Advances in residue hydrocracking

Recent developments in ebullated bed hydrocracking technology target high residue conversion and high quality products

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With the recent downturn in crude oil prices, the incentive to upgrade residues has also shifted as upgrading margins have been compressed. To maximise upgrading margins, technology solutions that maximise high quality, high hydrogen content transportation fuels (gasoline, kerosene, and diesel) and minimise unconverted residues are required.

Several technologies are available for residue upgrading, broadly characterised as carbon rejection technologies or hydrogen addition technologies. The principal residue conversion based on carbon rejection technology is delayed coking. Delayed coking is simple, robust, and can handle very high levels of feed contaminants. Roughly 25-30% of the residue is rejected as petroleum coke, or petcoke. Amongst hydrogen addition technologies, the principal ones are residue desulphurisation technologies (ARDS, VRDS, UFR, and OCR) and residue hydrocracking technologies such as LC-Fining. These technologies are well established and have proven to be efficient and reliable processes. Each technology has its own merits.

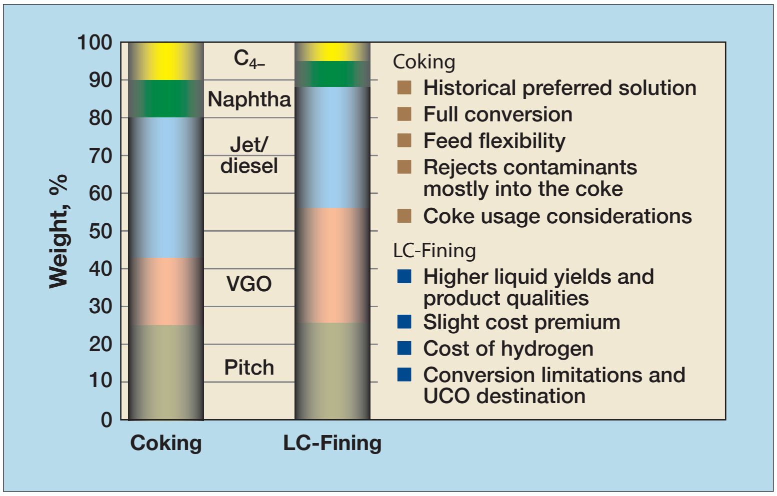


Figure 1 Coking and LC-Fining yields

For conventional residues such as light sour residues, they have similar yields (see **Figure 1**). Residue hydrocracking's main advantage is that its unconverted residue product is typically much higher in value than coke.

Historically, residue hydrocracking has had a slight capital cost premium and required more hydrogen because all products, including the bottoms, are hydrogenated. In recent years, the cost for high pressure equipment has gone down very significantly as has the cost of natural gas required to produce hydrogen. This reduces the capital cost gap between high pressure residue hydrocracking and low pressure processes such as delayed coking. It should be mentioned that the cost of a delayed coking project geared towards maximum diesel production has to factor in the cost of upgrading the coker gasoils and the hydrogen consumption in the hydrocracker. The global market for high sulphur

Licensed CLG residue hydrocracking units

Start-up	Client	BPSD	MTPA	Conversion, %	Processing objective
2022	Indian Oil Corporation, Mathura, India	38 000	2.00	92	Max. diesel: LC-Max at 92% conversion with integrated HCU
2022	Beowulf/Preem, Sweden	50 000	2.76	97	Max. diesel, first LC-Slurry licence, Euro V Diesel, ULSFO; integrated HDT and HCU
2020	CEPSA, Spain	38 000	2.05	78	Max. diesel and stable LSFO: LC-Fining; integrated HDT
2020	Thai Oil Sriracha Refinery, Thailand	72 000	4.07	90	Max. diesel: LC-Max@ 90% conversion with Integrated HCU
2019	BAPCO, Bahrain	68 000	3.75	78	Max. diesel; UCO to coker for anode grade coke: LC-Fining
2018	Russia	1000	0.6	94	Coker feed; 95% conversion; TIPS-RAS Slurry technology collaboration
2017	Sincier, China	50 000	2.76	91	Max. conversion to VGO: LC-Max @ 90% conversion
2017	Northwest Upgrading, Canada	30 000	1.66	78	Synthetic crude oil: LC-Fining
2010	GS Caltex, S. Korea	66 000	3.64	80-85	Max. conversion to VGO and stable fuel oil: LC-Fining
2010	Shell Canada/AOSP, Canada	47 300	2.61	78-82	Max. conversion to synthetic crude and stable fuel oil: LC-Fining with Integrated HDT
2007	Neste Oil, Finland	40 000	2.21	60-63	Max. diesel: LC-Fining with integrated HCU
2003	Shell Canada/AOSP, Canada	46 000	2.54	78-82	Max. conversion to synthetic crude and stable fuel oil: LC-Fining with integrated HDT
2003	Shell Canada/AOSP, Canada	46 000	2.54	78-82	Max. conversion to synthetic crude and stable fuel oil: LC-Fining with integrated HDT
2000	Slovnaft, Slovakia	25 000	1.38	62-65	Conversion and stable LSFO: LC-Fining
1998	Eni/RAM, Italy	25 000	1.38	63-69	Conversion and stable LSFO: LC-Fining
1988	Syncrude Canada	50 000	2.76	55-58	Conversion and UCO to coker: LC-Fining
1984	Marathon (Formerly BP), USA	75 000	4.14	75-80	Maximum conversion LC-Fining
Total		767 300	42.9		

Table 1

residue is expected to decline in the long term with environmental regulations becoming increasingly stringent, driven by International Maritime Organization restrictions.

All of these factors support high conversion residue hydrocracking solutions, which will have the best opportunity to meet future residue upgrading projects' requirements. What is also required to obtain the necessary financing for these projects are technologies that are based on commercially proven and reliable technologies. This requirement cannot be emphasised enough and is critical for any large project to proceed.

