to lose millions of dollars in revenue each day. It is imperative to maintain its productivity and efficiency, while utilising its maximum potential from top to bottom. Upgrading catalytic cracking technology has to be simultaneous with increasing efficiency, reducing maintenance cost, and improving the catalyst equilibrium cycle. Removing solids and ultimately increasing the life span of the unit is directly related to increasing the bottom line in refining.

With the increase in crude prices due to the International Maritime Organization's (IMO) 2020 regulation enforcement, the spread between lighter, less severe crudes and heavier, opportunistic crudes will become a bigger part of the refining sector's economics. Heavier, opportunistic crudes are already pushing the limits of catalytic cracking.[1] Refiners are increasingly considering the utilisation of more complex technologies for deeper conversion of challenging feedstock arising from the processing of opportunistic crudes. All major licensors have a suite of technologies designed for residual conversion and opportunistic feedstock upgrading. These technologies are tailored for processing heavier crudes and producing high quality final products.

Severe catalytic cracking activities come with the challenge of increased catalyst attrition, higher concentration of sediments and filterable solids within the slurry oil stream from the main column. This challenge can be efficiently addressed by adopting the right separation technology. Sediments are composed of large particles greater than 20 µm, while filterable solids are composed of smaller particles typically in the range of 20 µm to submicron level. The sources of the solids are iron sulfide, silica, clays, scales, ash, coke and catalyst fines. Contamination starts upstream after the desalter, and reaching downstream of the catalytic cracking unit. New catalysts, co-catalyst and additives, while benefitting the process, are at the same time adding more sediments, solids and poisoning metals to the bottom of the barrel, creating more challenges in removing these contaminants.

Fluidised catalytic cracking

During the Second World War, allied countries needed a new fuel to overcome the German air superiority. Higher octane and faster production were the goals. In 1942, the FCC was developed and ever since then refining would never be the same. The FCC unit upgrades heavier fractions, high molecular weight hydrocarbon fractions in vacuum gas oil (VGO) into lighter products such as high octane gasoline, naphtha, light cycle oil (LCO), heavy cycle oil (HCO), and slurry oil. The unit is composed of three major sections: the riser/reactor, the regenerator, and the fractionation. A fine powdered porous catalyst with zeolite (silicate and alumina) is fluidised in the hydrocarbon vapour, where a reaction takes place at 493 – 550°C and 10 – 35 psig.[2] Long chain molecules (high carbon numbers) are split into shorter molecules to achieve more of the high value fuel components. The catalytic reaction takes place within a few seconds, after which the reformate and catalyst are separated in a cyclone. The spent catalyst then goes back to a regenerator and is then heated to 715°C at 0.241 MPa (35 psig) in order to release flue gas. The catalyst powder can then be reused. Catalyst regeneration and separation can be considerably increased by adding a slurry separation or filtration technology to increase the value of the slurry oil. Upgrading slurry oil (SLO) to clarified slurry oil (CSO) allows refiners to generate more revenue from FCC fractionator bottoms. However, this is only one of the several benefits offered by using the right separation technology. Other benefits include an increase in life span of the FCC unit, prevention of erosion, and a reduction in maintenance costs. In this study, tank settling, mechanical filtration and electrostatic slurry separation were compared to determine how the separation technology has improved to keep up with the evolution of the FCC. The differences in efficiencies were especially noticed when comparing the modern electrostatic slurry separator to the obsolete mechanical filtration alternative and settling tanks solutions. Thus, choosing the appropriate separation technology is crucial for increasing the quality of the final products and overall performance of the FCC.

Residue fluid catalytic cracking

The residual fluid catalytic cracking (RFCC) unit dates back prior to the 1970s. The rapid increase in crude oil price and the desire to utilise more of the crude barrel drove the demand for residual oil processing in FCC. The feed to the RFCC includes streams that would otherwise be blended into fuel oil. Typical feeds of the RFCC include atmospheric resid (AR) – the bottoms from the atmospheric distillation tower, containing a mix of VGO and vacuum resid (VR). The VGO is a heavy cut from the vacuum distillation unit and it is sometimes added to the RFCC feed to increase throughput. Coker gasoil originated in the coker unit is also a major feedstock.

