SHELL FEED NOZZLE TECHNOLOGY

A low-cost, easy-to-implement fluidised catalytic cracking unit margin improvement opportunity

WHITE PAPER

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CONTENTS

1. SHELL FEED NOZZLES: A LOW-COST LEVER TO INCREASE MARGINS IN TODAY'S NEW REALITY

While today's new reality calls for a more conservative approach to capital investment, investing in margin improvement projects is usually key to maintaining one's competitive position.

In fluidised catalytic cracking (FCC), one of the most compelling low-capital opportunities may be upgrading to latest-generation feed nozzles. This technology from Shell Catalysts & Technologies, recently upgraded after a major research and development programme using new analytical techniques, pushes the boundaries for feed atomisation and is enabling refiners around the world to capture substantial margin increases.

For example, Shell feed nozzle technology provides a low-cost opportunity for refiners to:

- **process cheaper, lower-quality feeds** such as residues and difficult-to-crack materials;
- **increase yields** by reducing dry-gas yield, increasing conversion and shifting the yield structure to more valuable products; and
- **maximise operating severity** while relieving compressor and heat balance constraints.

Dispelling the myth that leaving existing feed nozzles in situ for an additional cycle is more cost effective than investing in new ones

Refiners can occasionally be reluctant to replace or upgrade their feed nozzles, instead preferring to get another run out of their existing ones. While that can save a relatively modest amount in capital cost, this saving is usually far outweighed by the loss of performance.

Shell feed nozzles, even previous generations of the technology, are sufficiently robust to operate for more than one cycle. Nevertheless, in most cases, the shift in yields and feed flexibility that they provide means that investing in new feed nozzles at the start of the cycle enables significantly higher profitability over the entire cycle.

Indeed, the payback can often be extremely fast: latest-generation Shell feed nozzles typically pay for themselves well within the first year of operation.

Upgrading feed nozzles versus trialling an FCC catalyst

At a time when refiners are looking for inexpensive, easy-to-implement margin improvement opportunities, replacing feed nozzles compares extremely favourably against other solutions that FCC unit technologists are likely to consider.

For example, the capital cost of implementing feed nozzles is equivalent, in many cases, to the operating expense of trialling a new catalyst – but without the risk.

Assumes that evaluating a new catalyst in a medium-sized FCC would involve about $2 million of operating cost (four tonnes of catalyst a day, at $3,000 a tonne including disposal, for six months)

2. THE BENEFITS OF IMPROVED FEED ATOMISATION

When atomised sprays are discharged from feed nozzles they transition from liquid sheets to non-spherical ligaments of poorly atomised agglomerations of liquid and then, ultimately, to droplets (Figure 1).

Shell's technology, which was developed using state-of-the-art spray characterisation techniques, reduces both droplet size and the formation of globules (large droplets combined with poorly atomised ligaments), which take a substantial length of time to vaporise in the riser.

The technology therefore maximises the number of droplets and total feed droplet surface area, and reduces the feed vaporisation time, which:

- increases the usable riser volume for catalytic cracking reactions to take place; increases
- product yield;
- reduces slurry oil production; and
- reduces thermal cracking, thus minimising dry gas production and improving the product distribution for more valuable products.

In addition, the technology helps to reduce the loading on both the wet gas compressor and air blower through lower dry gas and coke yields. Most refiners operate to one or both of these limits, so lifting these constraints can be key to squeezing more money from the unit (see Section 3).

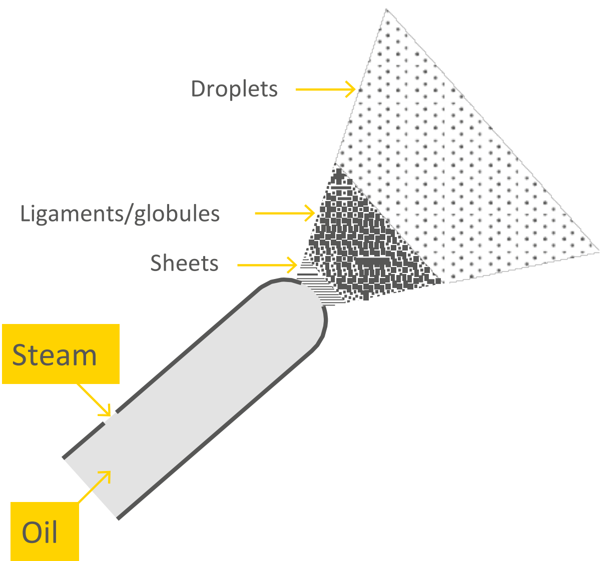


Figure 1: Typical spray transitions for a feed nozzle.

