Hydroprocessing revamp configurations

Upgrading existing hydrocrackers from single-stage to two-stage recycle offers significantly higher flexibility for increasing high-quality FCC feeds and naphtha/diesel production

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ChevronTexaco and now Chevron Lummus Global (CLG) have operated and licensed hydrocracking units of various configurations: SSOT, single-stage recycle (SSREC) and two-stage recycle (TSR). However, most contributions to hydrocracking have been in the TSR configuration. The benefits of a "clean" second stage – namely, improved activity and selectivity – have been developed for full or near-full conversion applications, with the single-stage configurations applied to lower-conversion units.

Figure 1, based on experiments with VGO and the same catalyst at different residence times, shows how the relative amounts of paraffins, naphthenes and aromatics change as hydrogen is added and the reaction proceeds. The upper plot shows that in a single stage, or the first of two stages, the paraffins do not react significantly, even at overall conversion levels of 65%. In fact, the unconverted bottoms from the first, or single, stage are rich in paraffins and naphthenes and low in nitrogen, making them an excellent FCC or steam cracker feedstock, or a waxy lube oil base stock. The lower plot shows the benefits of the second stage, where the unconverted bottoms at a conversion level of 37% are reprocessed with the same catalyst at the same pressure but at around 40°C lower and with clean circulating gas. The overall reaction rate is considerably higher than in the first stage. Paraffins are readily converted in this clean environment.

The following hydroprocessing innovations all give the refiners involved measurable value, including exploitation of innovative synergies between different hydroprocessing technologies.

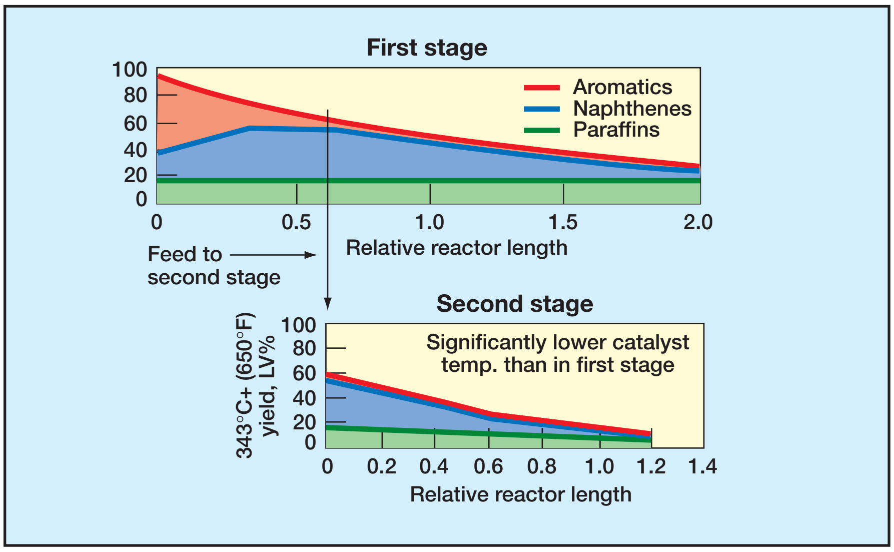

***Figure 1** Benefits of second-stage operation*

Lubes hydroprocessing

ChevronTexaco's lube hydroprocessing experience goes back to 1984 with the start-up of the Richmond lube oil plant (RLOP) for the production of premium base oils from crude oils that are deficient in high viscosity index (V.I.) components. These poor-lube-quality crudes, such as Alaskan North Slope and Heavy California Valley, were readily available but primarily used at that time for fuels production. With the new lube plant online, an old solvent-extraction facility tied to running Arabian gas oil and resid feedstocks was shut down.

RLOP produced light-, medium- and heavy-neutral base oils in parallel hydroprocessing trains. The light train, which made light- and medium-neutral, consisted of a hydrocracker followed by catalytic dewaxing/hydrofinishing, and the heavy train, making heavy-neutral, consisted of a hydrocracker and solvent dewaxer/hydrofinisher. ChevronTexaco developed a selective, wax isomerisation catalyst that was commercialised and used by RLOP in 1993. This new process became known as Isodewaxing. Instead of removing wax molecules as in solvent dewaxing or cracking them to light C_3-C_8 hydrocarbons as in classic catalytic dewaxing, the catalyst isomerises the wax molecules into lube oil.