Vacuum residue by its very nature is difficult to process due to its high viscosity and high levels of contaminants, such as sulphur, metals, asphaltenes, and carbon residue. Any conversion leads to a destabilising effect as surrounding resins, aromatics and saturates that keep the asphaltenic cores in solution disappear at a faster rate than the asphaltenes. The propensity for rapid catalyst deactivation in the reactor, as well as fouling caused by the precipitation of heavy asphaltenic material from the surrounding aromatics, especially at high conversions, has to be very carefully managed in order to achieve on-stream factors in line with the rest of the refinery. Unfortunately, while yields, properties, and chemical hydrogen consumption can all be quite accurately measured in state-of-the-art pilot facilities such as the ones Chevron Lummus Global (CLG) has in Richmond, California, data on long-term catalyst performance, reactor stability, and fouling in the reactor effluent and fractionation circuits are only available from commercial units.

CLG is the leading licensor of residue upgrading technologies, with the most barrels in commercial operation for residue desulphurisation and residue hydrocracking, and is the only licensor to have commissioned multiple large residue hydrocracking units in the last 13 years. The data from the last five units, all commissioned in the last 10 years, have added greatly to the knowledge database required for enhancing the reliability of operating residue hydrocracking units at high severity utilising LC-Fining ebullated bed technology (see **Table 1**).

This article focuses on CLG's high conversion residue hydrocracking based solutions, centred on its LC-Fining technology, a proven high conversion process. These solutions include:

- Processing of residue hydrocracked vacuum gasoil (VGO) requires special attention to the stream's characteristics and the environment in which the VGO stream is hydrocracked. Appropriate flow schemes are explained.
- Integration with downstream delayed cokers can effectively achieve 90 wt% con-

version. This has been commercially demonstrated with two of the LC-Fining licensees. It is an excellent high conversion solution for refiners with existing delayed coking as the investment cost, and hydrogen requirements are minimised.

- Conversion within the LC-Fining process can be significantly increased with the selective rejection of partially converted residue components. The LC-Max process is an integration of solvent deasphalting with LC-Fining which can increase conversion to 90 wt%.
- Replacement of the traditional ebullated bed catalyst with a slurry catalyst can achieve conversions over 95 wt%. The LC-Slurry process accomplishes this with a next generation active slurry catalyst, resulting in all products being used to make high quality finished products or suitable for downstream processing. LC-Slurry eliminates all feed quality restrictions and even SDA pitch can be hydrocracked utilising this process.

The process

The LC-Fining residue hydrocracking process has inherent flexibility to meet variations in feed quality/throughput, product quality, and reaction operating severities (temperature, space velocity, conversion, and so on, see **Table 2**).

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, catalyst consumption is reduced if the feed quality improves.

Typical operating parameters	
Reactor temperature	400-440°C (750-825°F)
Reactor pressure	100-200 Atm (1500-3000 psig)
Conversion, vol% 525°C+ (975°F+)	40-90%
Hydrogen partial pressure	70-170 Atm (1100-2500 psia)
Hydrogen consumption	120-340 Nm^3/m^3 (700-2000 SCF/Bbl)
Desulphurisation	60-90%
Demetallisation	70-92%
CCR reduction	40-70%

Table 2

The reactor

Core to the performance of the LC-Fining process is the reactor. Fresh feed and hydrogen enter the reactor at the bottom and pass up through a catalyst bed where hydrodesulphurisation and other cracking and hydrogenation reactions occur. A portion of the product at the top of the reactor is recycled by means of an internally mounted recycle pump. This provides the flow necessary to keep the catalyst bed in a state of motion somewhat expanded over its settled level (ebullated). This ebullation is the key to the process. The reactor environment caused by the ebullation is similar to that of a continuous stirred tank reactor and consequently the reactor operates under near isothermal conditions. The ebullation also prevents any pressure drop as in the case of a fixed bed. **Figure 2** is a schematic of an ebullated bed LC-Fining reactor.

The catalyst level is monitored and controlled by radioactive density detectors, where the source is contained inside the reactor and the detectors are mounted outside.