3. UNLOADINGTHEWETGASCOMPRESSORANDAIRBLOWER

Improving the atomisation and dispersion of the feedstock reduces:

- coking of the regenerated catalyst by unvaporised feed in the injection zone; and large
- temperature gradients within the riser that lead to thermal cracking reactions.

Consequently, improved atomisation and dispersion can reduce the loading on the wet gas compressor and air blower, which are common objectives for refiners (see boxed text, *Feed nozzles can help solve these commonly experienced problems*).

Reducing coking of the regenerated catalyst frees up combustion air for additional riser feed rate and/ or conversion within the coke-burning capacity of the unit. For similar flue gas operation, lower bed temperatures can be realised, which can open up opportunities to process more residue or crack more difficult feedstocks.

The reduction in thermal cracking reactions will lead to lower dry gas yield and lower loadings on the wet gas compressor and rectifying absorber column. The reactor severity and post-riser cracking time are key parameters in determining the impact of improved feed atomisation and dispersion on the dry gas yield. Riser outlet temperature is the key metric for reactor severity and generally tracks the dry-gas yield from the operation.

Figure 2 presents the reduction in dry-gas yield for several FCC units that have upgraded their feed nozzle technologies. All units have modern riser termination separation systems. In each case, unit conversion increases were achieved. Feedstock qualities ranged widely, including the extent of feedstock hydrotreating and the CCR content.

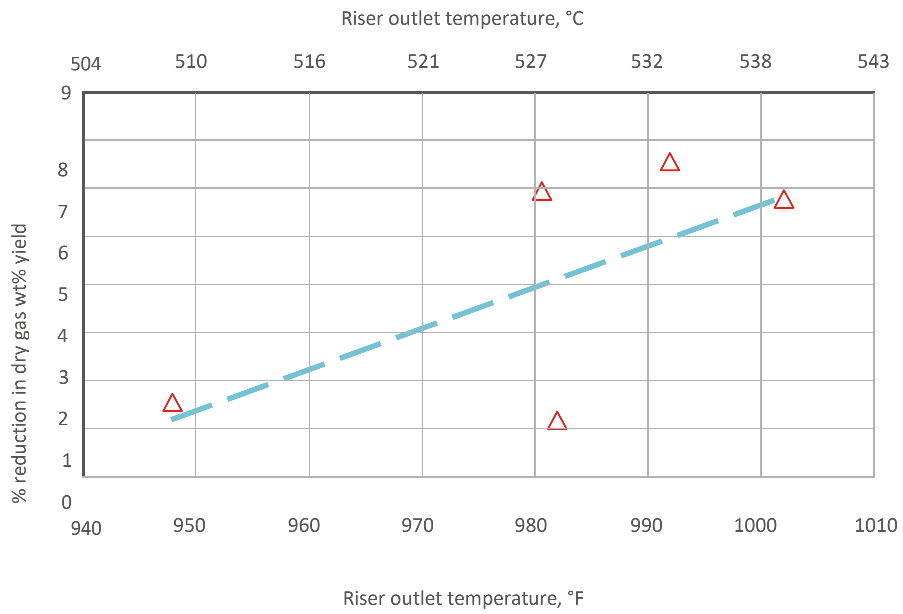


Figure 2: Dry-gas reductions following feed nozzle upgrades.

Feed nozzles can help solve these commonly experienced problems

Problem 1: "We're trying to increase FCC severity to get the most out of the feed that we are processing, but are constrained by the wet gas compressor limit."

Increasing severity via riser outlet temperature typically leads to increased dry gas production and operators commonly challenge the limit of their wet gas compressor.

Shell feed nozzle technology offers improved feedstock atomisation along with more uniform contacting of feed and catalyst across the entire riser cross section, which leads to faster feed vaporisation as well as better and more consistent quenching of regenerated catalyst in the riser. This in turn reduces dry gas production and, therefore, unloads the wet gas compressor and enables the severity to be increased.