These units use catalyst coolers (e.g. steam coils) in the regenerator or a second regeneration zone to remove excess heat. This is because vacuum residue generates substantially more coke than conventional FCC feeds, and excess heat is generated when the extra coke is burned away from catalyst.[3]

Heated feed is mixed with a heated catalyst and injected into a reactor, where the catalyst freely mixes with the feed as a fluid. As the feed is cracked, coke deposits on the catalyst, causing it to gradually deactivate. Cracked product is drawn off at the top of the reactor and is sent to a fractionator. Deactivated catalyst is drawn off the bottom of the reactor and is sent to a regenerator where the coke is burned off by injecting heat and air. The cleaned (regenerated) catalyst is then sent back to the reactor, and the cycle repeats.[4]

The RFCC slurry stream is more challenging to upgrade compared to FCC, but because of the great revenue potential that comes with CSO, licensors and refiners are integrating electrostatic slurry separators. This technology is the most effective solution to upgrade RFCC slurry oil into more valuable CSO, and is recommended by major licensors.

Deep catalytic cracking

Deep catalytic cracking (DCC) is a more severe cracking technology developed in 1990 which uses heavy hydrocarbon feedstock, such as VGO, vacuum tower bottoms (VTB) or VGO blended with deasphalting oil (DAO). The technology's main targets are maximising production of propylene (DCC type I) or maximising production of iso-olefins (DCC type II).

This process is the result of R&D and creative process engineering evolution applied to the existing FCC. Reaction-regeneration, fractionation and gas concentration are still the main core of this technology. Feedstock dispersed with steam is fed to the system, then contacted with the hot regenerated catalyst either in a riser plus fluidised dense bed reactor (for DCC type I) or in a riser reactor (for DCC type II) and is catalytically cracked. Reactor effluent proceeds to the fractionation and gas concentration sections for stream separation and further recovery. The catalyst with coke deposits is sent for stripping with steam and transferred to the regenerator where coke is removed by combustion using air. To balance the heat equilibrium of the system, the hot regenerated catalyst is sent back to the reactor at a controlled circulation rate.

Upgrading the slurry oil stream to valuable CSO will add to the bottom line, assisting the refinery with meeting stringent IMO 2020 guidelines while maximising revenue from the top to the bottom of the barrel. Electrostatic slurry separation technology is capable of handling the type of severity of DCC units, due to the lower API of feedstock and higher concentration of asphaltenes. Figure 1 shows the increased production of light olefins yields comparing FCC technology with the most recent DCC.

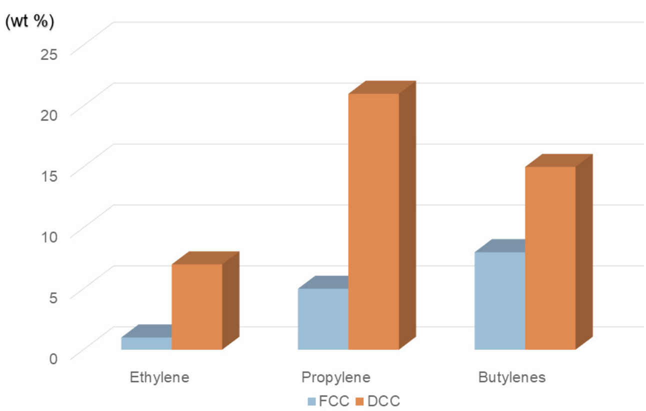


Figure 1. Comparison of light olefins yield between deep catalytic cracking (DCC) and fluidised catalytic cracking (FCC).[5]

From gas oil or resid feedstock to increased production of propylene

The main benefit of using the fluid catalytic cracking technology to achieve high propylene yields is the ability to process a wide range of feedstock from gas oil through residue. The process allows production of gasoline, distillates and light olefins to increase, particularly propylene and aromatics. It is characterised by the utilisation of two independent risers and a double regenerator, based on the RFCC process principles. The main riser cracks the resid feed under conditions to optimise fuels production; the second riser, or secondary riser, is operated to selectively crack specific recycle streams to maximise propylene production.

