

Refinery configurations for maximising middle distillates

A comparison of configurations for upgrading residual oil products for the maximum production of diesel

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Refiners globally continue to face numerous challenges as environmental laws become increasingly stringent. Principal among them in the near future will be the International Maritime Organisation's (IMO) proposed changes to bunker fuel oil sulphur limits, from the current limit of over 3.5% down to 0.5% globally and from 1% to 0.1% in Emission Control Areas (ECA, see Figure 1). Global demand for high-sulphur residual fuel oil (HSFO) is steadily declining too, by 35% since 1995. Both of these changes will significantly impact a refiner's ability to market any significant quantity of HSFO at a price that will maintain refinery profitability. Refineries currently making a significant amount of fuel oil and lacking the complexity to upgrade the residual oil to premium products (middle distillates) will face two difficult options: either invest in commercially proven and reliable solutions to convert HSFO to more valuable liquid products such as Euro V diesel to greatly improve the refinery's profitability, or face a threat to shut down the refinery as the operation becomes uneconomical to continue.

Shift in product demand

The IMO's looming specification changes (see Figure 1) are likely to accelerate the decline in demand for HSFO by the year 2020, if not earlier. Worldwide, including emerging markets such as China, India and the Middle East, there is a shift in product demand from gasoline to diesel. Ethanol substitution in gasoline and improvements in engine

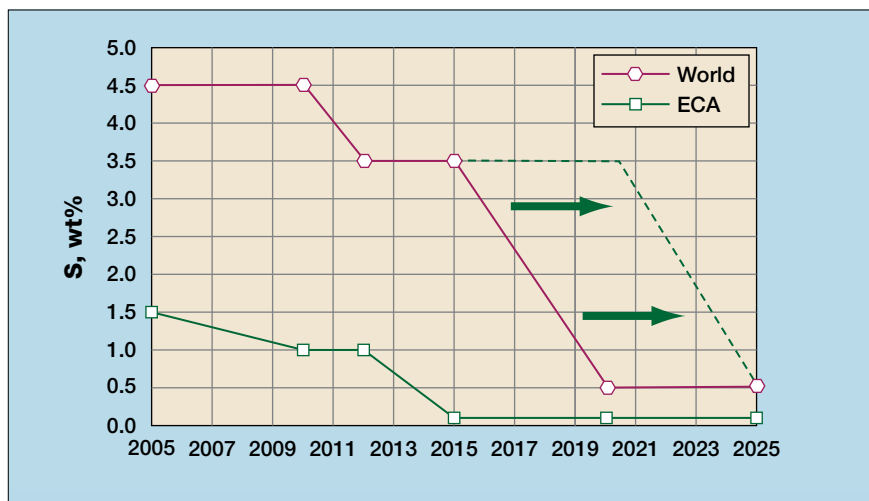


Figure 1 Requirements of IMO regulations

Source: International Maritime Organisation

technology are just two of the reasons why the demand for diesel continues to outpace that of gasoline. IMO regulations will indirectly increase diesel demand further as refiners are forced to blend in additional low-sulphur diesel to meet fuel oil sulphur specifications. Worldwide, production of mid-distillates is projected to account for 55% of the rise in oil demand expected over the next 20 years. The shift to diesel puts emphasis on bottom-of-the barrel processing.

Growing demand

Worldwide demand for refined products is projected to increase significantly in the next 20 years, driven by population growth and the transition of emerging markets into the global economy, with the majority of growth coming from China in particular and Asia in general. According to OPEC, global demand for diesel fuels is expected to grow by 10 million b/d by 2030, driven by an increased share of

diesel-driven vehicles in Europe and developing countries.

Current refining investment is predominantly made in Asia, the Middle East, Russia and Latin America — regions with growing demand for refined products. Tightening of product quality specifications will accelerate the implementation of deep conversion units in existing refineries, but often these refineries are constrained by plot space, hydrogen and other infrastructural issues. Grassroots, export-oriented refineries are all geared towards high conversion to mid-distillates.

For the strategically oriented refiner, stringent requirements for high-quality products actually present an opportunity to invest in the right technologies to significantly improve refinery margins. Based on increasing product demand and the closure of multiple non-performing refineries, refining margins are expected to recover by 2015.

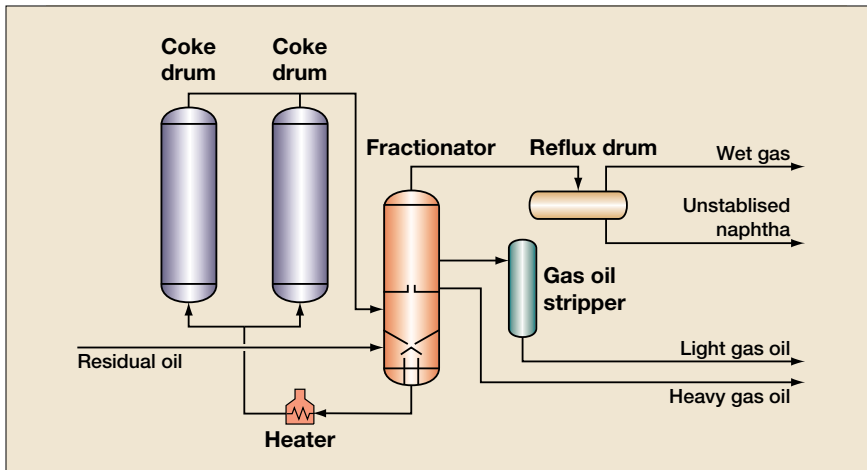


Figure 2 Schematic of a delayed coking unit

A wider and more intense requirement for the deployment of emissions reduction technologies may also act as a catalyst for new investments. Modern hydroprocessing technology will eliminate the need for expensive downstream remediation technologies.