Problem 2: "We'd like to increase conversion and propylene yield bet we're constrained by the air blower limit."

With poorly atomised feed, a significant portion of the feed remains unvaporised. As a result, the unvaporised feed excessively cokes the circulating catalyst and reduces the FCC unit's ability to increase conversion when the air blower is a constraint.

Shell feed nozzles not only have improved atomisation of the feed, but also reduce the volume of unatomised feed (liquid globules) in the spray. Consequently, the feed vaporises quicker, converts to valuable products and reduces the amount of coke laydown on the catalyst from the feed (instantaneous coke). As a result, higher conversion and propylene yield is achieved at the same coke demand.

Problem 3: "We'd like to improve margins by taking advantage of opportunity crudes but we're constrained by the air blower limit and want to limit slurry production."

Operating feed nozzles that do not properly atomise the feed (droplets too big or too much unatomised liquid) dissuades feed flexibility, and restricts the capability of processing more difficult, higher coke making feeds.

Shell feed nozzles effectively atomise more difficult feeds, thus allowing the refiner the flexibility of running these feeds while staying within their air blower constraint and upgrading slurry.

4. AUDITEDRESULTSOFNEWSHELLFEEDNOZZLEINSTALLATIONS

4.1. Pulau Bukom LRCC unit

The challenge

Pulau Bukom refinery in Singapore has a long residue catalytic cracking (LRCC) unit that was designed to crack feedstocks with a Conradson carbon residue (CCR) content of about 5 wt%. The typical feedstock cracked at the LRCC unit over recent years has had a CCR content of 3.4 wt% with a 1000°F+ (538°C+) fraction of 40.7 wt%.

The unit typically runs 5,500 t/d of long residue using a regenerator that operates with a catalyst cooler and under partial combustion. Residue feed is particularly challenging to atomise as it can be quite heavy as well as having an elevated viscosity. Often, FCC unit operators will tackle these challenges by using additional atomisation steam and higher feed preheat temperatures. Additional steam is generally effective if the feed nozzle is optimally designed for it; if not, then the additional steam can cause deterioration of the spray pattern [1]. Pursuing higher feed preheat temperatures can shift the heat balance, thereby reducing conversion and the yields of desired products.

The solution

In its 2018 turnaround, the site implemented Shell's upgraded feed nozzle technology and achieved better atomisation, dispersion and mixing with the circulating catalyst. The improvement is shown in Table 1, which presents the audited yield shifts after the feed nozzle upgrading.

Component	Yield shift* (wt%)
Dry gas	–0.4
Propylene/propane (PP)	–0.1
Butane/butylene (BB)	–0.5
Gasoline	3.7
Light cycle oil (LCO)	–0.9
Slurry oil	–1.8
Conversion	2.7

*Audited at constant coke yield

Table 1: Audited yield shifts after Pulau Bukom LRCC unit feed nozzle upgrade.

The slurry reduction was significant, as expected from an upgraded feed nozzle technology for cracking a residue feedstock. Figures 3 and 4 present the slurry oil quality shifts with respect to specific gravity and total aromatics. Crackable components that were present in the slurry oil before the turnaround were ultimately cracked to lighter products following the feed nozzle upgrade.

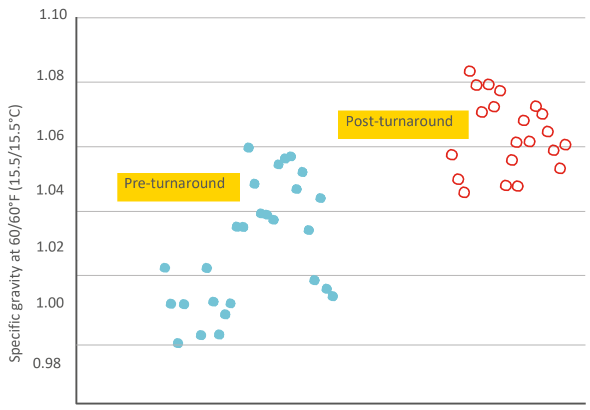


Figure 3: Slurry oil specific gravity before and after the feed nozzle upgrade.