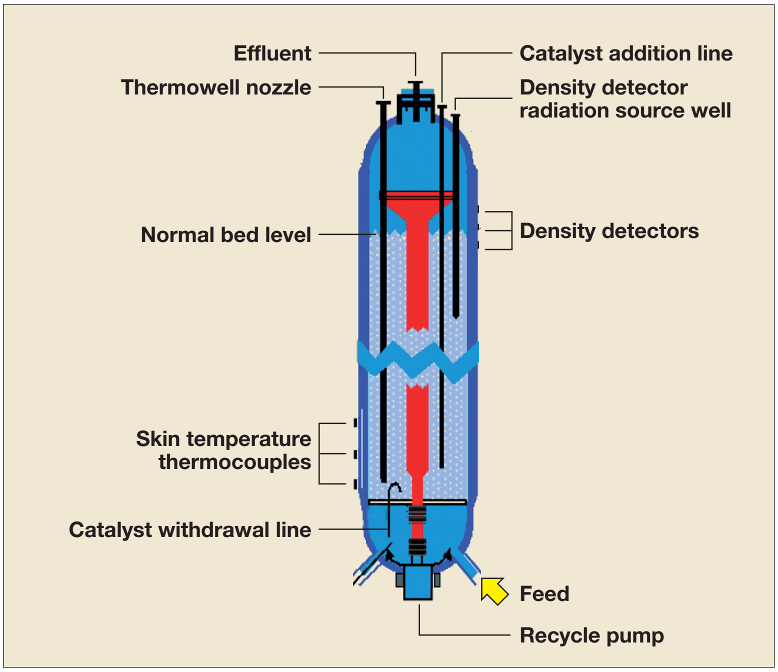


Figure 2 LC-Fining reactor

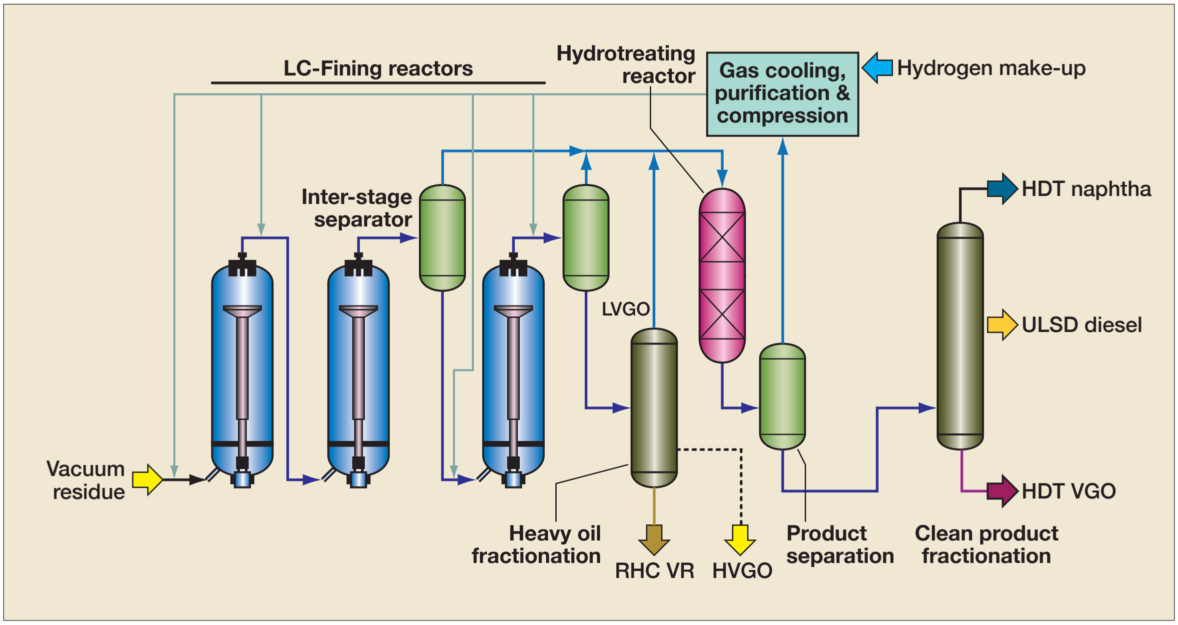


Figure 3 Simplified LC-Fining process with integrated hydrotreating

Temperature is monitored by internal couples and skin couples. The performance of the ebullated bed is continuously monitored and controlled with the density detectors and temperature measurements that verify proper distribution of gas and liquid throughout the catalyst bed. Temperature deviations outside the normal expected ranges that might suggest maldistribution will cause the distributed control system (DCS) and safety instrumented system (SIS) to activate alarms and/or initiate automatic cutback actions, including reducing heater firing, increasing quench oil introduction, reducing hydrogen purity, and reducing system pressure.

Catalyst is added and withdrawn while the reactor is in operation. The reactors can be staged in series, where the product from the first reactor passes to a second reactor and, if necessary, to a third reactor. After the final reactor, the product goes to a high pressure/high temperature separator.

Process description

Figure 3 is a simplified process flow diagram of an LC-Fining unit with a close-coupled, integrated, fixed bed hydrotreater.

Oil feed and hydrogen are heated separately, combined, and then passed into the hydrocracking reactor in an upflow fashion through an ebullated bed of catalyst. Under the effects of time, temperature, and hydrogen pressure, and aided by the catalysts, the feed oil is cracked and hydrogenated to produce lighter, higher quality products. A portion of the liquid from the vapour/liquid disengagement pan at the top of the reactor is recycled through the central downcomer by means of a pump mounted in the bottom head of the reactor. This flow provides the needed velocity to expand the catalyst bed.

The hydrodesulphurisation and hydrocracking reactions are exothermic in nature; because of the mixing effect of the internal recycle liquid, the catalyst bed operates essentially isothermally. Catalyst is added and withdrawn batchwise to maintain an equilibrium catalyst activity without the need for unit shutdown.

Reactor products flow to the pressure-high temperature separator. The reactor effluent vapour after undergoing a washing step, along with atmospheric and vacuum distillates recovered from the downstream fractionation system and any virgin distillates, are all charged to a ‘wide-cut’, close-coupled, integrated, fixed bed hydrotreater/hydrocracker located immediately downstream from the last ebullated bed reactor. The inlet temperature to the first bed is controlled by adjusting the mixed phase temperature exiting the hydrotreater/hydrocracker feed furnace. The effluent from the hydrotreating reactors is separated into a vapour and heavy distillate liquid stream, with the liquid stream routed to the hydrotreated distillate fractionator. The vapour stream is cooled and purified at high pressure using membrane separation technology, as depicted in the flow schematic. The purified recycle gas then mixes with make-up hydrogen and is recompressed and recirculated as treat gas to the LC-Fining reactors.

Catalysts

A series of catalysts is available for use in LC-Fining units. The first generation catalysts in commercial use had adequate HDM/HDS activity with acceptable sediment levels. These were less expensive than more recently developed, enhanced contaminant removal/sediment control catalysts. New generation catalysts are needed to produce low sulphur fuel oils (from vacuum bottoms) of 2 wt% sulphur or less with minimum sediment levels (<0.15 wt%) for pipeline stability. The other requirement of a good catalyst is to maintain improved reactor operability/stability at high temperature/high residue conversions.

The residue hydroprocessing catalysts are small (1/32-1/8in size), extruded, cylindrical pellets made from an aluminum base. The pellets are impregnated with active metals (Co, Ni, Mo, W, and other proprietary materials) that have good hydrogenation, demetallisation, desulphurisation, and sediment control activity. Catalyst manufacturing processes are tailored to manipulate physical and mechanical properties such as size (length and diameter), attrition resistance, crush strength, pore size distribution, pore volume, and effective surface area. Catalytic performance is affected by the complicated nature of the 'active site' and dispersion and distribution of activators and promoters.

Pore size control and distribution are key factors in the behaviour and formulation of residue conversion catalysts. The pore sizes need to be sufficiently large to allow the diffusion of the large asphaltene molecules that require upgrading. Unfortunately, as the pore diameter increases, the surface area and the hydrogenation activity decrease. The diffusion of large molecules is reduced further because of pore mouth plugging due to carbon laydown and metal sulphide build-up from vanadium and nickel atoms which are removed from the residue feed. Metal sulphides are formed from the oxidative state of the catalyst in the reactor environment (presulphiding reactions with sulphur in heavy oils, and so on).