It is our view that refining should be viewed as an ongoing business, where long-term average margins and product price differentials will support the investments that are needed.

Residue upgrading technologies

In view of the increasingly stricter regulations expected in the near future, along with the emerging trends in product demand, CLG evaluated multiple combinations of

residue conversion technologies, keeping the intentions of a global refiner in mind. The conversion technology:

- Should be commercially proven and reliable with a good on-stream factor
- Should maximise the most valuable product (diesel) while retaining the capability to address niche product demands for the foreseeable horizon
- Should be flexible to handle more difficult feedstocks
- Should be environmentally compliant to meet future stringent specifications
- Should have enough complexity so that the refinery remains profitable when margins remain depressed for prolonged periods (based on

current trends only such refineries will survive in the future)

- Ideally, should be part of a conversion platform encompassing complementary technologies.

Technologies on the cusp of commercialisation were excluded, because we did not want to prescribe any solution without a reasonably long operating history. For example, there are several slurry-phase residue conversion processes on the verge of commercialisation, but without a commercial operating history there is no data on reliability and on-stream factor — a major consideration in any residue upgrading process because of the difficult nature of the feedstock.

Major refinery processes included in this evaluation were:

- Delayed coking
- LC-Fining (a high-conversion residue hydrocracking process)
- Residue desulphurisation (RDS)
- Solvent deasphalting (SDA)
- Combinations of the above, along with secondary processes such as hydrocracking, residue catalytic cracking (RFCC) and gasification (VR and coke), FCC feed/product desulphurisation and various gasoline-producing processes.

In the studies we conducted for various clients, the residue conversion technologies that rose to the forefront were delayed coking, LC-Fining and RDS. The screening



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Advantages and disadvantages of delayed coking

Advantages

Lower on plot capital investment compared to hydrogen addition processes
 Can handle very poor-quality (high in contaminants) feeds
 Widely used, with many references

Favoured in low crude oil price environment
 No residual liquid product to deal with

Disadvantages

Coke handling, plot area limitations, and transportation and logistics
 Additional environmental health and safety (EHS) requirements
 Hydrogen addition still required to upgrade products and the process does not share the same process platform as other hydroprocessing units
 Loss of liquid yield compared to hydrogen addition processes
 Coke disposition is a major issue

Table 1

phase quickly ruled out several technologies as being too expensive, such as gasification, or not geared towards maximising diesel, the product of choice. A brief description of the primary upgrading processes follows.

Delayed coking

Delayed coking is the most widely used residue conversion technology and is particularly valuable when a long-term off-take arrangement for coke exists. Almost every major grassroots refinery in the world has considered it as a primary residue conversion process, with the exception of locations such as Scandinavia, Western Europe and Eastern Canada, where coking units are not preferred. Fuel-grade coke is used in infrastructure projects (cement, power) and demand remains robust in developing countries. However, with even more large coking units coming online, coke demand could come under pressure.

Vacuum residue, normally destined for fuel oil, is thermally cracked to obtain nearly 70% of distillate products. All distillate products require further hydroprocessing to make finished products. Coker naphtha requires special and more severe hydroprocessing compared to straight-run naphtha. Light coker gas oil (LCGO) that boils in the diesel boiling range has a much higher nitrogen content compared to straight-run diesel and operating pressures required for hydroprocessing are relatively higher. Heavy coker gas oil (HCGO) boils in the vacuum gas oil (VGO) boiling range. HCGO has much higher total aromatics, nitrogen, polycyclic aromatics and asphaltenes, and requires more severe operating conditions compared to straight-run

Installed LC-Fining units			
Start-up	Client	BPSD	Unconverted oil
2011	Shell Canada	47 300	Stable HSSC
2010	GS Caltex	60 000	Stable FO
2007	Neste Oil	40 000	Stable FO
2003	Shell Canada	79 000	Stable HSSC
2000	Slovnaft	23 000	Stable LSFO
1998	AGIP Petroli	25 000	Stable LSFO
1988	Syncrude Canada	40 000	Coker feed
1984	BP-Amoco	75 000	Coker feed
Total	8 units	389 300	

Table 2

VGO. HCGO is either sent to a FCC feed pretreater (in a gasoline-oriented refinery) or a hydrocracking unit (in a diesel-oriented refinery). The coke produced by a standalone delayed coker (see Figure 2) is lower value fuel-grade coke. If a hydroprocessing unit precedes the delayed coking unit, the coke produced from the delayed coking unit can be of superior anode-grade quality, suitable for use in the aluminium industry. Table 1 shows the main advantages and disadvantages of the delayed coking process.