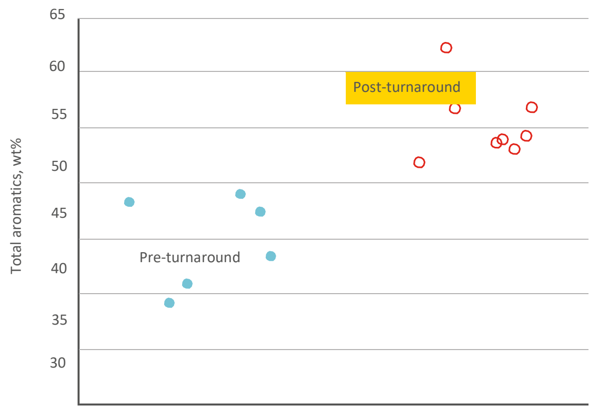


Figure 4: Slurry oil aromatics content before and after the feed nozzle upgrade.

Table 1 also indicates a dramatic increase in gasoline selectivity along with a narrowing of the yield profile and a reduction in both BB and PP. The gasoline shift was also observed at Deer Park refinery [2].

The gasoline selectivity gain and lower BB and PP can be explained by the observed shift in the riser temperature one-third up from the feed injection zone after the upgrade (Figure 5).

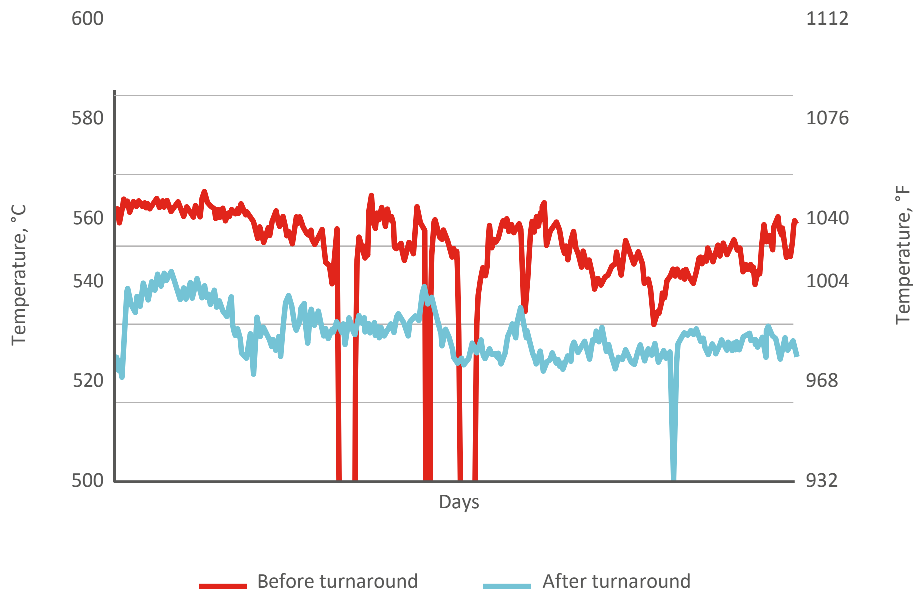


Figure 5: Riser temperature (one-third up from the feed injection zone) shift after turnaround.

The average riser temperature shift of 27°F (15°C) shown in Figure 5 is about twice that previously reported at Deer Park [2], which indicates that the LRCC unit riser had been operating with a high level of non-uniform radial mixing. The feed nozzle upgrade dramatically improved feed atomisation and dispersion, as was demonstrated by the significant temperature reduction above the feed injection zone.

Published modelling work by Gupta and Rao [3] on feedstock atomisation effects in FCC risers has shown that, as feedstock droplet size decreases (improved feed atomisation), so does the catalyst temperature along the entire length of the riser.

The remarkable gasoline yield selectivity shift observed is consistent with Theologos et al. [4], who reported hydrocarbon and catalyst temperature profiles along the FCC riser for a variety of feedstock droplet sizes. Their work showed that the largest droplets penetrated deeper into the riser but quenched the circulating catalyst the least. If an atomised spray contains a high percentage of large droplets then radial, non-uniform mixing with the circulating catalyst will take place. As a result, hot catalyst will travel further up the riser and promote high-temperature, undesirable cracking reactions, such as gasoline prematurely cracking to light products. Therefore, the upgraded LRCC unit feed nozzles have enhanced internal mixing and eliminated the premature gasoline cracking.

