A winning combination

Gary M. Sieli, Lummus Technology, USA, and Nash Gupta, Chevron Lummus Global LLC, USA, discuss delayed coking and the LC-FINING ebullated bed hydrocracker technology.

Refinery operations are often characterised in one of two ways: refineries with residue upgrading technologies and those without. For those refiners without this capability, the quantity of heavy, high sulfur crude that can be processed is limited. The addition of a residue upgrading technology such as delayed coking or ebullated bed hydrocracking will allow these refineries to process larger quantities of heavy, high sulfur, lower priced crudes, resulting in increased profitability.

Many refiners who already have some residue upgrading capability are looking to improve the profitability of their refinery further by processing larger quantities of heavy crudes. For these refiners, the downstream processing of the incremental residue must be addressed. For example, if a refinery already has a delayed coker and is interested in processing additional quantities of heavy, high sulfur crude, the choices for processing the incremental residue are:

- Add a gasifier.
- Revamp the existing coker.
- Add a new coker.
- Debottleneck the coker by adding a residue conversion process such as ebullated bed hydrocracking upstream of the coker.

The addition of a gasifier should only be considered if the syngas can be used to produce hydrogen, power and/or chemicals economically. The revamp of the existing coker is often a viable option, however, the amount of additional capacity that can be achieved is limited. In many cases, the quantity of incremental residue can only be handled through an additional new coker. In either case, the refiner must consider how to handle the incremental coke production. This will most likely require additional conveying and storage and, in some cases, harbor improvements for ship loading.

An alternative approach is the addition of an ebullated bed hydrocracker, such as an LC-FINING® unit, upstream of the existing coker. This approach minimises the impact on the existing coker, produces larger quantities of higher valued middle distillate products, and minimises the incremental quantity of coke produced.

In this article, two studies are evaluated to show how the combination of delayed coking and ebullated bed hydrocracking can significantly increase the conversion capabilities of a refinery versus either technology alone.

The LC-FINING process

The LC-FINING process is an ebullated bed residue hydrocracking process licensed by Chevron Lummus Global. The process features high distillate yields and high heteroatom and metals removal, and is an efficient way of handling petroleum bottoms and other heavy hydrocarbons. It is safe, reliable, and easy to operate. Commercial designs range from desulfurisation at moderate conversion for the production of low sulfur fuel oil, to high conversion, with the unconverted bottoms routed to downstream processes such as coking or gasification.

Adding a LC-FINING unit

In the first study, the differences in the cost and economics of adding an LC-FINING unit to an existing delayed coking refinery versus the addition

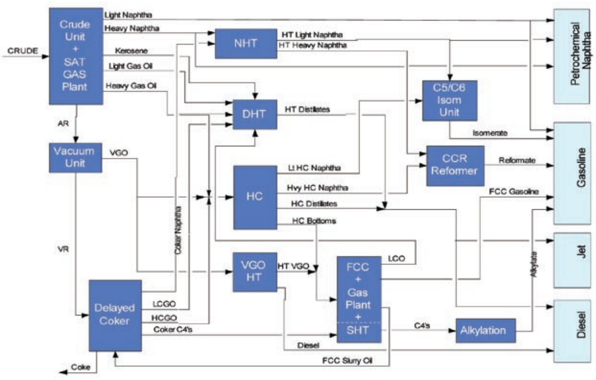

Figure 1. Base delayed coking refinery block flow diagram.

Table 1. Crude slate

Crude	Base refinery	Upgraded refinery	US$/bbl
	Blended crude composition, vol.%		
Urals[1]	17.5	45.64.48	
Maya[2]	17.5	45	60.39
Bonny Light[3]	32.5	5	70.57
Sarir[4]	32.5	5	66.74
Total	11	11	

[1]2007 average spot price for Amsterdam-Rotterdam-Antwerp (ARA).
[2]2007 US West Coast spot price plus US$ 5.00 additional shipping.
[3]Assumed equivalent to average 2007 spot price for Brass River ARA.
[4]Assumed equivalent to average 2007 spot price for Es Sider ARA.

of incremental coking capacity were compared. A 200 000 bpd refinery represented the base case delayed coking refinery. A simplified block flow diagram of the base refinery is presented in Figure 1.

