Cover Story

HIGHS & LOWS

Gary M. Sieli, Chevron Lummus Global, USA, explores process options designed to address the International Maritime Organisation's fuel oil sulfur limits.

The maximum sulfur content of marine bunker fuel oils is being reduced from 4.5% to 0.5% or lower, depending on the specific location, as part of a global effort to reduce air emissions from international shipping. This change will have a significant impact on refiners, forcing them to decide whether or not to exit the bunker fuel oil market altogether, to invest in bottom of the barrel upgrades such as delayed coking, hydrocracking and distillate hydrotreating, or to seek ways to address the new sulfur limit while limiting capital investment and improving profitability. There are a number of refinery technologies designed to address the problems facing refiners as a result of these fuel oil and diesel sulfur limits. This article offers refiners a number of potential residue treating processing solutions.

Refiners are faced once again with the need to modify their product slate to conform to new environmental regulations. Efforts to clean up the atmosphere have extended to fuel oil burned at sea. In October 2008, the International Maritime Organisation (IMO) adopted new standards to control exhaust emissions from the engines that power ocean going vessels. The new standards are geographically based; ships operating in areas with air quality problems, designated as emission control areas (ECAs), are required to meet tighter emission limits. The new standards will be phased in over a period of several years. Table 1 summarises the proposed fuel sulfur standards and the start date.

Beginning in 2010, new and existing ships operating in ECAs will be required to use fuels with a maximum sulfur level of 1 wt%, decreasing to 0.1 wt% in 2015, ultimately representing a 98% reduction from the current global cap. In 2020, emissions from ships operating outside of designated ECAs will be required to use fuels with a maximum sulfur level of 0.5 wt%, representing a 90% reduction from the current global cap. The latter specification is subject to review in 2018, but no delay past 2025.[1]

These emission reductions may also be achieved by the installation of onboard flue gas desulfurisation. While this technology has been commercially proven in land based industrial facilities around the world, it is unlikely that it will be commercially accepted as a ship based application. Furthermore, other issues surrounding the use of this technology, including the discharge of the treated wastewater, need to be resolved. The number of ships that will actually be retrofitted for this application is therefore unclear. It is more likely that ships will be retrofitted to burn low sulfur diesel fuel while operating in ECAs. Refiners that currently serve the bunker market have already started considering future options.

Options available to refiners

The number of options available to refiners producing high sulfur fuel oil (HSFO) is limited. These are:

- Continue business as usual. Many refiners currently producing HSFO will continue with this operation. Marketability of HSFO will become more difficult and prices will almost certainly decline. While a change to lower sulfur crude is possible, the higher cost of these crudes typically makes this a costly option.

- Exit the residue fuel oil market completely. Many refiners are considering the implementation of bottom of the barrel upgraders, including delayed coking and residue desulfurisation (RDS) and residue fluid catalytic cracking (RFCC) combinations, producing more low sulfur distillates, including marine diesel.
- Invest to reduce the sulfur content of the fuel oil and continue to serve the bunker market. Investments should be carefully evaluated to take full advantage of available process options and the associated benefits of these options.

Unfortunately, the changes outlined by the IMO will have repercussions for many refiners, particularly in Asia, where much of the world's bunker fuel is produced. For many small refiners (100 000 bpd capacity or less), total bottom of the barrel upgrades are too costly. These refiners will need to consider investment options that enable them to reduce the sulfur content of the fuel oil while simultaneously achieving other incremental benefits that can improve their return on investment.

Desulfurisation of atmospheric and/or vacuum residues, by RDS and VRDS, respectively, remains the premier technology available for the production of low sulfur fuel oil (LSFO) from residues and is widely used in Asia. While this technology is not cheap, proper integration of RDS or VRDS into an existing refinery can offer additional processing benefits that can improve profitability and return on investment.