Value delivered

The new Shell feed nozzles significantly upgraded slurry and LCO to gasoline, but, because the new nozzles had better atomisation, there was better quenching of the regenerated catalyst leading to a lower riser temperature above the feed zone. This lower riser temperature reduced gasoline cracking to BB and PP, as seen in Table 1. Now though, the LRCC unit has flexibility in regaining the lost BB and PP: the improvement in riser temperature can be used to increase severity and get higher BB and PP while also further upgrading bottoms, or the severity can be kept the same and more BB and PP can be produced through catalyst reformulation or through catalyst additives.

In addition, under certain conditions the unit was feed rate limited by the riser temperature one-third up from the feed injection zone. The nozzle upgrade brought the site relief from this constraint. The unit no longer experiences this limit.

Key results

Riser temperature shift: **27°F (15°C)**

Slurry yield: **1.8% decrease**

Gasoline yield: **3.7% increase**

4.2. Puget Sound FCC unit

The challenge

Puget Sound refinery in Washington, USA, was keen to optimise the economics of its FCC unit, which processes a blend of vacuum gasoil and unhydrotreated heavy coker gasoil.

The solution

During its 2019 turnaround it installed latest-generation Shell feed nozzles, which helped to increase the yield of valuable products, such as PP and BB, and significantly reduce slurry yield, as shown in Table 2.

Component	Yield shift* (wt%)
Dry gas	–0.3
PP	0.2
BB	0.4
Gasoline	–0.4
LCO	0.4
Slurry oil	–1.0
Coke	0.1
Conversion	0.6

*Audited at similar feed quality and rate

Table 2: Audited yield shifts after Puget Sound FCC unit feed nozzle upgrade.

Unlike at Pulau Bukom, the bottoms upgrading was not seen in gasoline selectivity, but rather in a shift to more BB and PP. This is primarily because a unit upgrade in 2014 had already achieved good feed atomisation and dispersion within the circulating catalyst, and the new riser was operating with a low level of non-uniform radial mixing.

Consequently, the extent to which gasoline was prematurely being cracked to light products was already low. So, instead of more gasoline, higher PP and BB yields have been achieved through the conversion increase.

Value delivered

The yield shifts reported in Table 2 generated significant margin for the refinery. In addition, the improved feed atomisation and vaporisation resulted in lowering the regenerator bed temperature by about 39°F (22°C); this enabled the refinery to crack more heavy coker gasoil and enhance its flexibility in processing less crackable feedstocks.

Key results

Regenerator bed temperature reduction: **39°F (22°C)**

Slurry yield: **1% decrease**

BB yield: **0.4% increase**

PP yield: **0.2% increase**

4.3. Sarnia FCC unit

The challenge

Sarnia refinery in Canada operates its FCC to an air limit throughout the year, which is particularly constraining during the summertime.

The solution

During its 2016 turnaround, the site installed latest-generation Shell feed nozzles.

Value delivered

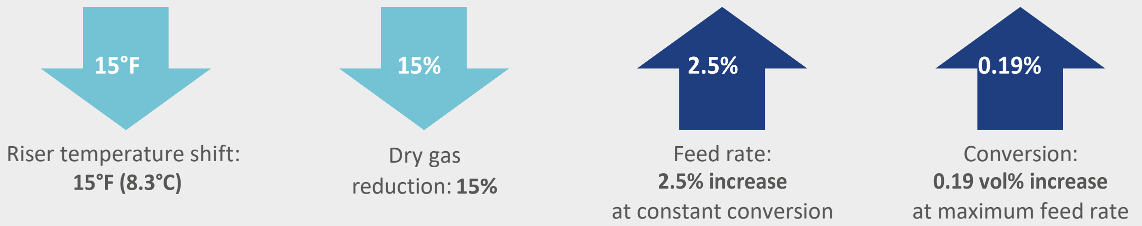
The site benefited from lower coke production from the new Shell feed nozzles, which helped to relieve the air blower constraint. As a result, the site was able to improve the performance of its FCC in the following ways:

1. increased rate at constant conversion: for the six months of the year when the unit is air blower (coke burn) constrained, the maximum feed rate cannot be sustained. Under these conditions, the new feed nozzles **enable a 2.5% higher feed rate at constant conversion**.