Fixed-bed residuum upgrading

The Chevron RDS hydrotreating process and the Gulf HDS resid process were introduced as ways to desulphurise fuel oil to meet environmental limits while processing high-sulphur crudes and converting some residuum to lighter products. The companies and technologies merged in 1985. The ability to replace catalyst while on stream was commercialised in 1992 with ChevronTexaco's proprietary on-stream catalyst replacement (OCR) moving bed reactor technology, which essentially installed a hydrodemetalation (HDM) reactor to "guard" the RDS unit, thereby increasing the latter's flexibility. An OCR reactor operates with the feed upflow and contains the necessary internals to allow addition and withdrawal of OCR catalyst. The benefits of upflow relative to fixed-bed downflow are shown in Figure 2.

KNPC in Kuwait is set to enhance its existing resid desulphurisation unit using OCR technology. With minimal modifications and limited tie-in work completed in late 2004, the unit is expected to achieve more than a 25% feed rate increase from its original design and a 25% increase in its run length while meeting the same product objective.

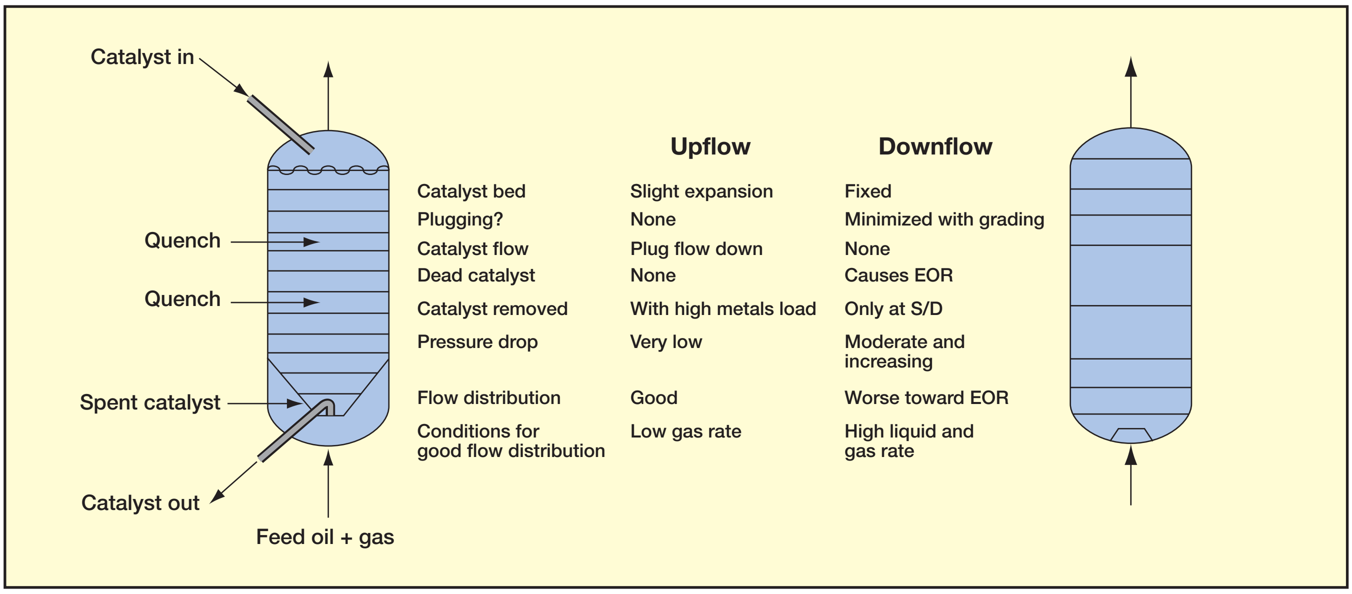

Figure 2 *Upflow versus downflow reactors*

Ebullated bed residuum hydrocracking

ABB Lummus Global added the proprietary LC-Fining process to the CLG portfolio. Whereas a typical conversion level in fixed-bed residuum upgraders is 35–50%, LC-Fining is designed for the very high conversion of difficult residua using ebullated bed reactor technology. Conversion levels range from 55–85%. Reactor section flow scheme and reactor internals improvements have allowed single train capacities to reach 50 000bpd while cutting capital investment. Catalyst developments have also led to decreases in catalyst consumption.