The temperature and catalyst circulation rates are higher than those used for a conventional gasoline mode operation. The main riser temperature is optimised and controlled with a mixed temperature control (MTC) system. Reaction products are then rapidly separated from the catalyst through a high-efficiency riser termination device.

Recycle feed is re-cracked in the secondary riser under more severe conditions compared to the main riser. A precise selection of recycle cuts combined with adapted commercial FCC catalyst and additives lead to high propylene yields with moderate dry-gas production.

Both the main riser and secondary riser are equipped with a rapid separation system. The deactivated catalysts are collected into a single packed stripper, which enhances steam stripping efficiency of the catalyst. Catalyst regeneration is carried out in two independent stages to minimise permanent hydrothermal activity loss. The first stage is operated in a mild partial-combustion mode that removes produced moisture and limits catalyst deactivation. The second stage finishes the combustion at higher temperature to fully restore catalyst activity. Another important benefit of using this technology is the ability to process residue feed containing high metal concentrations. This is successfully achieved, adding the continuous catalytic regenerator (CCR) to the equation. For even better results, the addition of a catalyst cooler is recommended.[6]

The reaction and regeneration sections use a cold-wall design that results in minimum capital investment and maximum mechanical reliability and safety. Units are tailored to fit the market needs (feedstock and product slate) and can include a wide range of turndown flexibility. Available options include power recovery, waste heat recovery, flue gas treatment, light olefins recovery/purification and slurry filtration. For the purpose of slurry upgrading, electrostatic slurry separation technology is recommended due to the severity of the process and to eliminate plugging issues likely to occur with mechanical filtration.

High severity FCC

Considering the fact that a third of propylene worldwide is generated through FCC highlights the importance of the new high severity fluid catalytic process, which is capable of delivering up to 25 wt% propylene by converting heavy hydrocarbon feedstock such as VGO, AR, VR, and DAO. Under severe FCC conditions, the unique design of down-flow reactor along with instantaneous contact time (0.5 – 1 sec.) delivers an increased olefin yield production. The patented catalyst formula is free from rare earth elements. Maximising the production of propylene is not the only objective of this technology. A considerable amount of butanes, gasoline and aromatics are also produced as valuable byproducts.

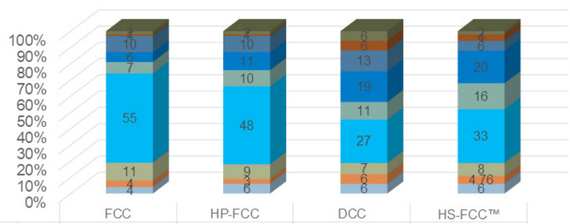
The combination of down-flow reactor, high reaction temperature, short contact time and high catalyst-to-oil (C/O) ratio, results in two competing cracking reactions: thermal cracking and catalytic cracking. Thermal cracking contributes to the production of dry gas while catalytic cracking enhances the yield of propylene.

By using a down-flow reactor system, both the catalyst and the feed flow downwards with gravity through the reactor to minimise back mixing and obtain a narrower distribution of residence times. This maximises the production of intermediate products such as gasoline and light olefins. The down-flow reactor allows a higher C/O ratio because the lifting of catalyst by vaporised feed is not required, and the down-flow configuration ensures plug flow without back mixing.

The high severity fluid catalytic process is operated under considerably higher reaction temperatures (550 – 650°C) than conventional FCC units. Under these conditions, however, thermal cracking of hydrocarbons also takes place concurrently with catalytic cracking, resulting in increased undesirable products, such as dry gas and coke.[6] Short contact time (less than 0.5 sec.) of the feed and product hydrocarbons in the downer minimises thermal cracking. Therefore, undesirable successive reactions such as hydrogen transfer, which consume olefins, are suppressed. In order to attain the short residence time, the catalyst and the products have to be separated immediately at the reactor outlet. For this purpose, a high efficiency, short residence time product separator has been developed that is capable of suppressing side reactions (oligomerisation and hydrogenation of light olefins) and coke formation.