LC-Fining

The LC-Fining process is a residuum conversion process that hydrocracks the most difficult, heavy, lower-value hydrocarbon streams such as petroleum residua, heavy oils from tar sands and shale oils to lighter, more valuable products such as VGO, diesel and naphtha. The process involves an ebullated-bed reactor (see Figure 3) that completely mixes oil and hydrogen. Due to continuous addition and the withdrawal of small quantities of catalyst, the run lengths between shutdowns are long. Unconverted oil from the LC-Fining unit can be used as fuel oil

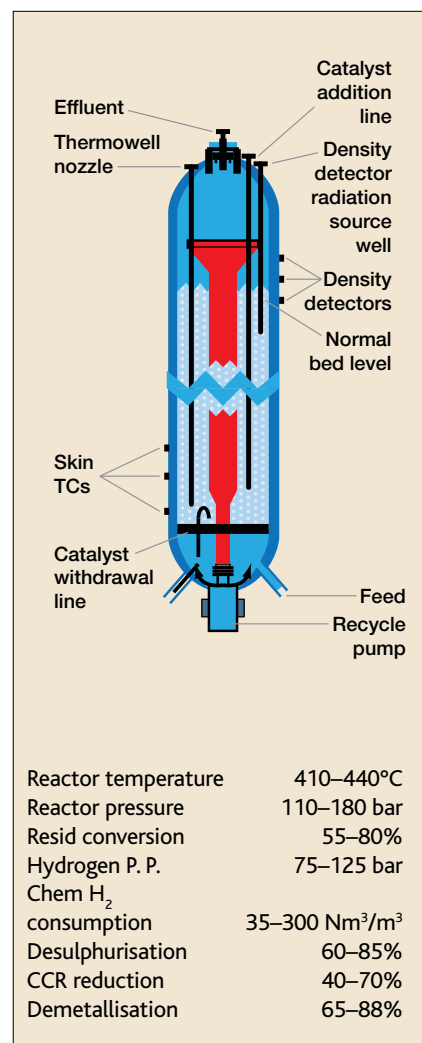


Figure 3 Schematic of a LC-Fining reactor with typical operating conditions

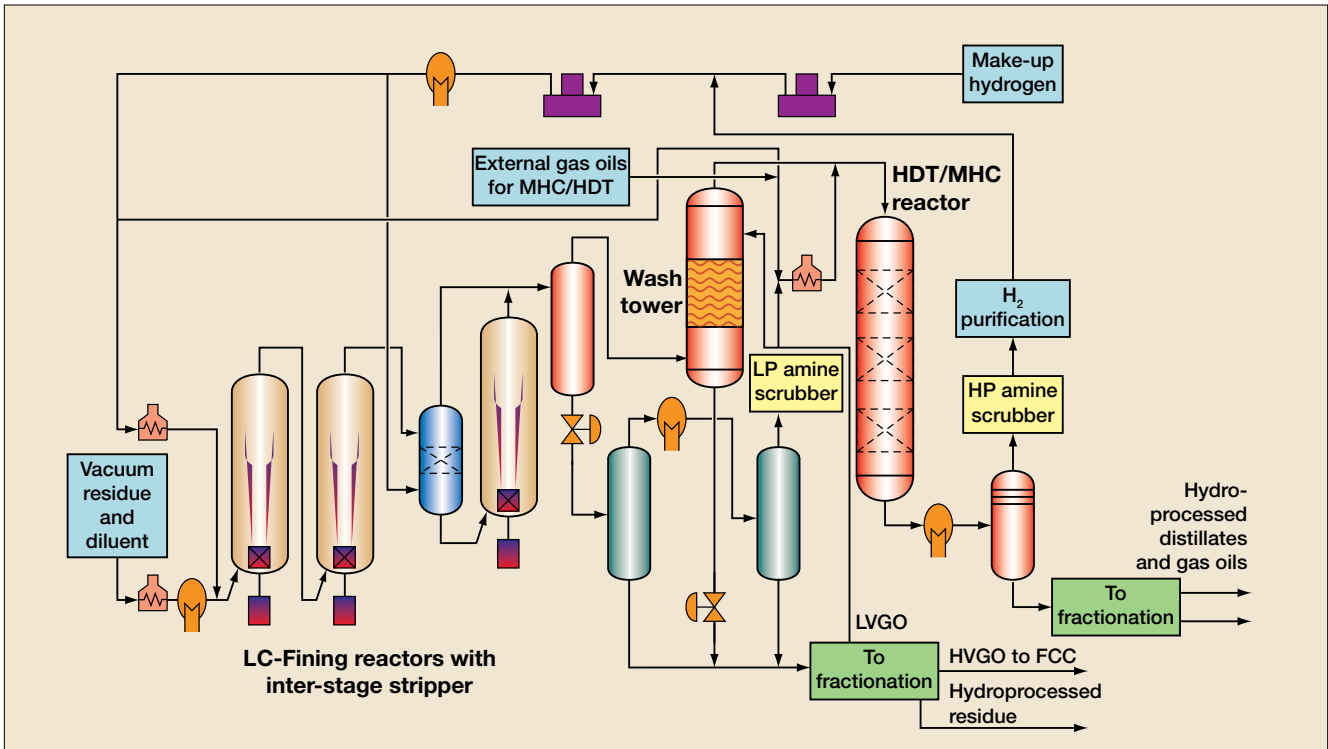


Figure 4 LC-Fining process with integrated hydroprocessing

Advantages and disadvantages of LC-Fining	
<p>Advantages</p> <ul style="list-style-type: none"> Higher liquid gain compared to delayed coking Can handle feeds higher in metals and other contaminants compared to fixed-bed processes Long run lengths Can be integrated easily with other hydroprocessing units Ebullated-bed technology is a mature technology and over 30 years' operating experience has led to many technological advances and made the process very reliable Requires less plot space compared to delayed coking units 	<p>Disadvantages</p> <ul style="list-style-type: none"> On plot investment is higher than delayed coking units Residue stability may become a concern at high conversions (feed dependent) Middle Eastern feeds, for example, have no stability concerns even at high conversions (proven commercially) More complex process compared to delayed coking and requires better operator training Not as much commercial experience as delayed coking units but adequate Spent catalyst disposal (trucks, rail car) has to be considered. Spent catalyst normally sent to metals reclaimer Unconverted oil disposition can become an issue depending on sulphur/stability specifications

Table 3

or as feed to power plants or a delayed coking unit. Maximum conversion is dependent on feed-stock. Operating unit conversion ranges from 60% to over 80%.

The LC-Fining unit operates at pressure levels similar to high-pressure hydroprocessing and therefore offers excellent opportunities for capital reduction by permitting integration of either hydrotreatment (Shell, Canada) or complete hydrocracking (Neste, Finland, see Figure 4).

The conversion of Conradson carbon is economically important if LC-Fining vacuum bottoms are fed to a downstream coking unit. A lower carbon-content resid product