Revamp options

As previously mentioned, typical hydrocracking configurations include: SSOT for low-to-moderate conversions with limited feed flexibility, product selectivity and product quality; and TSR for high-to-full conversion applications with excellent feed and product flexibility. Many existing refineries with SSOT configurations are looking for revamp options to meet more stringent fuel specifications, to increase feed flexibility or to boost fuel make. The conventional solution is to add reactor volume in series or to include a "saturation" reactor if better product quality is desired, but there is actually less expensive and more flexible option available.[1]

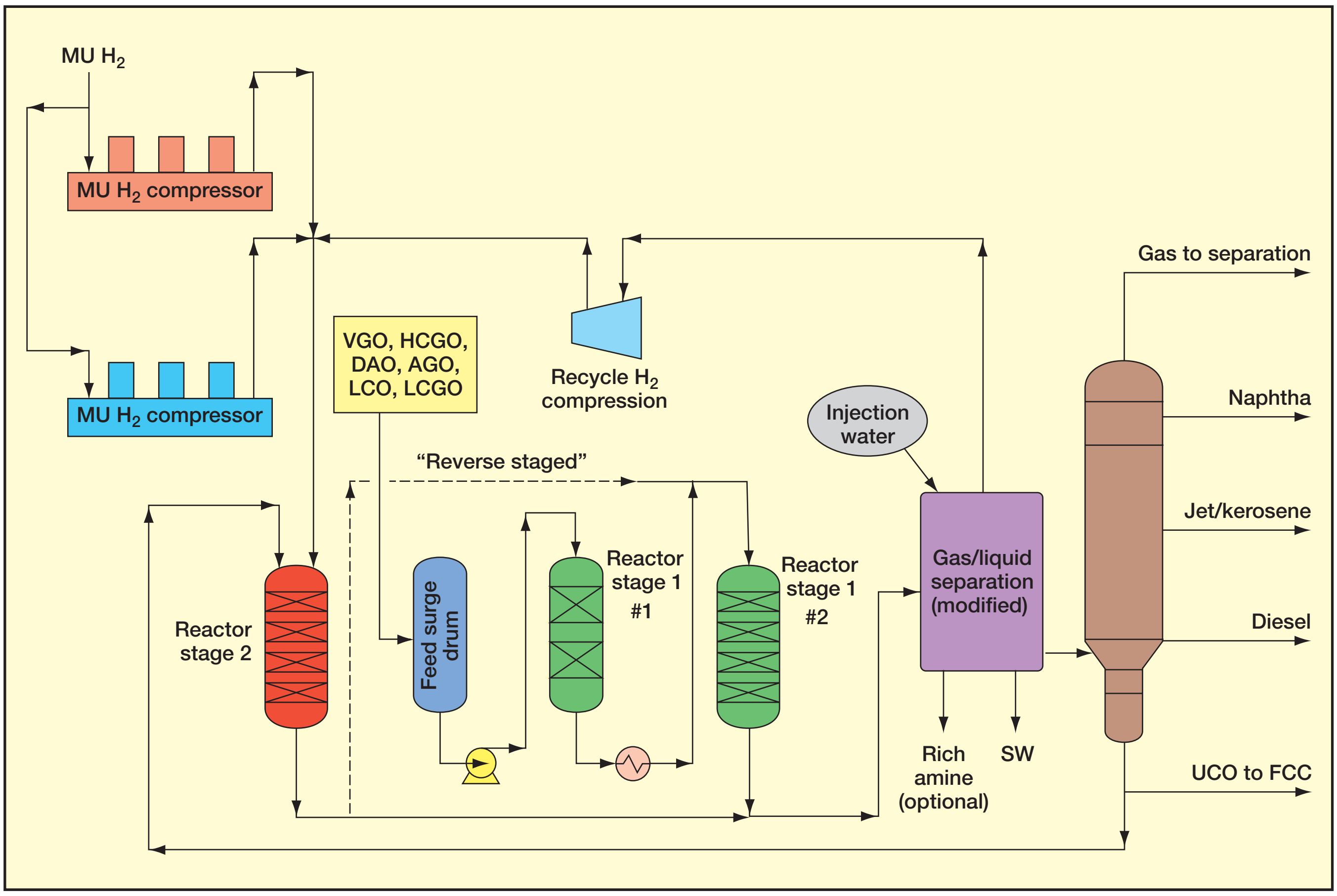

Figure 3 *SSREC converted to TSR*

A small reactor is added upstream from the existing reactor, converting the SSOT into a partial, or full, recycle TSR configuration. By utilising the second-stage environment described earlier, two to three times less catalyst volume is needed compared to conventional solutions. This approach exploits the synergy between what an SSOT achieves and what a TSR can achieve, proven in its application at Premcor refinery's heavy oil upgrade project in Port Arthur, Texas, USA. The feed for this project consisted of 60% heavy coker gas oil (HCGO), 20% light cycle oil (LCO) and only about 20% straight-run heavy vacuum gas oil (HVGO) derived from Maya crude. This combination is difficult to hydrocrack due to high aromaticity and nitrogen.