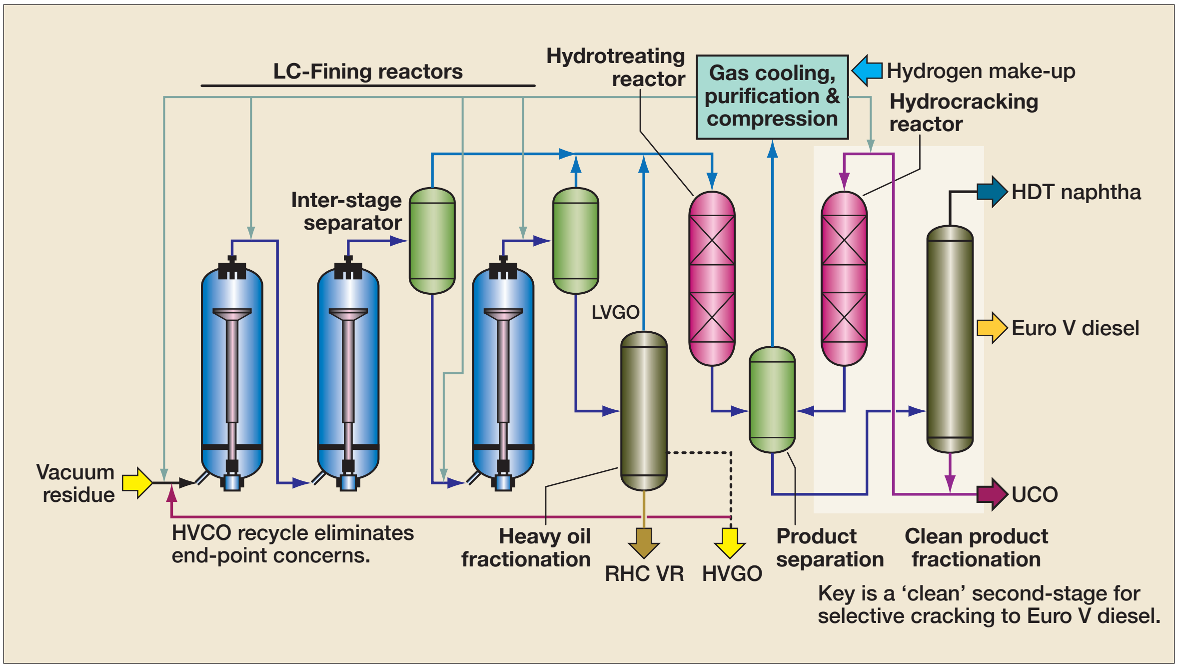
Catalysts are also optimised for specific functions such as metals removal, sulphur removal, carbon residue reduction, and high conversion while maintaining a clean product low in organic sediments. The catalyst system developed for the Marathon LC-Fining unit at Texas City utilises a proprietary demetallisation catalyst in the first reactor and a high activity nickel/molybdenum desulphurisation catalyst in the second and third reactors. All of CLG's catalysts are manufactured by ART, which also provides all of CLG's residue desulphurisation catalyst and participates heavily in joint catalyst development.

Integrated fixed bed hydrotreater/hydrocracker

Several recent designs incorporated a close-coupled, integrated, fixed bed hydrotreater/hydrocracker immediately downstream of the reactors. In this design, the vapour stream from the reactors, the distillate recovered from the heavy oil stripper overhead, and the straight-run atmospheric and vacuum gasoils are fed to a wide-cut, fixed bed hydrotreater/hydrocracker operating at essentially the same pressure level as the reactors.

By incorporating the fixed bed hydrotreater within the LC-Fining reaction system, the high pressure system service count is reduced significantly. Excess hydrogen in the reactor effluent vapour is used to hydrotreat the straight-run and distillate fractions; the need for additional recycle gas compression is reduced. As a result, the investment compared with a standalone hydrotreater/hydrocracker is reduced by 35-40%.

CLG has been the first to commercialise multiple residue hydrocracking with integrated hydrotreating units and residue hydrocracking with close-coupled integrated distillate hydrocracking (see **Figure 4**). Integration of hydrocracking requires careful attention to both residue hydrocracking and VGO hydrocracking operations. A very thorough understanding at the molecular level is required to comprehend the nature of components formed via residue hydrocracking. CLG has spent over 15 years devel-



HVCO recycle eliminates end-point concerns.

Key is a 'clean' second-stage for selective cracking to Euro V diesel.

Figure 4 LC-Fining with integrated hydrocracking

oping the right type of catalysts, reactor configurations and operating conditions to upgrade residue derived VGO.

Recent developments in high conversion of residue

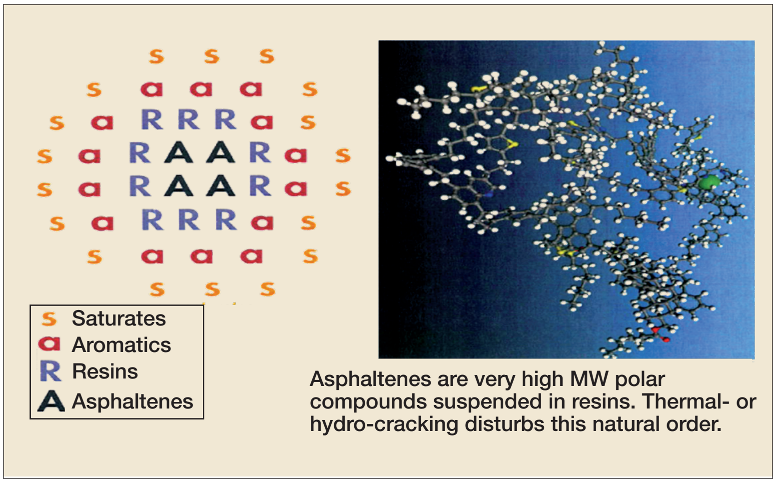
Residue hydrocracking conversion limits

With residue hydrocracking there are many factors that affect the sediment formation rate and consequently the reactor operability and residue conversion limits, including:

- Residue asphaltene content and type
- Resin and aromatic content of the feed
- CCR and asphaltene reactivity
- Thermal severity (LHSV and temperature)
- Catalyst type and activity
- Hydrogen partial pressure
- Fuel oil blending components
- Type and quantity of diluents.