to the coking unit means less coke make and thus a higher yield of liquid fractions that can subsequently be converted to transportation fuels.

The LC-Fining unit has inherent flexibility to meet variations in feed quality/throughput, product quality and reaction operating severities (temperature, space velocity, conversion and so on). This flexibility is a direct result of the ebullated catalyst bed reactor system. In an ebullated-bed unit, if the metals or sulphur content of the feed increases, the product quality is maintained by increasing catalyst consumption. Conversely, the catalyst consumption is

reduced if the feed quality improves.

There are only two ebullated-bed processes in the world that have been proven by long commercial history: LC-Fining and H-Oil. Table 2 is a list of operating LC-Fining units, and Table 3 shows the main advantages and disadvantages of the process.

The unconverted oil from the LC-Fining unit is normally used as fuel oil. When combined with a delayed coking unit downstream, the unconverted oil is converted to distillates and anode-grade coke, which fetches a far higher price compared to fuels-grade coke. While LC-Fining can handle a relatively high

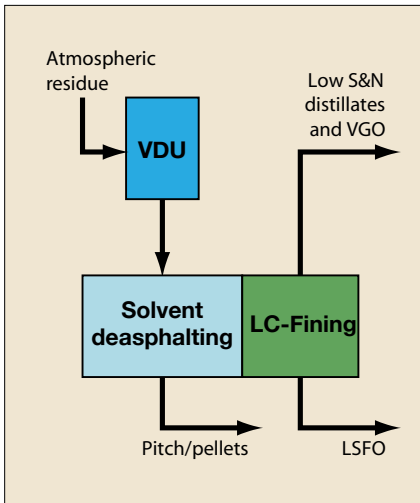


Figure 5 SDA upstream of an LC-Fining unit

metals content in the feed, the high level of nickel and vanadium in the unconverted LC-Fining bottoms could limit the production of anode-grade coke in the downstream delayed coking unit. LC-Fining by itself produces significantly more liquid yield compared to delayed coking and improves the refiner's volume gain.

The LC-Fining process is also easily integrated with a solvent deasphalting unit either upstream (see Figure 5), downstream (see Figure 6) or as an inter-stage process.

An upstream SDA significantly reduces metals, CCR and asphaltenes. Operating conditions required in the LC-Fining unit

become less severe and conversions can be pushed much higher. The yield slate shifts towards lighter products and catalyst consumption drops significantly. Without heavy asphaltenes in the process, unit operating factors improve as well. The obvious disadvantage is the loss of global conversion, as a significant volume of residue is removed as pitch and, without a dedicated disposition of the large volume of pitch (such as a gasifier), the economics may not be favourable. The option becomes very attractive in those situations where an SDA is already in operation and there is a need to upgrade the DAO to diesel rather than routing to an FCC unit for conversion to gasoline.