Compared to a conventional SSOT solution, the catalyst volumes required, hydrogen consumed and product qualities all benefited from the OPC (???) solution. Also, having both first and second stages in the same recycle loop saved capital. With the fractionation system between the two stages, only a portion of the 650°F-plus material is processed in the second stage; the remainder is routed directly to the FCC. This approach takes full advantage of the first-stage processing conditions, ideal for producing FCC feed while minimising hydrogen addition to this stream, and also of the clean second stage, with its relatively low reactor temperatures and higher space velocities for excellent fuels properties.

Finally, the ability to recycle kerosene in the second stage, from the fractionator, to gain aromatic saturation and to convert it to higher-value naphtha during the gasoline season was also implemented. This innovation and basic engineering design meat that Premcor with its lump-sum turnkey contractor Foster Wheeler executed the OPC hydrocracker, along with all the other elements of its heavy oil upgrade project, in 31 months from conceptual design to mechanical completion.[1]

Upgrading SSREC to TSR

A study conducted by CLG for a US refiner involved the revamp of a SSREC with two reactors to a two-stage hydrocracker with an increase in capacity of around 50%. The two SSREC reactors would be reconfigured to TSR mode (Figure 3). In addition to the capacity increase, the TSR hydrocracker offers flexibility to shift conversion between naphtha and diesel. The rise in capacity would allow the client to process more LCO. The existing recycle compressor did not require modification. This revamp scheme results in a cost-effective way of increasing hydrocracker capacity and at least one unit using this concept is being engineered.