2. increased conversion at maximum feed rate: during the remaining six months, the new feed nozzles **provide 0.19 vol% more conversion at maximum feed rate**.

In addition, the new Shell feed nozzles also delivered value through a **dry gas reduction of about 15% and a reduction in mix zone temperature of 15°F**.

Key results



5. FCC PRETREATMENT–FCC OPTIMISATION SCENARIO

The installations described above are examples of implementing feed nozzle technology improvements in the FCC unit in isolation. However, the implications of upgrading feed nozzle technology for upstream units such as the FCC-PT should also be considered for realising maximum benefits. The following scenarios highlight the advantages of such an integrated approach.

FCC units that crack partially or fully hydroprocessed feedstocks have advantages with respect to crude and import feed quality flexibility. Product yield selectivities are often better than for FCC operations that lack this upstream equipment. The FCC-PT can provide the FCC with:

- **upgraded feed quality**, thus improving its crackability and product yield selectivity;
- **lower feed sulphur**, thus enabling lower sulphur products and flue gas sulphur oxide (SOx) emissions;
- **lower FCC catalyst usage** rates due to the removal of contaminant metals;
- **reduced feed carbon content**, relieving air-blower-constrained FCC operations; and
- **lower concentrations of precursors** that can increase FCC flue gas stack nitrogen oxide (NOx) emissions.

The optimisation of the FCC along with the FCC-PT is an important undertaking that should be evaluated to bring the most value to the site. The following example illustrates this point and demonstrates the capabilities of Shell's FCC feed nozzle technology.

Shell Catalysts & Technologies' FCC kinetic model for simulation and optimisation, SHARC,[1] was used to develop the example. The model provided predictions of FCC performance with changes in FCC-PT conditions and FCC technology changes.

A refiner operates an FCC-PT–FCC complex (Figure 6) in which:

- a high-pressure FCC-PT operates at constant feed hydrodenitrogenation (HDN) for a 32-month cycle that aligns with mid-cycle for the FCC operation; and
- the FCC cracks 100% of the FCC-PT product at 60 MBPD under partial-burn regeneration.

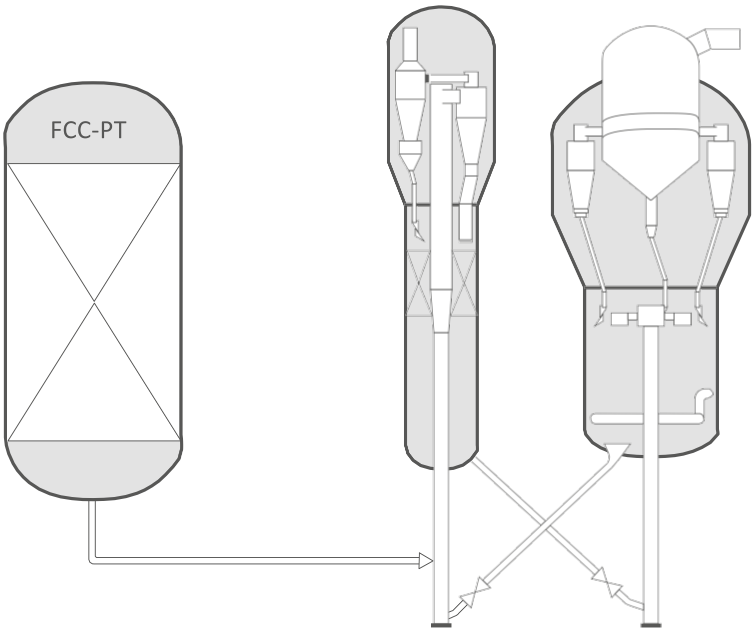


Figure 6: FCC-PT/FCC schematic.

[1]SHARC is a Shell trademark.

The FCC-PT start-of-run (SOR) and end-of-run (EOR) product qualities are different as, in this example, the severity needs to increase over the operating cycle to maintain constant HDN. The higher EOR severity also tends to lower aromatics and increase FCC crackability, thereby lowering slurry yield and increasing transportation fuel yields. Table 3 presents the influence of the two FCC-PT conditions on FCC performance at constant coke yield.