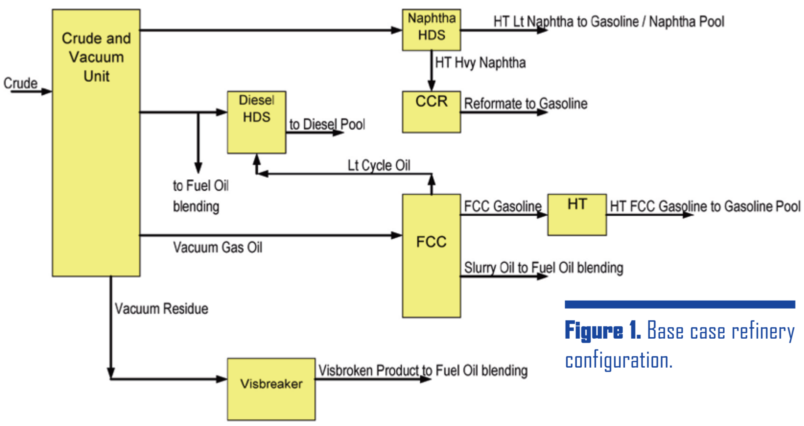

Figure 1. Base case refinery configuration.

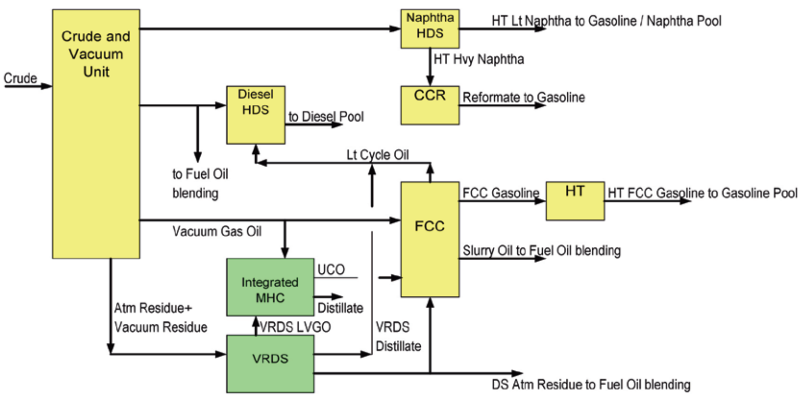

Figure 2. Upgraded refinery configuration.

Production of LSFO with less than 0.1% sulfur from atmospheric and/or vacuum residues is difficult and impractical using RDS or VRDS technology; however, production of 0.5% sulfur LSFO is achievable, and the decision to invest in this technology will depend on the price of 0.5% sulfur LSFO relative to the price of HSFO. Refiners interested in pursuing this option should also explore the numerous variations of the technology that are available to maximise the economic benefit of this investment. Some of these variations include:

- Desulfurising a combined atmospheric/vacuum residue (VRDS), while maintaining a single train operation to reduce the investment cost.
- Processing a portion of the desulfurised atmospheric residue in an existing FCC. Many refiners already process limited quantities of atmospheric or even vacuum residue in existing FCCs.
- Inclusion of an integrated mild hydrocracking reactor to process virgin vacuum gas oils as well as vacuum gas oils from the RDS operation. This can increase the production of middle distillates and improve FCC feed quality.

Each of these options will produce 0.5% LSFO while offering additional processing benefits.

VRDS configurations

The justification for any investment to produce 0.5% LSFO will depend on the price of the 0.5% sulfur LSFO versus the price of HSFO. Numerous estimates exist.[2] The consensus, however, is that the price for 0.5% sulfur LSFO will be at least US$ 70/t higher than the price of HSFO. Using this pricing relationship as a basis, a study was undertaken to understand how a small refinery (100 000 bpd capacity) could benefit from an investment in a VRDS unit. The study also explored variations of the VRDS configuration and the benefits associated with these variations.

The base case FCC refinery configuration is shown in Figure 1. A 50/50 blend of Arabian light and Arabian heavy crudes was assumed for all cases explored in this study. Average 2008 Singapore spot prices were assumed for all crudes and products.

The combination of Arabian light and Arabian heavy crudes was selected for this study because these crudes are processed in many refineries and have been commercially processed in several RDS and VRDS units throughout the world, particularly in Asia. The processing of heavier, higher sulfur, lower cost crudes in an RDS or VRDS configuration is also possible. However, crudes having a very high metal content (Ni + V), such as Venezuelan crudes, require larger RDS or VRDS catalyst volumes, resulting in an increase in the investment and a deterioration of the economics.

Four VRDS cases were evaluated:

- Case 1: VRDS processing a blend of atmospheric and vacuum residue, with VRDS feed

Table 1. Proposed fuel sulfur standards		
Start date	ECA fuel sulfur limit (wppm)	Global fuel sulfur limit (wppm)
July 2010	10 000	
January 2012		35 000
January 2015	1000	
January 2020		5000

metals (Ni + V) limited to 120 wppm and the capacity limited to a single train.