A 65/35 blend of light and heavy crudes was assumed for the base refinery, with the light sweet crude represented by a 50/50 blend of Sarir and Bonny Light crudes, and the heavy crude represented by a 50/50 blend of Urals and Maya crudes.

For the upgraded refinery cases, the quantity of heavy crude was increased to 90% of the total crude blend. Details of the crude slate for both refinery cases are presented in Table 1.

Natural gas was assumed to be available for hydrogen production and to supplement refinery energy requirements. Methyl tertiary butyl ether (MTBE) was assumed to be available for gasoline blending. All product properties were specified in accordance with Euro IV specifications. Product prices are average 2007 Rotterdam cargo free on board (FOB) prices available from Platts.

Upgraded refinery cases

Case one

An LC-FINING unit was added to the base case delayed coking refinery. The LC-FINING unit was a single train unit processing virgin vacuum residue blended with 5% FCC slurry oil. Conversion of the 566 ˚C+ vacuum residue was set at 72 vol.%. At this conversion, the unconverted LC-FINING residue could not be used as fuel oil blendstock and needed to be processed in the existing delayed coker. All of the LC-FINING naphtha, distillate and vacuum gas oil were hydrotreated either in existing facilities or an integrated hydrotreating reactor. Unconverted LC-FINING bottoms were processed in the existing delayed coker, together with virgin vacuum residue, as required to maintain the 28 000 bpd capacity.

Case two

The capacity of the existing delayed coker was maintained at 100% of the base case coker (28 000 bpd) and a new delayed coker was added to handle the incremental capacity.

The investment costs for all new processes and utility systems were included in the model. The cost of incremental capacity that could be achieved through unit revamp was equivalent to the cost of new capacity. The investment cost for offsites such as incremental coke handling and storage and product tankage was also included in the model as a fixed percentage of the in side battery limits (ISBL) cost.

All product rates obtained for the base case refinery were maintained as minimums in the upgraded refinery, except for the gasoline product. Preliminary results showed that relatively large quantities of purchased MTBE were required to supplement the reduced quantities of naphtha from the heavy crude's processing. Since most European refiners are long on gasoline, this modest reduction in gasoline production (approximately 15 - 20%) was deemed acceptable.

Table 2 presents the incremental product rates and imported feed requirements for the upgraded refinery cases, while Table 3 summarises the required new

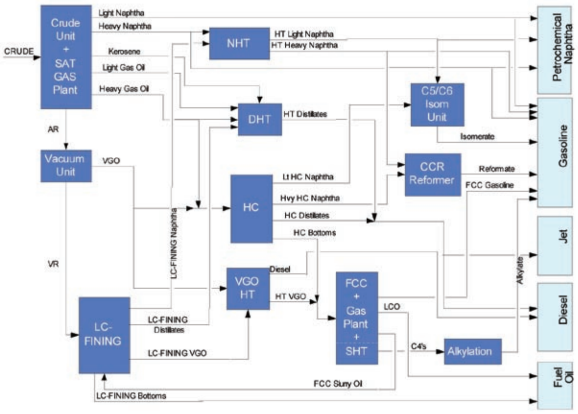

Figure 2. LC-FINING refinery block flow diagram.