The SDA process can also be integrated downstream, where deasphalting removes the heaviest asphaltenic residue from the unconverted oil. The DAO can be recycled back to the LC-Fining process, while the pitch can be blended in with incremental VR to an existing delayed coking unit (BP, Texas City). Conversion is boosted and the volume of pitch to be handled is reduced significantly.

Residue desulphurisation

RDS is a fixed-bed process that has multiple beds of catalyst to remove

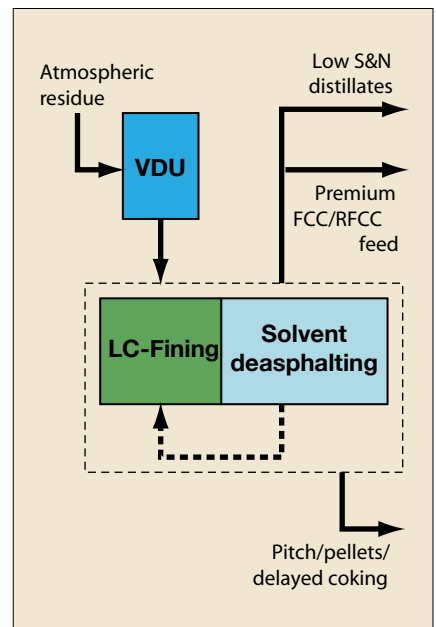


Figure 6 SDA downstream of an LC-Fining unit

metals, nitrogen and sulphur from petroleum residua in the presence of hydrogen (see Figure 7). Conversion results from the level of desulphurisation required and is not by itself a target. The process is normally used to produce low-sulphur fuel oil or to produce a feed stream that is suitable for cracking in a residue FCC (RFCC) unit.

The RDS process is by far the most widely used residue upgrading process. Catalyst and process innovations for RDS include the upflow reactor (UFR) and onstream