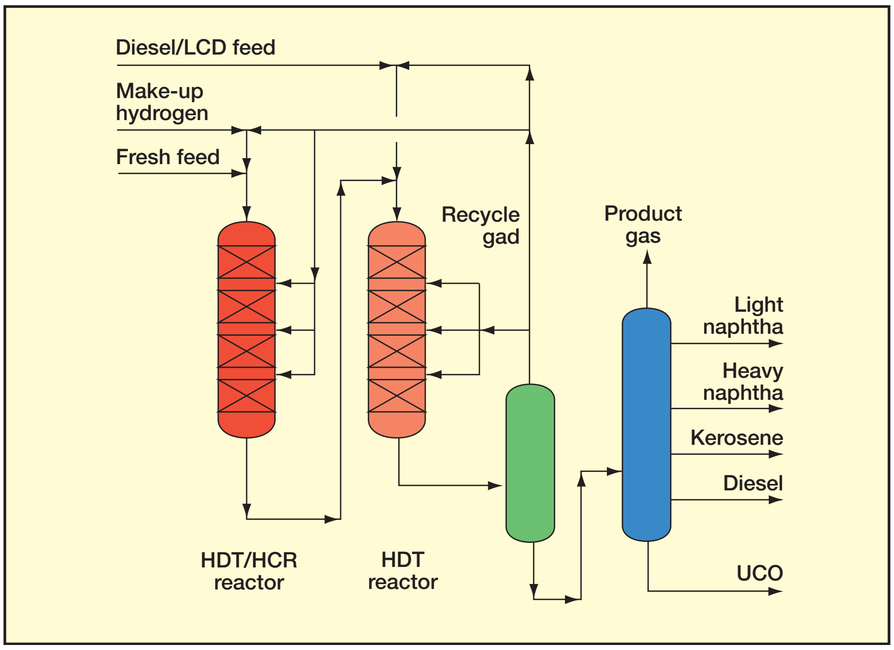

Figure 4 Split-feed injection

Split-feed injection and SSRS

The OPC innovation may have been driven by the need to produce two kinds of product – FCC feed and fuels with difficult feed – economically. In contrast, the split-feed injection concept evolved from the need to upgrade vastly different kinds of feeds in a cost-effective manner. The need in this case was to upgrade both FCC feedstocks and FCC products (cycle oils) and it was accomplished by combining the pre-treatment of FCC feed and post-treatment of FCC product (LCO) in one unit.

Unconventionally, hydrotreatment takes place in catalyst beds downstream from the hydrocracking catalyst to avoid cracking gas oils that are already in the desired product boiling range. Then, to save costs, the hydrocracking reactor effluent acts as a heat sink for the hydrotreating step, minimising the quench gas requirements associated with desulphurisation and saturation of the LCO-containing feed. This innovation saved BP at Bulwer Island, Australia, 30% of the capital investment it was contemplating for a standalone hydrotreater. The benefits and flexibility gained from the split-feed injection scheme (Figure 4) were significant enough that, during the early stages of the project, BP increased the amount of hydrotreating feedstock from 50–150%. BP's installation of CLG's proprietary split-feed injection hydrocracker started up in 2000 as part of the Queensland clean fuels project.[2]

The concept of having one reactor's effluent as a heat sink for a second reactor, a smaller attribute of the split-feed injection configuration, became a major function of the proprietary single-stage reaction sequence (SSRS) scheme. Here, the TSR configuration forms the basis for a high-conversion application. In this application, the second-stage reactor is placed upstream of the first-stage reactor. The useful benefits provided by this configuration include:

— Unused hydrogen from the second stage provides a portion of the hydrogen needed for the first stage, reducing overall gas circulation rate

— Similar to the split-feed scheme, the second-stage effluent serves as a heat sink for the first, reducing quench requirements and further lowering the gas recycle rate.

The benefits of the traditional TSR configuration remain intact – superb mid-distillate yields and qualities and maximum conversion at minimum cost – but the novel scheme saves further investment and operating costs. West Pacific Petrochemical Co Ltd (WEPEC) in China is constructing a 1.5 MMTA hydrocracker in Dalian and will start up this SSRS configuration in 2006.

Upflow reactor technology

Although OCR technology was fully commercial, there was a need to extract most of the value provided by OCR's upflow reactor while minimising capital investment and avoiding catalyst-handling facilities. This is why the proprietary upflow reactor (UFR) technology was developed. While it cannot provide all the demetalation benefit of an OCR, it is useful in other ways. Since it is not a moving bed, multiple beds of different catalysts can be used, including combinations of HDM and HDS catalysts. By far the