In order to compensate for the drop-in conversion due to short contact time, the high severity fluid catalytic cracking process is operated at a high C/O ratio.

The advantage of operation at high C/O is the enhanced contribution of catalytic cracking over thermal cracking. High C/O maintains heat balance and helps minimise thermal cracking, over cracking, and hydrogen transfer reactions. Figure 2 shows the yield comparison between the traditional FCC and the more severe catalytic cracking technologies.



	FCC	HP-FCC	DCC	HS-FCC™
Fuel Gas	2	2	6	2
Ethylene	1	1	6	4
Sat. C3+C4s	10	10	13	6
Propylene	6	11	19	20
C4s	7	10	11	16
Gasoline	55	48	27	33
LCO	11	9	7	8
Slurry	4	3	6	4.76
Coke	4	6	6	6

Coke Slurry LCO Gasoline C4s Propylene Sat. C3+C4s Ethylene Fuel Gas

Figure 2. Yield comparison between the traditional FCC and the more severe catalytic cracking technologies (wt%).[7]

Case study

Saudi Aramco is currently advancing its global chemicals growth strategy with the inauguration of the first phase of S-Oil's new residue upgrading and olefin downstream complex, located at its integrated refining and petrochemical operations in Ulsan, South Korea. The new complex features the latest refinery technologies, which have raised S-Oil's petrochemical portion from 8% to 13%, and includes production of propylene and gasoline.[8] The two companies will collaborate on Phase 2 of the complex. This will involve construction of a US$6 billion, 1.5 million tpy mixed-feed steam cracker and olefins downstream project, and is scheduled for completion by 2024.

South Korea's biggest refiners have been shifting their focus from refining to non-refining businesses in recent years while the petrochemical industry will be investing US$13.06 billion by 2023.

The state-of-the-art facility features the first commercial 76 000 bpd high severity fluid catalytic cracking unit, developed by a major licensor, including production of propylene (300 000 tpy), polypropylene (405 000 tpy) and gasoline (907 000 tpy).

The high severity fluid catalytic cracking process operates at critical conditions and concentrations. This makes the process more challenging, especially at the bottom of the barrel where high concentrations of solids, contaminants and catalysts are undermining the possibility of upgrading the slurry oil stream.

Although there are many advantages of new high severity fluid catalytic cracking technology, there is also a resulting disadvantage. The high severity fluid catalytic cracking slurry stream is highly concentrated with asphaltenes, increased ash, heavy metals, coke and unfilterable solids for normal mechanical methods.

Several different filtration and separation technologies, claiming to be the most efficient and reliable in the market, were reviewed in order to find the most suitable solution capable of upgrading this challenging slurry oil stream producing high quality clarified slurry oil. With heavy asphaltene and coke content, mechanical filtration was ruled out due to the inherent plugging characteristics. The technology which proved most efficient in the concentrated slurry was the electrostatic slurry separator.

Conclusion

The evolution of the refining industry is moving toward a more severe catalytic cracking approach, making refineries capable of processing heavier opportunistic crudes to increase refining capabilities and decrease feedstock-associated costs. Along with severe cracking, petrochemical integration is gaining popularity as a feasible solution for increasing refinery production of olefins and aromatics, with predominantly higher yields of propylene. The market is driving refineries to increase their processing capabilities to gain more profits with the less expensive heavier crudes. Processing heavier crudes, however, presents a series of challenges. The electrostatic separator for slurry oil operates continuously without plugging or blockage from asphaltene with an average efficiency at the outlet of <30 ppm catalyst fines. Proven robust technologies, such as the Gulftronic Electrostatic Separator, are needed to successfully handle the challenges accompanying high severity processing and the need to increase profits from the bottom of the barrel. The results of applying this technology will bring important revenue to the refinery along with a high separation rate of catalyst fines for severe cracking technologies. A middle size refinery with an FCC unit utilising electrostatic separation can generate an average of US$10– 15 million/yr in revenue. Even more profits are generated by savings in the overall CAPEX through lower maintenance and operating costs over conventional mechanical filtration methods. With these findings it is evident that more attention should be focused on choosing the right separation technology for upgrading the bottom of the barrel.

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