Of these, the asphaltene content, CCR reactivity, thermal severity, catalyst activity, hydrogen partial pressure, and available aromatic diluents are strong factors. Many pilot plant tests have shown that sediment formation is directly proportional to the asphaltene content of the feed and inversely proportional to the CCR reactivity. However, there are a number of higher asphaltene-containing vacuum residues, such as those derived from Athabasca bitumen or Kuwaiti crude, which are quite easy to process. This is a result of the higher associated resin and aromatic content of these residues (see **Figure 5**).

CLG has done substantial research trying to analyse the nature of asphaltenes in feeds from different crude sources. These ongoing studies indicate for example that the nature



Asphaltenes are very high MW polar compounds suspended in resins. Thermal- or hydro-cracking disturbs this natural order.

Figure 5 Residue stability

of asphaltenes in Urals crude is very different from those in Middle Eastern crudes; at the same level of conversion, Urals unconverted oil (UCO) has a much higher sediment content compared to Athabasca or Middle Eastern residue derived products.

A wide range of heavy oils has been processed in LC-Fining units. For example, the Marathon unit in Texas City handles many of the poorest quality vacuum residua in the world, including Mexican, Venezuelan, Heavy Middle Eastern, and M-100. Feed typically is under 5°API and has more than 4 wt% sulphur and more than 400 ppm metals.

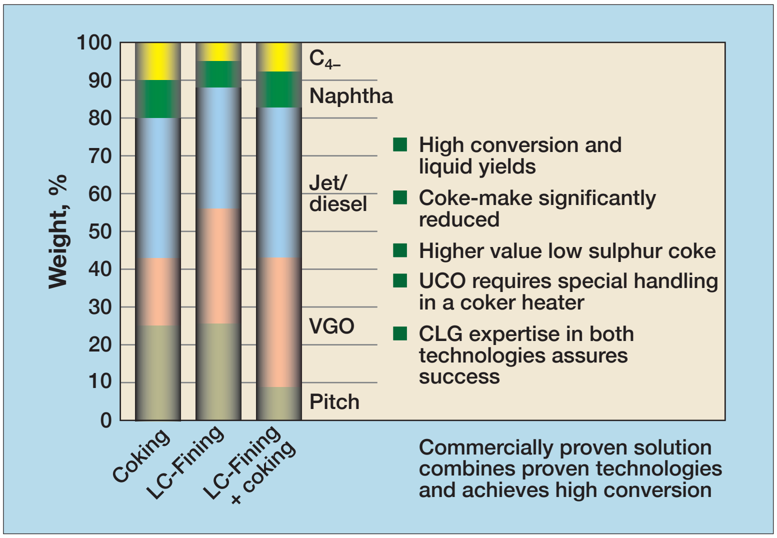


Figure 6 Yield benefits of LC-Fining + coking

Integration with delayed coking

As addressed earlier, residue conversion poses multiple challenges, including:

- Conversion restricted by the nature of feed.
- Sediment formation rises rapidly at higher conversions; conversion often limited by back-end fouling.
- Full reactor potential (capital utilisation) often restricted by sediment specification on UCO.
- Hydrogen is wasted in hydrogenation of asphaltenes in UCO.

Two of our licensees send their unconverted residue to downstream delayed cokers. This results in an overall conversion increase of 15-20% when comparing LC-Fining + delayed coking to LC-Fining only (see **Figure 6**).