	FCC-PT, SOR	FCC-PT, EOR
Riser temperature, °F (°C)	985 (529)	985 (529)
Regenerator temperature, °F (°C)	1356 (736)	1360 (738)
Cat/oil ratio, wt/wt	6.1	6.0
Conversion, wt% yield	70.7	71.2
Slurry	14.4	13.2
LCO	14.9	15.6
Gasoline	47.3	47.9
BB	8.1	8.0
PP	5.0	5.0
Dry gas	4.2	4.2
Coke	6.1	6.1
Dry gas, MMSCFD (scm/h)	25.7 (30,300)	25.7 (30,300)
Wet gas, MMSCFD (scm/h)	45.1 (53,100)	45.0 (53,000)

Table 3: FCC performance under SOR and EOR FCC-PT conditions.

The refiner recognises the margin advantage of processing a FCC feed that has improved crackability. However, by operating the FCC-PT at a severity higher than necessary to maintain HDN, the catalyst operating cycle would be shortened. This could create complications for site turnaround planning and scheduling, as dual FCC-PT cycles would no longer align with the FCC operating cycle. So, instead, the refiner considers how new feed nozzles might upgrade the FCC-PT product and help to preserve the FCC-PT operating cycle.

Table 4 presents the effect of upgrading the FCC feed nozzles to Shell's technology under FCC-PT SOR conditions at constant coke yield. A drop in regenerator temperature and a decrease in dry gas yield are both observed. As a result, the cat/oil ratio increases and liquid yields improve. With a lower wet gas compressor loading there is room to increase riser temperature. An increase of 10°F (6°C) increases conversion by 0.5 wt% and shifts the yield structure to a lighter distribution, all within the wet gas compressor capacity.

	Existing feed nozzles	Upgraded feed nozzles	
Riser temperature, °F (°C)	985 (529)	985 (529)	995 (535)
Regenerator temperature, °F (°C)	1356 (736)	1337 (725)	1350 (732)
Cat/oil ratio, wt/wt	6.1	6.5	6.6
Conversion, wt% yield	70.7	71.1	71.6
Slurry	14.4	14.2	14.0
LCO	14.9	14.7	14.4
Gasoline	47.3	47.9	47.8
BB	8.1	8.4	8.3
PP	5.0	5.2	5.4
Dry gas	4.2	3.5	4.0
Coke	6.1	6.1	6.1
Dry gas, MMSCFD (scm/h)	25.7 (30,300)	21.7 (25,600)	24.3 (28,600)
Wet gas, MMSCFD (scm/h)	45.1 (53,100)	41.9 (49,300)	44.7 (52,600)

Table 4: FCC performance with upgraded feed nozzles under FCC-PT SOR conditions.

Table 5 presents the impact of upgrading the FCC feed nozzles to the latest Shell technology under FCC-PT EOR conditions. The upgraded feed nozzles improve the yield structure beyond what can be achieved through improvements in EOR feed quality in the FCC-PT.

	Existing feed nozzles	Upgraded feed nozzles	
Riser temperature, °F (°C)	985 (529)	985 (529)	995 (535)
Regenerator temperature, °F (°C)	1360 (738)	1348 (731)	1359 (737)
Cat/oil ratio, wt/wt	6.0	6.4	6.4
Conversion, wt% yield	71.2	71.8	72.2
Slurry	13.2	12.9	12.7
LCO	15.6	15.3	15.1
Gasoline	47.9	48.6	48.5
BB	8.0	8.4	8.3
PP	5.0	5.2	5.3
Dry gas	4.2	3.5	4.0
Coke	6.1	6.1	6.1
Dry gas, MMSCFD (scm/h)	25.7 (30,300)	21.9 (25,800)	24.5 (28,900)
Wet gas, MMSCFD (scm/h)	45.0 (53,000)	42.0 (49,500)	44.8 (52,800)

Table 5: FCC performance with upgraded feed nozzles under FCC-PT EOR conditions.

Under both SOR and EOR FCC-PT operating conditions, the Shell FCC feed nozzles are predicted to give additional improvements in yield structure as well as to expand operating flexibility. The refiner can augment its FCC capability through reasonable capital investment while retaining the 32-month FCC-PT operating cycle and perhaps even extending the cycle.

Furthermore, the added capability of the new feed nozzles also provides the opportunity to modify and optimise the catalyst system and reactor internals in the FCC-PT to, for example, pursue opportunity feeds.