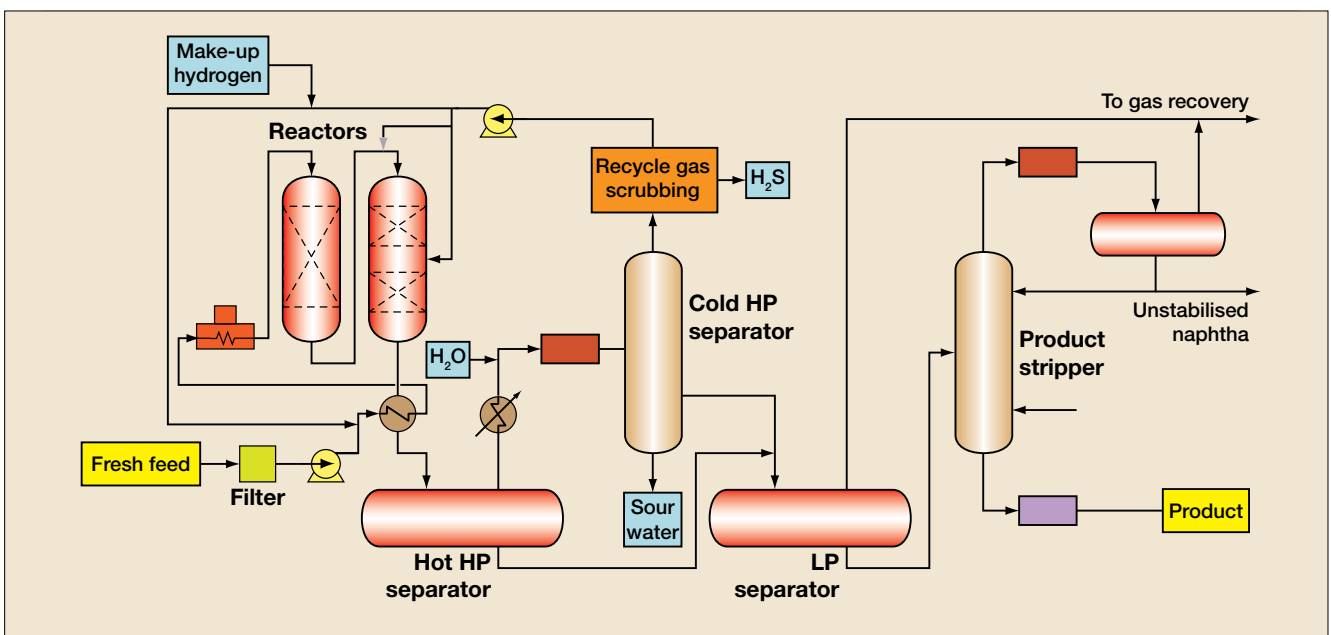


Figure 7 Schematic of RDS process

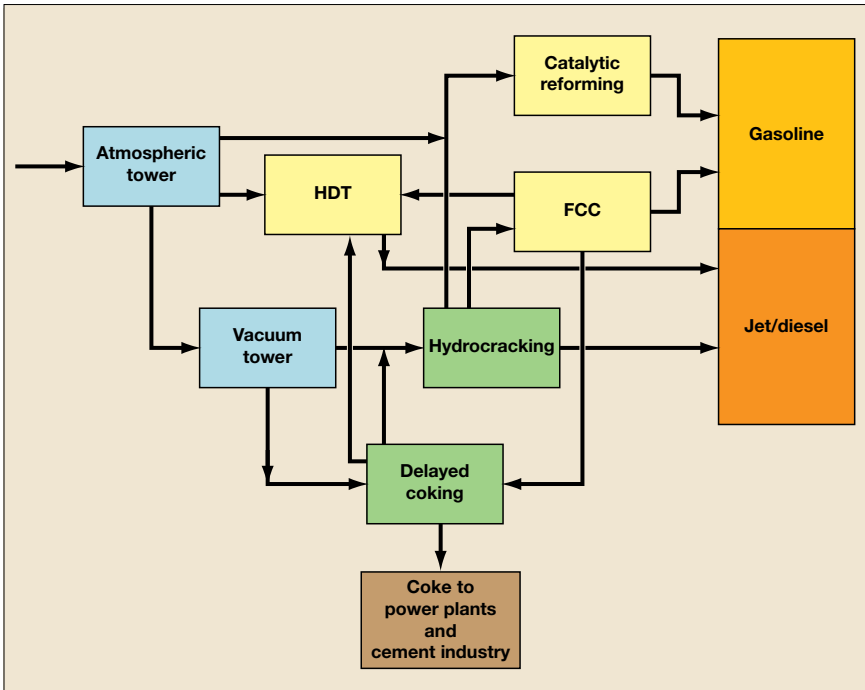


Figure 8 Simplified refinery with delayed coking as a residue conversion process

catalyst replacement (OCR). UFR is typically used in revamp situations or when concerns about metals levels and catalyst pore mouth plugging might shorten downflow reactor run lengths due to excessive pressure drop. OCR is used when the metals level in the feed is excessive.

RDS is a widely used technology, especially in the Far East. It is the only technology that can produce <math><0.5\text{ wt}\%</math> sulphur fuel oil. The technology is used in this context in Japan, but the most prevalent use of RDS is as a unit feeding a RFCC unit for the production of gasoline.

Upgrading configurations

CLG explored several configurations, including some that are based on the residue upgrading platforms described here, along with other major processes such as hydrocracker, hydrotreater and FCC to maximise conversion to mid-distillates.

Refinery with delayed coking as primary upgrader

The configuration shown in Figure 8 is one of the most common refinery configurations and is a benchmark against which other configurations have been evaluated. The configuration is robust and, depending on the crude slate, the capacities of the hydrocracking and FCC unit vary to obtain the right balance between gasoline and diesel production. In extreme situations, where gasoline production is to be avoided, the configuration will have no catalytic reforming and no FCC unit.

Figure 9 shows a refinery configuration where there is virtually no demand for gasoline and the refiner is only interested in making middle distillates and petrochemicals naphtha. Such a