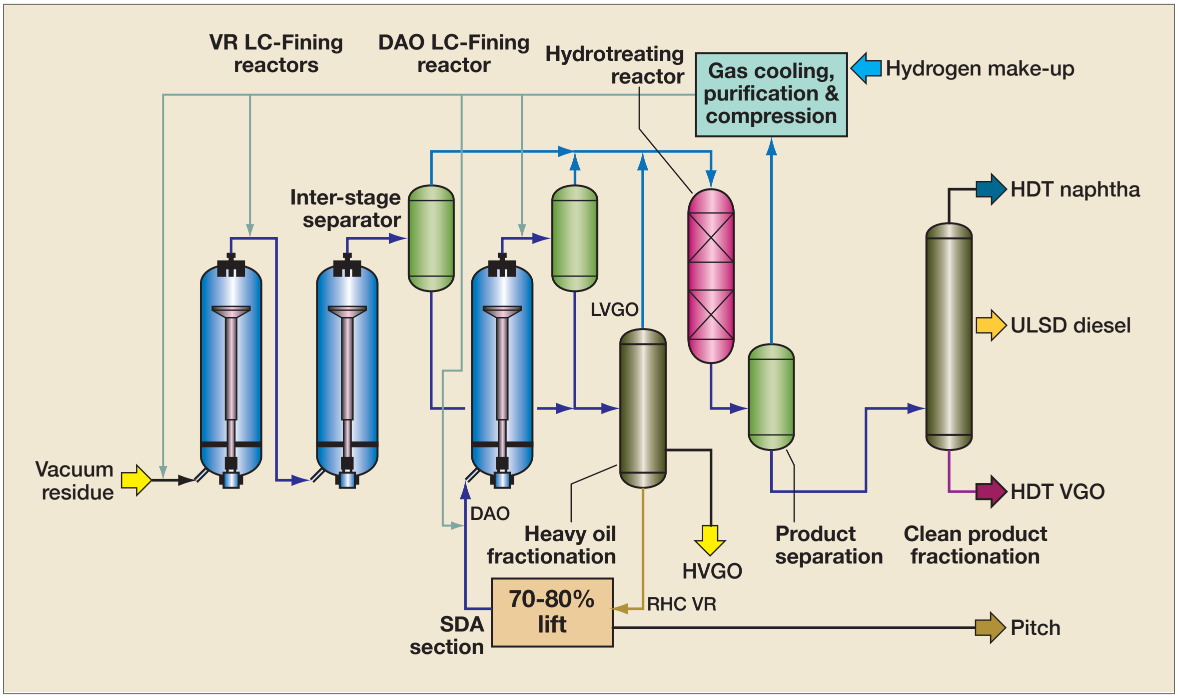


Figure 7 Schematic of the LC-Max process

Relative performance of LC-Max compared to LC-Fining

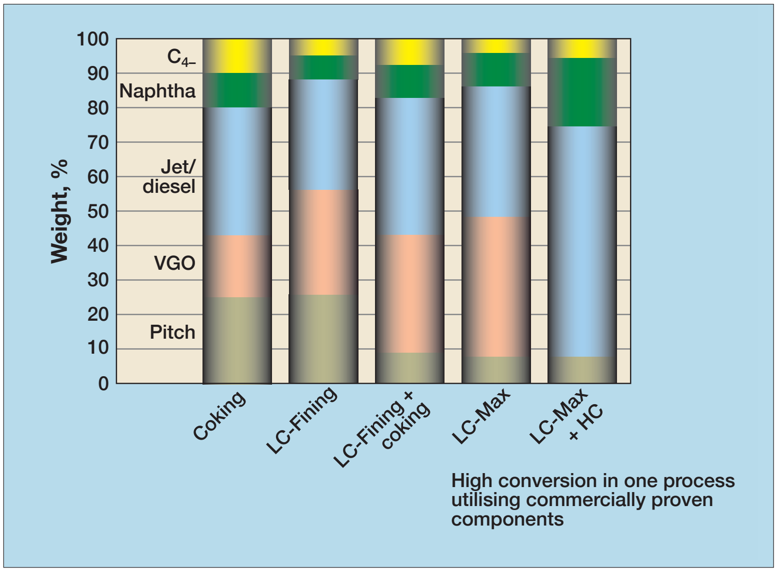
	LC-Fining	LC-Max
Conversion, %	60-80	85-90
Feed flexibility	Good	Excellent
Reactor volume	Base	Similar
Chemical hydrogen	Base	Base x 1.15 for 20% higher conversion
Catalyst addition rate	Base	Base x 0.8
Bottoms product	SCO, LSFO, coker feed	Boiler feed, gasifier feed
Fractionation section fouling	Base	<< Base

Table 3

The LC-Max process

CLG's LC-Max process, first licensed in 2013, addresses all of the residue hydrocracking conversion limitations issues to obtain high conversions of up to 90 wt%, even on difficult Russian Urals residue, as well as ensuring reduction in fouling of equipment in the fractionation section. This is accomplished by incorporating an intermediate solvent deasphalting step before continuing the conversion reactions.

Whole vacuum residue is mildly hydrocracked in a first reaction stage at a conversion level below which sediment issues become a concern (~55-70 wt%, depending on the nature of the feedstock). Reactor effluent from this stage is sent to an intermediate fractionation system which recovers distillates from the reactor effluent. The unconverted residue (UCO) is then sent to a solvent deasphalting system (included as part of the LC-Max technology) which removes the partially converted asphaltenes and other high molecular weight, highly aromatic molecules from the UCO. The 'clean' deasphalted oil (DAO) is sent to a second reaction stage where conversion upwards of 90% can be achieved. The negligible asphaltene content of DAO permits the second reaction step to run hot (438°C, 820°F) without risk of asphaltene sedimentation. This results in an overall conversion of up to 90 wt% (see **Figure 7**).



High conversion in one process utilising commercially proven components

Figure 8 LC-Max yields

The flow scheme has been validated in rigorous long-term pilot tests with actual UCO from commercial units that were deasphalted. The process makes the residue hydrocracking process far less susceptible to the nature of asphaltenes in the feed, and even for feeds with very 'difficult' asphaltenes, such as Urals VR, CLG has data showing conversion levels of 90 wt%.

Relative to LC-Fining, LC-Max significantly increases conversion in a cost effective manner (see **Table 3**). Because of the rejection of the partially converted asphaltenes, not only is the conversion increased but the catalyst consumption is decreased. The higher conversion however does require more hydrogen, but unlike thermal slurry processes the incremental hydrogen consumed is near linear with the incremental conversion obtained.

Relative to LC-Fining + coking, LC-Max has a significant capital and operating cost advantage. Yields are also more attractive as indicated when comparing the yields of the respective technologies (see **Figure 8**).

LC-Max VGO will also be good FCC feed if gasoline or C_3/C_4 derivative products are desired. Alternatively, the VGO can be fully converted in an integrated hydrocracker as discussed earlier in this article. With an integrated hydrocracking reactor, a high quality diesel yield upwards of 65 wt% or greater can be obtained.

The LC-Max process, and for

that matter LC-Fining, can easily be integrated in refineries with existing solvent deasphalting units. Likewise, LC-Fining units can be converted to LC-Max units. The extent of the revamps will depend on each unit's own configuration. The intermediate DAO also drastically reduces the volume of rejected pitch.

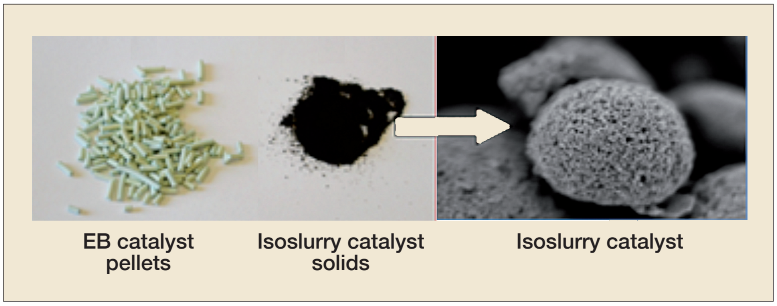


Figure 9 Isoslurry catalyst

Other SDA options and their limitations

Other process combinations can result in higher conversion. Integrat-ing solvent deasphalting with LC-Fining is one of these routes.

A deasphalting unit placed upstream of the residue hydrocracking unit will force the refiner to handle inordinately large amounts of pitch and – because so much of the vacuum residue is rejected as pitch – reduce overall conversion to ~65-%. An outlet for the pitch, such as partial feed to a large existing delayed coker, would be required to make this flow scheme viable.

Placing a SDA unit downstream of a LC-Fining unit can result in high conversion, but another hydrotreater would be needed to treat the heavy DAO to produce a suitable feed to a RFCC. The VGO + DAO yield from this process combination will be 50 wt% or possibly higher than the vacuum residue feedstock. Additionally, an existing FCC may not be designed for this significant increase in feed rate. Placing the SDA unit downstream of the LC-Fining unit also does not prevent the sediment deposition/fouling issues and, for difficult feeds, will limit conversion in the LC-Fining unit.