Table 2. Upgraded delayed coking refinery incremental product rates and imported feeds

	Case 1		Case 2	
	Add LC-FINING		Add incremental coking	
	bpd	000 tpy	bpd	000 tpy
Product slate				
Euro IV 92 RON gasoline	-12 963	-461	-17 349	-644
Petrochemical naphtha	6432	248	11 491	442
Jet A1 & JP-8	0	2	0	1
Euro IV diesel	7012	325	2082	94
Regular diesel[1]	1402	68	416	18
Bunker fuel oil (180 cst)	0	0	0	0
Bunker fuel oil (380 cst)	0	0	0	0
Sulfur		111		89
Coke		87		394
Net liquids	1882	380	-3361	394
Imported feeds				
Incremental natural gas		122		56
Incremental MTBE	366	15	447	19

[1]Regular diesel production specified as 20% of Euro IV diesel production for all cases

Table 3. Upgraded delayed coking refinery incremental process unit capacity

	Case 1		Case 2	
	Add LC-FINING		Add Incremental coking	
	000 tpy	bpd	000 tpy	bpd
Crude unit	1273	0	1273	0
Vacuum unit	1070	16 000	1070	16 000
Delayed coker			1252	21 000
LC-FINING	1686	30 000		
H_2 plant (SMR)	50	60 million ft^3/d	17	23 million ft^3/d
Amine regeneration (DEA)		1956 gpm		1556 gpm
Sulfur recovery + tail gas treating	166	473 tpy	132	377 tpy

process unit capacities. Table 4 presents a breakdown of the estimated ISBL and out side battery limits (OSBL) costs, incremental revenue and calculated internal rates of return (IRR) for each case. The %IRRs were calculated assuming a 70:30 debt:equity ratio, 20% income tax, and 15 year project life.

These results show that the incremental coking capacity required for case two (21 000 bpd) was too large to be achieved through revamp of the existing unit. A new delayed coker will need to be added. Also, the additional coke produced in case two (394 000 tpy) may require additional coke handling infrastructure. Incremental coke production for case one is only 87 000 tpy. This relatively small increase in coke production will have minimal impact on the existing coke handling system.

The net change in gasoline and naphtha in both cases was essentially the same. If gasoline production were maintained in both cases through the purchase of additional quantities of MTBE, the cost associated with the MTBE purchase lowered %IRRs for both cases, but the relative results remained the same.

In both cases, most of the economic benefit was from the savings associated with the purchase of the heavier crude slate. However, the net incremental revenue associated with the LC-FINING case is significantly larger than the incremental coking capacity case, due mostly to the larger diesel production.

Although the total investment cost associated with the addition of the 30 000 bpd LC-FINING unit was more than US$ 264 million higher than the addition of 21 000 bpd of incremental coking capacity, the incremental net revenue difference (approximately US$ 124 million/y) was sufficient to justify the incremental cost.

For refiners concerned about coke sulfur, the addition of the LC-FINING unit to the existing refinery produced a coke with a sulfur content of 4.94%, while the addition of incremental coking capacity produced a coke with a sulfur content of 5.34%.

Adding a delayed coker

In the second study, the economics of adding a delayed coking unit to a refinery operating an LC-FINING unit were assessed. A 200 000 bpd refinery processing 100% Urals crude represented the base case refinery with an LC-FINING unit producing a 180 cst, 1.5 wt% sulfur fuel oil. The study assumed that this LC-FINING refinery was interested in eliminating its bunker fuel oil production and increasing its diesel production by adding a delayed coker to the refinery, with the coker processing the unconverted LC-FINING bottoms.

Figure 2 is a simplified block flow diagram of the LC-FINING refinery. Crude and product pricing are as previously defined.

In the base refinery, the LC-FINING unit was a single train unit processing 540 ˚C+ vacuum residue blended with 5% FCC slurry oil. Conversion of the 540 ˚C+ vacuum residue was set at 65 vol.% for the production of stable LC-FINING bottoms that could be blended with cutter stock for fuel oil production. The LC-FINING unit's conversion was increased to 75%, with all of the unconverted LC-FINING bottoms processed in the new delayed coker. Naphtha from the coker was processed in the existing naphtha hydrotreater. Light coker gas oil was processed in the existing distillate hydrotreater. Heavy coker gas oil was processed in the existing hydrocracker.

The gasoline, naphtha and distillate volumetric production rates established in the base refinery were defined as minimum rates in the upgraded refinery operations.