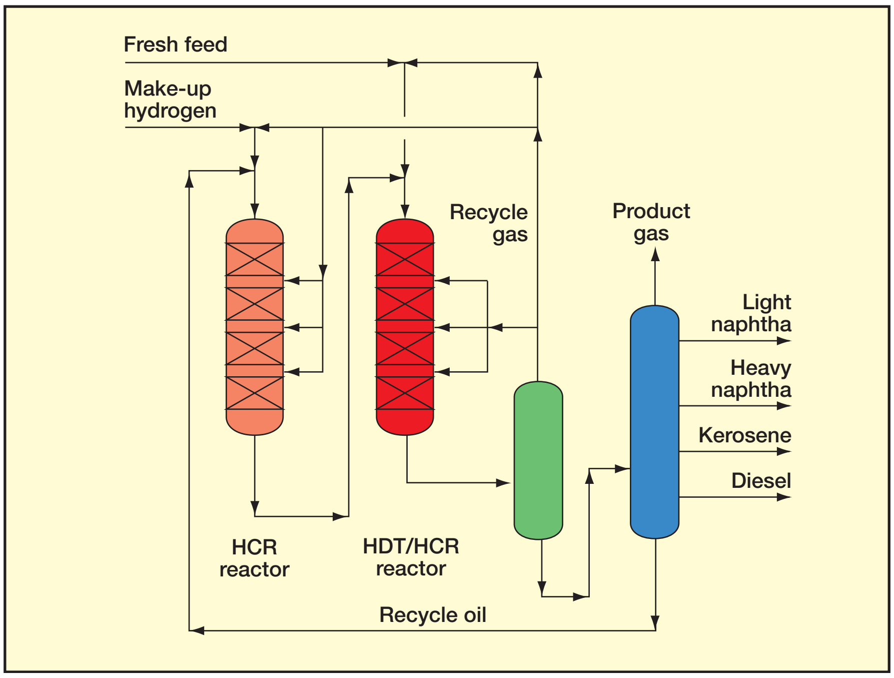

Figure 5 *Single-stage reaction sequenced Isocracking*

Evaluation of the catalyst performances – Qilu UFR			
	SOR (design)	SOR (actual)	Dec 2000
S remove ratio, %	88.7	90.6	84.4
N remove ratio, %	34.4	46.9	34.9
Metal remove ratio, %	87.6	83.2	87.6
CR remove ratio, %	60.0	58.7	58.3
Conversion ratio, 538(C$^+$, %	33.5	36.0	35.2
Chemical hydrogen consumption, Nm^3/m^{-3}	176	140	110

Table 1

greatest attribute of the UFR, as well as the OCR, is its low pressure-drop. This avoids typical limitations in the recycle compressor, and so revamping an existing vacuum resid desulphurisation (VRDS) unit becomes not only feasible but economically very attractive, as the Shengli refinery of Sinopec's Qilu Petrochemical Corp in China discovered.

Qilu's original VRDS unit was licensed by ChevronTexaco, with FCC feedstock and fuel oil being the main products. To meet company strategies, this refinery had to feed high-sulphur imported crude while increasing the VRDS capacity. The UFR process allowed Qilu to process Mid-East crudes at 43% increased capacity at one-fifth the cost of building a new unit to achieve the same objective. Qilu started up the UFR in late 2000 and its performance was demonstrated in December (Table 1). Although in the subsequent years demand for resid upgrades has been low, interest is currently picking up, as evidenced by the KNPC OCR. A new UFR design is currently being developed for a refiner in Europe, with start-up anticipated in 2006. An interesting feature of the UFR is its ability to be easily revamped into an OCR if the additional catalyst-handling capability facilities can be accommodated and more processing capability is desired in future.

The huge need for more residuum conversion, especially in the Middle East, will certainly drive new applications of fixed and ebullated bed technologies over the next decade.

Integration of residue and distillates hydrocracking

Integration of residue and fuels hydrocracking will result in significant cost savings. This concept uses the hot hydrogen-rich stream from the residue units – fixed or ebullated bed – to satisfy the hydrogen and most of the heat requirements of the downstream hydrocracking unit that is integrated to produce high-quality distillates. Capital saving is around $30–50 million.

Realising these benefits most recently is the Scotford Upgrader, which is part of the Athabasca Oil Sands Project. Shell Canada operates the unit on behalf of several partners. The plant processes 80 000bpsd of heavy residue (-4(API) and treats the gas oils and lighter products from the LC-Fining reactors to further improve product properties within the integrated mild hydrocracker (Figure 6). The combination of these technologies allows the unit to make high-quality, saleable fuels or intermediate products, not only by treating LC-Fining products but also other refinery streams, which may be inferior. The synergy enables cost savings in lower capital investment and lower operating costs – the close coupling of the two reactors allows the hydrocracking reactor to utilise the excess hydrogen in the LC-Fining effluent. The Scotford Upgrader successfully started up in 2003 and plans are under way for further expansion.