Pitch from the LC-Max unit can be used in several ways including:

- Blended with vacuum residue and sent to a delayed coker.
- Combusted in a boiler designed for heavy residues.
- Sent to a gasifier where either power or hydrogen can be generated. For a 40 000 b/d LC-Max unit, approximately 160 MW of power or 160 t/d of hydrogen can be produced.
- Sold as a solid fuel to purchasers of coal or coke.

To support the combustion of pitch and its sale, CLG has worked with the leading supplier of residue solidification equipment and also the leading supplier of circulating bed boilers to develop a cost effective and practical solution for solidification and producing an acceptable form of the solid pitch to meet circulating fluidised bed boiler feed specifications. The pitch is also an acceptable feed to other types of boilers, such as arch-fired solid fuel type boilers used for coke or coal.

The pitch also can be handled and then combusted as a liquid fuel, but may require cutter stocks, depending on the pitch's characteristics.

LC-Slurry

From 2015, CLG was given the rights to license the slurry hydrocracking process, LC-Slurry, developed by Chevron. It is the product of over 25 years of development by Chevron, the most recent 13 years of which were based on using the LC-Fining reactor platform. After initial trials with bubble reactors, Chevron selected the LC-Fining liquid circulation platform based on its commercial history and to avoid the scale-up factor associated with bubble reactors. The process is primarily catalytic and is a step out from most residue conversion processes developed to date. The process is characterised by high liquid yields and high quality distillates. No coke or solids residue is produced.

The unconverted residue is of higher quality than that from other processes and can be used as a blending component in production of low sulphur fuel oil or utilised as coker or RFCC feedstock. All products from LC-Slurry have high value and no undesirable products are produced.

The process utilises the Isoslurry catalyst (see **Figure 9**). The catalyst's properties result in efficient hydrogenation activity needed to convert the heavy end to useful products and ensure that the reactor effluent is clean, which means that the

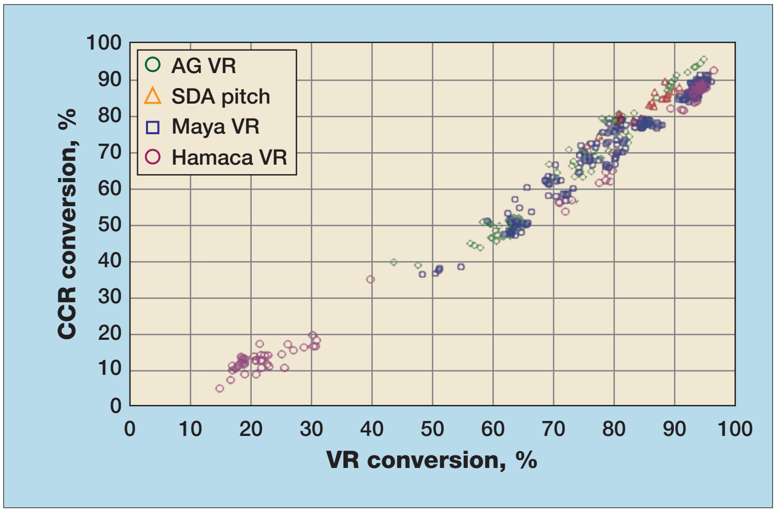


Figure 10 LC-Slurry conversion

fractionation section equipment is not subject to fouling.

CLG's approach of using a nickel promoted molybdenum slurry catalyst with a defined structure has been found to be superior to other approaches that have been tried such as using organo-moly liquids as catalyst precursors.

In contrast to the LC-Slurry clean system concept, thermal slurry processes that operate with higher temperatures require large amounts of inactive or low activity solids and cannot produce a high quality heavy oil product as Isoslurry does.

The combination of a nickel-molybdenum slurry catalyst with the LC-Fining reactor system allows even the most difficult VRs, SDA tars, and other heavy residues to be upgraded reliably and selectively.

The process is designed for the most difficult of vacuum residua originating from Venezuela (Hamaca, Zuata), Mexico (Maya), and other regions with extremely difficult feeds (see **Figure 10**). Consequently, for feeds such as Middle Eastern vacuum residue, conversion above 95% can be easily achieved. This is achieved due to high CCR conversion. However, it is also applicable to processing more mild residues, and those that are relatively unstable, such as Russian Urals.

There is no scale-up risk associated with the reactor design for LC-Slurry because it uses the same ebullated bed process platform as in the LC-Fining process. And because LC-Slurry uses the same equipment as LC-Fining, there are no long-term equipment reliability validation requirements.