It should be noted that refiners that operate their FCC-PT at constant feed hydrodesulphurisation (HDS) can likewise benefit from new FCC feed nozzles. These refiners face a similar FCC-PT cycle-shortening challenge should they pursue an operating severity that is higher than necessary in order to maintain HDS.

Additionally, new FCC feed nozzles will benefit refiners who hydrodesulphurise the FCC gasoline in their FCC-PT–FCC complexes. These refiners can uncouple the gasoline octane loss from the overall HDS of the complex. The new feed nozzles provide the flexibility of raising riser temperature and generating more gasoline octane, thus mitigating the octane loss from HDS and yielding a higher-octane, desulphurised FCC gasoline.

6. KEY TAKEAWAYS

As a result of a major Shell Catalysts & Technologies research and development programme using new analytical techniques, the organisation has developed upgraded feed nozzle technology that has pushed the boundaries for feed atomisation.

Consequently, this provides a low-cost opportunity for refiners to:

- **process cheaper, lower-quality feeds** such as residues and difficult-to-crack materials;
- **increase yields** by reducing dry-gas yield, increasing conversion and shifting the yield structure; and
- **maximise operating severity** by unlocking compressor and heat balance constraints.

Shell has implemented and audited the technology at six assets, where results have included:

- **39°F (22°C) reduction in regenerator bed temperature; 3.7% increase in**
- **gasoline yield;**
- **15% reduction in dry gas;** and
- **2.5% increase in feedrate.**

Two more implementations will take place in 2021 at joint-venture and third-party locations.

The technology complements the benefits already provided by FCC feed hydrotreaters and expands the options for upgrading the FCC-PT to optimise the FCC-PT–FCC complex.

REFERENCES

1. Kunz, K., Ludolph, R., Carroll, C. and Cui, Z. (2016), "Developing Feed Nozzle Technology from an Owner/Operator Perspective," AFPM Cat Cracker Seminar, Houston, USA, CAT-16-8.

2. Ludolph, R., Kunz, K., Hunt, D. and VanRoeyen, J. (2017), "Performance Assessment of Feed Nozzle Upgrade," AFPM Annual Meeting, San Antonio, USA, AM-17-46.

3. Gupta, A. and Rao, D. S. (2001), "Model for the performance of a fluid catalytic cracking (FCC) riser reactor: Effect of feed atomization," *Chemical Engineering Science*, 56, 4489–4503.

4. Theologos, K. N., Lygeros, A. I. and Markatos, N.C. (1999), "Feedstock atomization effects on FCC riser reactors selectivity," *Chemical Engineering Science*, 54, 5617–5625.

ABOUT THE AUTHORS

Robert A. Ludolph, FCC Principal Technologist, Shell Catalysts & Technologies

Robert provides technical advice, assurance and leadership to advance the process technologies and operations at Shell wholly-owned, joint venture and third-party-licensee sites. He has BS and MS degrees in chemical engineering and is a registered Professional Engineer with 43 years of refining experience including 36 years specialising in FCC.

Zhe Cui, FCC Research and Development (R&D) Technologist, Shell Catalysts & Technologies

Zhe works on FCC R&D, has a PhD degree in chemical engineering and 16 years of industry experience that include eight years specialising in FCC technology.

Srinivasa Rao Kusume, FCC Senior Technologist, Shell Catalysts & Technologies

Rao provides technical assistance to FCCs in design and operation in Asia-Pacific. Rao has a BTech degree in chemical engineering and 32 years of refinery experience, including 25 years specialising in FCC optimisation, troubleshooting, safeguarding, and margin and reliability improvements.

Mohammad Umer Ansari, FCC Senior Technologist, Shell Catalysts & Technologies

Mohammad provides technical services for optimisation, troubleshooting, catalyst selection and design for Shell and third-party FCCs in the Americas. He has BTech and MTech degrees in chemical engineering and has been working in the refining and petrochemical industry for 23 years, including 14 years with Shell.

Todd Foshee, FCC Licensing Technology Manager, Shell Catalysts & Technologies

Todd leads the licensing efforts for Shell's FCC technology to third-party customers and is part of a team that provides the process design on FCC projects to both Shell and third-party clients. Todd has BS and MS degrees in chemical engineering along with 25 years of experience in the hydrocarbon processing industry that includes process design, site support and operations.

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