- Case 2: as Case 1, with an integrated mild hydrocracking reactor included as part of the VRDS and mild hydrocracking conversion limited to 22%.
- Case 3: as Case 1, with a portion of the desulfurised atmospheric residue processed in the existing FCC limited to 2 wt% Conradson carbon in the FCC feed (limited RCC).
- Case 4: as Case 3, with an integrated mild hydrocracking reactor included.

A simplified block flow diagram of the proposed upgrades is presented in Figure 2. In all the upgrader cases, the FCC was limited to a minimum capacity of 60% of the base case capacity to avoid unrealistically low FCC capacities. Table 2 includes crude and product prices and summarises the results of this study.

As shown in Table 2, all of the cases provide a payout period of three years or less, indicating that the inclusion of a VRDS into an existing refinery for the production of LSFO (0.5% S), even in a relatively small refinery of 100 000 bpd, can be economically justified at a HSFO to LSFO price differential of US$ 70/t or greater.

The coprocessing of a small portion of the desulfurised atmospheric residue (up to a CCR limit of 2 wt %) in the existing FCC dramatically improves these results, with a relatively small increase in investment cost.

Similar economic returns are realised with the inclusion of a mild hydrocracking reactor integrated with the VRDS, while also processing a small portion of the desulfurised atmospheric residue in the existing FCC. Although this particular configuration has a higher investment, the reduction in FCC feed sulfur will significantly reduce SO_x emissions in the FCC regenerator, an important factor for those refiners looking to reduce emissions.

Conclusion

The stringent fuel oil sulfur limits adopted by the IMO will impact many refiners all over the world, particularly in Asia, where a large portion of the world's bunker fuel oil is produced. Refiners can continue to service the bunker market, producing low sulfur fuel oils that satisfy these sulfur limits by investing in VRDS process configurations tailored to satisfy their specific refinery needs while minimising investment and maximising profitability. Additional marine fuel markets will be increasingly supplied by low sulfur diesel through added residue upgrading.

References

1. EPA, International Maritime Organisation Adopts Program to Control Air Emissions from Oceangoing Vessels, EPA420-F-08-033, October, 2008.
2. BeicipFranlab, Advice on Marine Fuel, October, 2003.

Table 2. Summary of results

Case		Base	1	2	3	4
Description	Average 2008 Singapore spot price (US$/bbl)	-	VRDS	VRDS + MHC	VRDS + limited RCC	VRDS + MHC + limited RCC
Crudes (bpd)						
Arabian light	95.30	50 000	50 000	50 000	50 000	50 000
Arabian heavy	88.27	50 000	50 000	50 000	50 000	50 000
Imported feeds						
MTBE	101.13	4870	3891	4011	4624	5178
Natural gas (million ft^3/d)	4/million BTU	0	16	19	12	16
Products						
Propylene (PG)	1100/MT	2426	1491	1511	2195	2546
C3/C4 LPG	66.43	2226	2080	2089	2251	2347
Mixed C4s	63.43	4676	3198	3285	4544	5288
Euro IV 92 RON gasoline	106.18	36 897	29 475	30 384	35 027	39 226
Euro IV 95 RON gasoline	107.51	3690	2948	3038	3503	3923
Naphtha	88.69	2421	3734	3622	3092	2619
Euro IV diesel	124.24	18 466	25 299	25881	27 910	27 907
3.5% S HSFO (380 cst)	76.25	33 275	2209	0	3306	0
0.5% S LSFO (180 cst)	87.23	0	34 698	35 998	24 493	24 313
Total products (less MTBE)		99 207	101 241	101 797	101 697	102 991
Volume expansion (%)		-0.79	1.24	1.80	1.70	2.99
VRDS capacity (bpd)		-	29 000	30 600	29 000	31 100
VRDS feed (%AR/%VR)		-	63/37	63/37	63/37	63/37
MHC capacity (bpd)		-	-	7100	-	12 700
FCC feed S (wt%)		2.77	2.77	1.78	1.96	0.76
Delta net revenue (US$ million/py)		Base	201	233	268	332
TIC (US$ million (USGC))			571	691	615	792
Simple payout (years)			2.8	3.0	2.3	2.4