In the reaction section, VR is converted to VGO and lighter

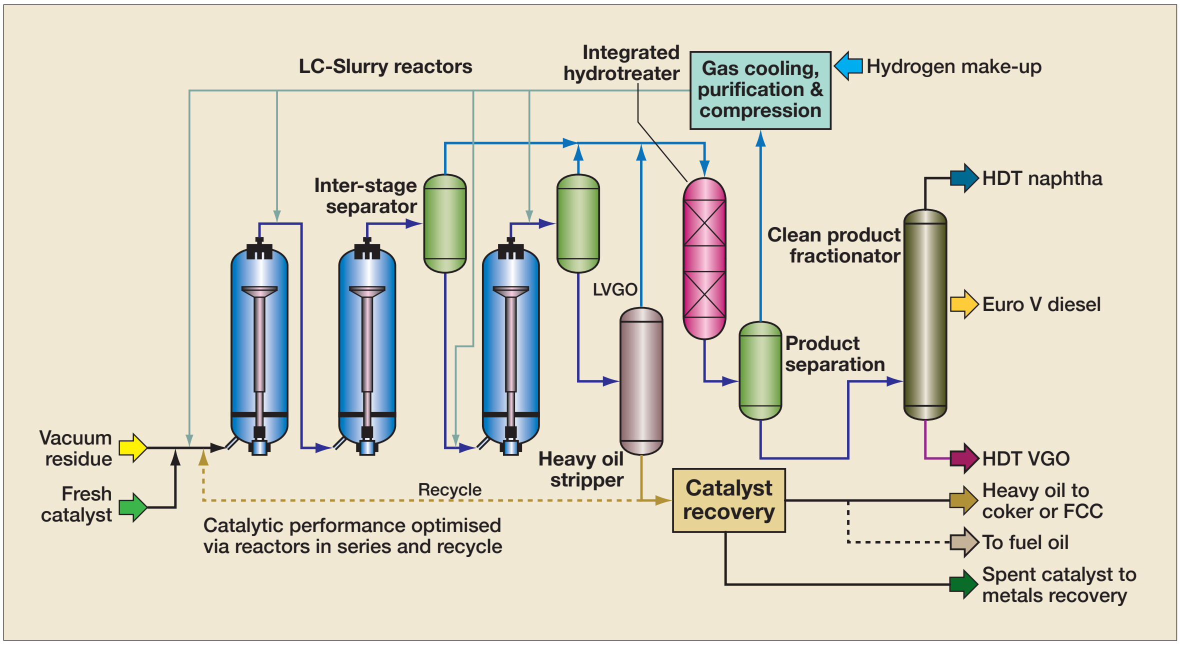


Figure 11 LC-Slurry flow scheme

products through three reactors in series with an intermediate gas liquid separator between the last two reactors. The catalyst is injected into the feed on a continuous basis. The reactor operating conditions are very similar to those used with LC-Fining. Unconverted oil after fractionation is sent to the catalyst recovery unit where catalyst is removed from the heavy oil (see **Figure 11**).

Another advantage of LC-Slurry is the simplicity of the catalyst addition system as well as the catalyst recovery system.

Isoslurry is provided in an oil slurry so that it can be injected continuously into the reactor section. Also, catalyst is recycled within the unit to maximise performance while minimising the required fresh catalyst dosage.

Used catalyst is quantitatively removed from the heavy bottoms oil in the catalyst recovery section (CRS), yielding a solids-free heavy oil and dry catalyst solids that are sent to a metals reclaimer. This is a continuous system that is simple to operate. It uses proven liquids/solids filtering and separation equipment, readapted from similar service in other industries. All spent catalyst is removed from the heavy oil (see **Figure 12**). Spent catalyst is then suitable for sending to a metals reclaimer, similar to other hydrotreating spent catalysts. Solids-free heavy oil can be routed to coking, RFCC, LSFO, and so on.

LC-Slurry yields relative to other CLG offerings are weighted to more distillates, less VGO, and significantly less unconverted residue (see **Figure 13**).

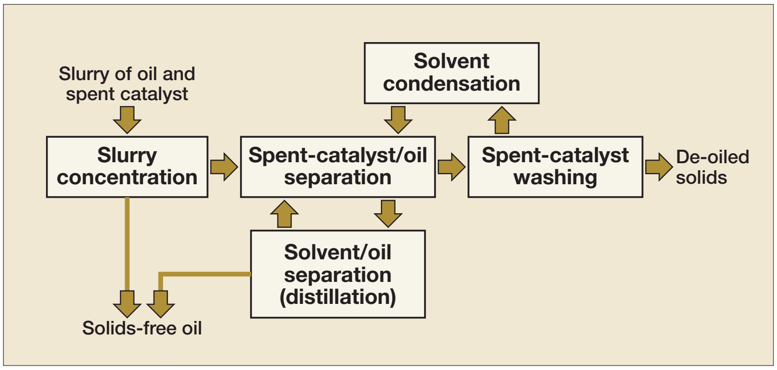


Figure 12 LC-Slurry flow scheme

Hybrid slurry with Isoslurry catalyst

The hybrid slurry concept originated from the research conducted by Chevron for the programme designed for extremely difficult feeds originating in Venezuela and with the ability to operate at upwards of 95% conversion. The essential feature of this system is that it captures coke while suppressing sediments. A substantial portion of the conversion in LC-Fining is thermal in nature and thermal zones exist within the reactor. The ebullated bed catalyst provides high catalytic density but has slow turnover time. The slurry co-catalyst suppresses sediment formation in the thermal zones as it continuously removes coke and coke precursors with a fast turnover time.

The hybrid slurry concept will permit refiners that have a base LC-Fining platform to increase conversion significantly by increasing temperature without increasing the risk of sedimentation. The process will also permit the refiner to process opportunity crudes with higher propensity towards sedimentation. The hybrid slurry system will reduce coke fouling of the ebullated bed catalyst and permit the use of higher activity ebullated bed catalysts.

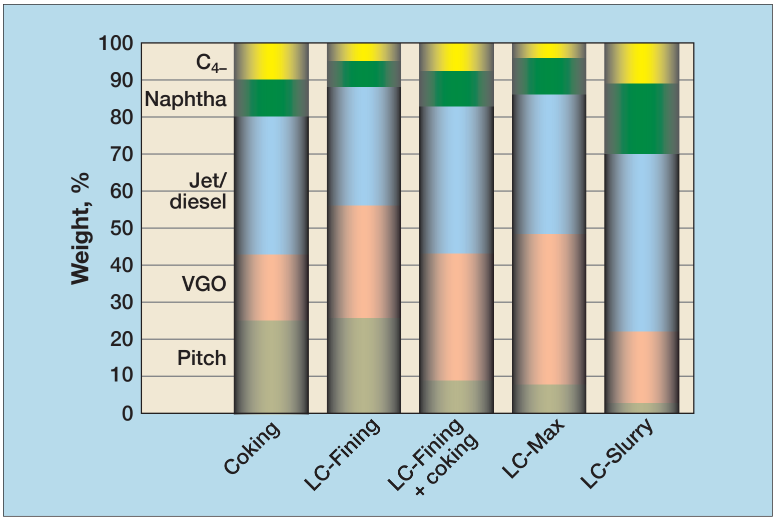


Figure 13 Comparison of yields

Conclusion

Integrating LC-Fining with an existing coker is an opportunity for refiners with existing cokers to obtain high conversion and produce high quality products, including the type of coke produced.

LC-Max is an extension of LC-Fining to achieve high conversion through the addition of a selective asphaltene rejection step. It provides refiners with high conversion based on the LC-Fining process.

LC-Slurry is a step forward in residue hydrocracking as it converts the entire vacuum residue to high value products and uses hydrogen efficiently. As such, its upgrading margins are high.

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