Table 5 summarises the incremental product rates and imported feed requirements and Table 6 summarises the required new process unit capacities associated with the addition of the delayed coker to the LC-FINING refinery. Table 7 presents a breakdown of the estimated ISBL and OSBL costs, incremental revenue, and calculated internal rates of return for the upgraded refinery. The %IRR was calculated assuming a 70:30 debt:equity ratio, 20% income tax, and 15 year project life.

These results showed that the elimination and conversion of the low sulfur fuel oil to distillates produced an excellent return on investment. The elimination of the lower value, low sulfur fuel oil and the production of higher value distillates, together with the nearly US$ 30/bbl price differential between distillates and low sulfur fuel oil, was the force behind the high %IRR obtained.

In this particular example, the impact on the existing refinery operations was limited. The kerosene sweetening unit eliminated the need to invest in the revamp of the existing hydrotreater to process the light coker gas oil from the delayed coker. The heavy coker gas oil product backed out heavy virgin gas oil feed from the hydrocracker feed, which was processed in the distillate hydrotreater, eliminating the need to revamp the hydrocracker.

Table 4. Upgraded delayed coking refinery estimated total installed cost (US$ million) and %IRRs

	Case 1	Case 2
	Add LC-FINING	Add incremental coking
Investment costs		
ISBL	611.92	409.17
Utilities and offsites	167.06	105.12
Total installed cost	778.98	514.29
Incremental gross revenue	67.39	(87.38)
Incremental raw materials	(195.45)	(215.72)
Incremental utilities	9.54	(0.90)
Net incremental revenue	253.30	129.24
%IRR	26.14	18.13

Table 5. LC-FINING refinery and delayed coker incremental product rates and imported feeds

	bpd	000 tpy
Product slate		
Euro IV 92 RON gasoline	0	-32
Petrochemical naphtha	3069	148
Jet A1 & JP-8	0	2
Euro IV diesel	13 761	645
Regular diesel (note)	2752	132
Bunker fuel oil (180 cst, 1.5% S)	-21 228	-1111
Bunker fuel oil (380 cst, 1.5% S)	0	0
Sulfur		4
Coke		178
Net liquids	-1646	-215
Imported feeds		
Incremental natural gas		-18
Incremental MTBE	0	0
Incremental FCC slurry oil	0	0

Conclusion

The results suggest that the combination of an LC-FINING ebullated bed hydrocracker and a delayed coker can increase a refinery's profitability, particularly for those refiners looking to increase diesel production. For an existing delayed coking refinery interested in processing larger quantities of heavier crude, the addition of an LC-FINING unit can provide a higher rate of return than the addition of incremental coking capacity. For a refinery that currently operates an LC-FINING unit producing low sulfur fuel oil, the addition of a delayed coker and conversion of the fuel oil to higher valued products can yield an excellent return on investment.

References

1. Platts OPR Extra; January, 2007 through December, 2007
2. PAPPOS, N., MSc, and SKJØLSVIK, K.O., MSc, 'The European Marine Fuel Market - Present and Future', Paper at ENSUS 2002, International Conference on Marine Science and Technology for Environmental Sustainability, Newcastle, November 2002.
3. REYNOLDS, B., GUPTA, N., BALDASSARI, M., and LEUNG, P., 'Clean Fuels From Vacuum Residue Using the LC-FINING Process.'

Table 6. LC-FINING refinery and delayed coker incremental process unit capacity

	000 tpy	bpd
Kerosene sweetening	138	3000
Delayed coker	525	9000
H_2 plant (SMR)	8	9 million ft^3/d
Amine regeneration (DEA)		70 gpm
Sulfur recovery + tail gas treating	4	17 tpd

Table 7. LC-FINING refinery and delayed coker estimated total installed cost (US$ million) and %IRR

Investment costs	
ISBL	149.87
Utilities and offsites	78.13
Total installed cost	228.00
Incremental gross revenue	208.00
Incremental raw materials	(5.91)
Incremental utilities	0.59
Net incremental revenue	213.32
%IRR	70.30