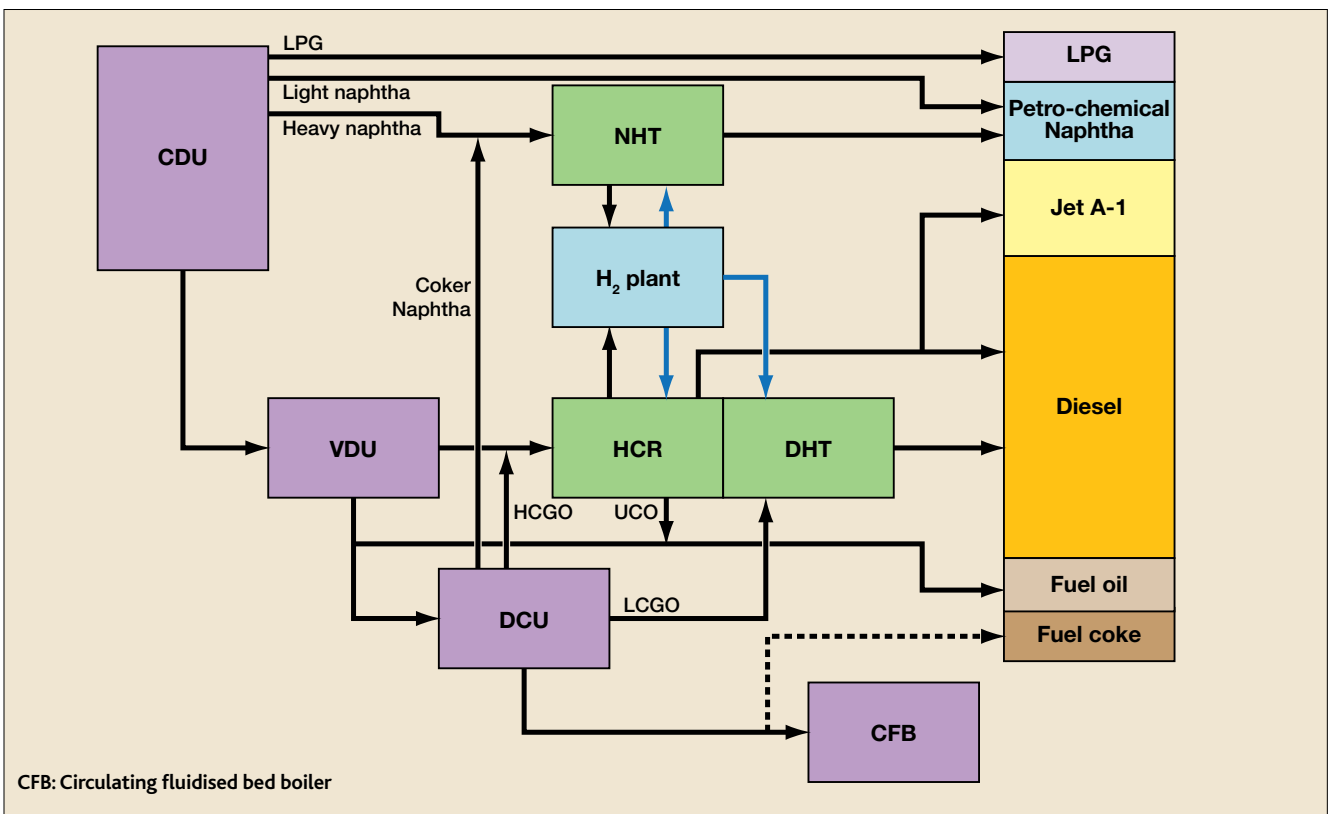


Figure 9 A delayed coking-based refinery with no gasoline production

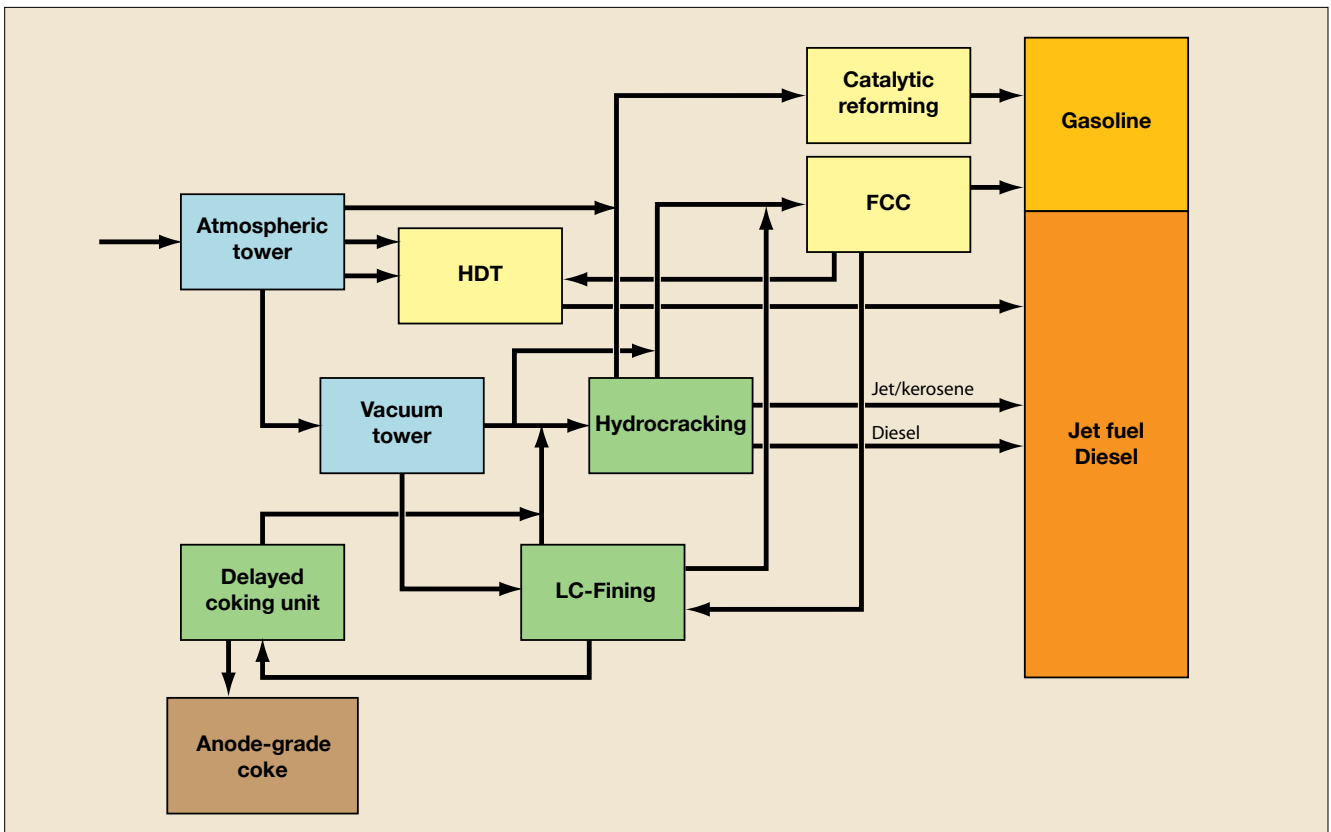


Figure 10 Optimised residue conversion using LC-Fining and delayed coking

configuration is likely to become increasingly important in the next decade.

Further optimisation of the delayed coking-based refinery

The overall profitability and return on investment in the configuration depicted in Figure 10 improves significantly with the addition of

the LC-Fining process to the upgrading of residue.

The LC-Fining unit is the primary residue conversion process, where conversion is pushed to the maximum because unconverted oil stability is not an issue. The unconverted oil, low in sulphur and metals, is converted to high-priced anode-grade coke in the delayed

coking unit, which also converts part of the UCO to distillates to be processed in downstream hydro-processing units. This configuration has no undesired or low-valued products and is therefore truly "bottomless".

Furthermore, the configuration is very amenable to phasing; the LC-Fining unit can be built first and

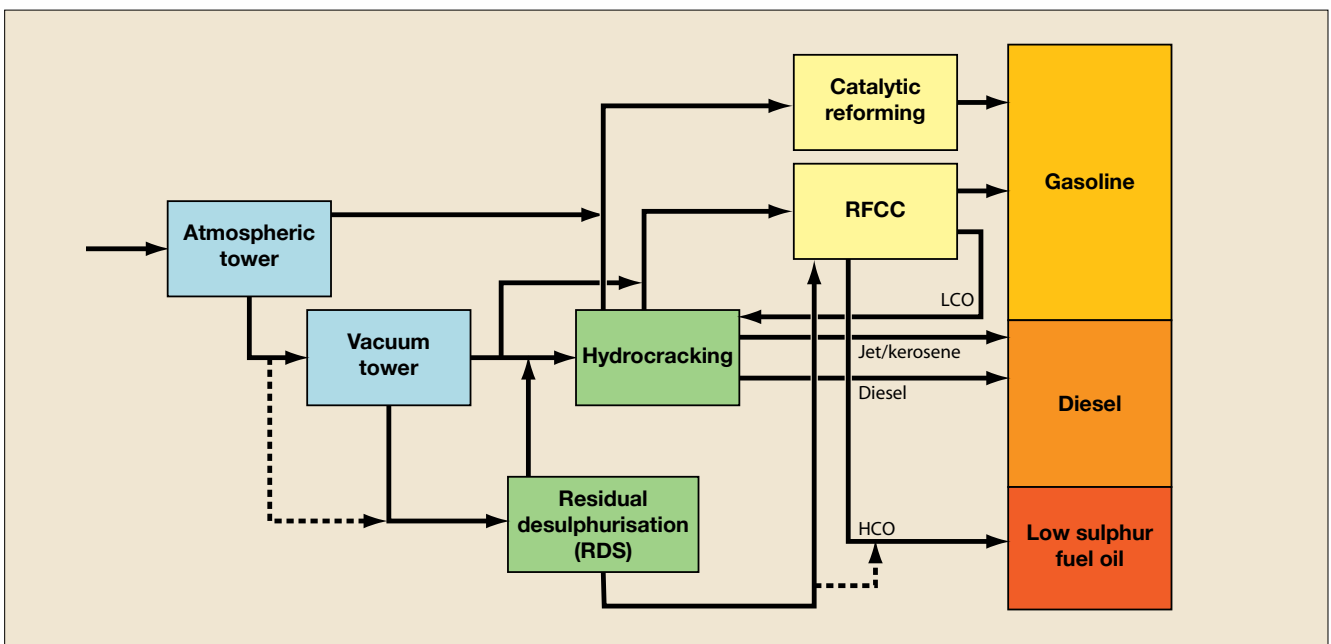


Figure 11 Refinery scheme with RDS as residue upgrader

will be profitable until such time as there is a market for fuel oil. The delayed coking unit can be phased in after a few years.

The solution with RDS becomes relevant when there is a high premium for very low-sulphur fuel oil and there is a fairly high demand for gasoline, or alternately a market exists for incremental propylene from the RFCC. If maximising diesel is the objective, this configuration is not the optimum one because it will either make too much low-sulphur fuel oil or too much gasoline, or significant quantities of both, at the expense of diesel. In a revamp, CLG has integrated RDS and hydrocracking technologies for ENI's Taranto refinery in Italy to produce Euro V diesel from residuum along with low-sulphur fuel oil.

Recommended configuration

After detailed analysis, we came to the conclusion that LC-Fining, when combined with delayed

coking, provides the maximum return and the highest NPV, followed by the "delayed coking alone" option. The recommended technology platform is proven and the solution is not dependent on the unreliable future of fuel oil. The solution is robust, because LC-Fining and delayed coking can handle very difficult feeds. Furthermore, with the proliferation of delayed coking units worldwide, the solution will provide a refiner with a competitive edge in terms of higher volumetric gain and the much higher priced anode-grade product.

LC-FINING is a mark of Chevron Lummus Global.

Further reading

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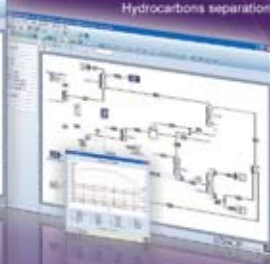
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