After the commercialisation of integrated LC-Fining and Isocracking technologies, CLG was awarded a second large integrated project by Fortum, Finland. This project will upgrade 40 000bpsd of vacuum residue to VGO and lighter products (~80% conversion). The VGO-range material will be sent to an integrated TSR that will convert most of the VGO to ultra-low sulphur diesel (ULSD) and lighter products. The unit uses an enhanced hydrogen recovery and recycle system that saves nearly 10MW of power while maintaining optimum gas-to-oil ratios and quench capabilities in all reaction sections. One of the most critical aspects of integration is attention to safety and emergency procedures for the combined unit.

Integrated fuels and lubes production

The benefits of hydrocracking to produce feed for lubricant base stocks, as well as other downstream processing such as FCCs and ethylene plants, are well known and in evidence at plants around the world. In most of these cases, there is a dedicated lube hydrocracker, followed by dewaxing and finishing steps. What is more unusual is the integration of a hydrocracker, primarily devoted to making high-quality fuels, especially ultra-low sulphur, low aromatics diesel, while also making excellent feed for a dewaxing/finishing unit. The benefits of such an approach are obvious: minimise capital investment relative to building separate fuels and lubes hydrocrackers and lower the refiner's cost of producing high-value lube base stocks, thus providing a competitive edge.

A Korean refiner demonstrated the efficacy of revamping an existing SSREC hydrocracker into a fuels and lubes hydrocracker producing extremely high V.I., Group III base oils.[3] The benefits of using existing facilities to greatly enhance value addition were fully recognised by this refiner. However, the configuration used had inherent

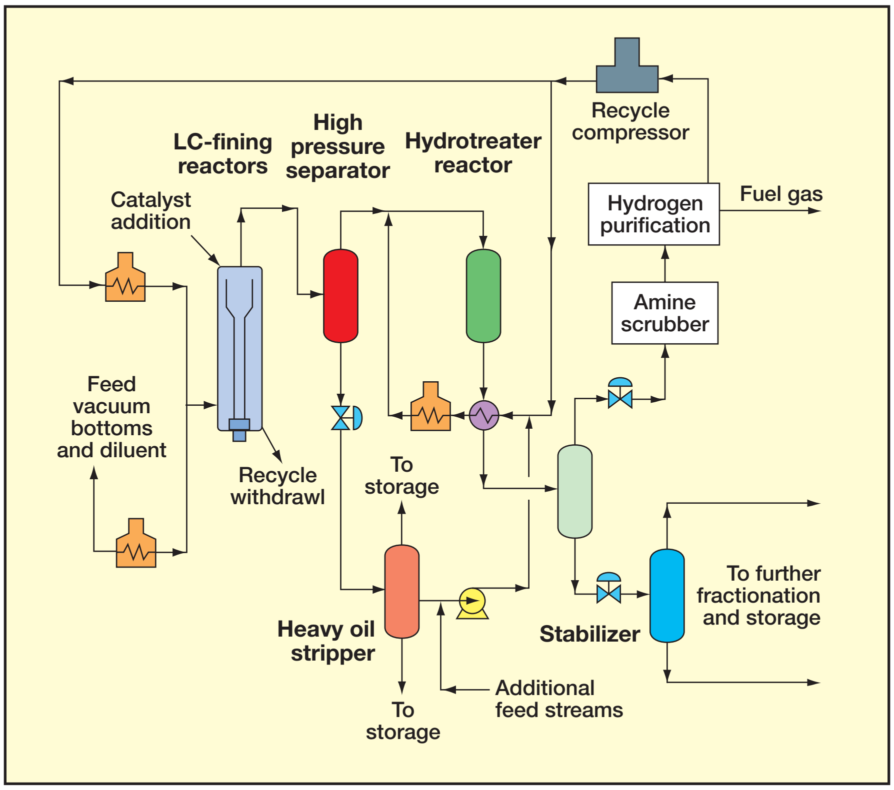

Figure 6 LC-Fining with integrated hydrotreating simplified flow scheme

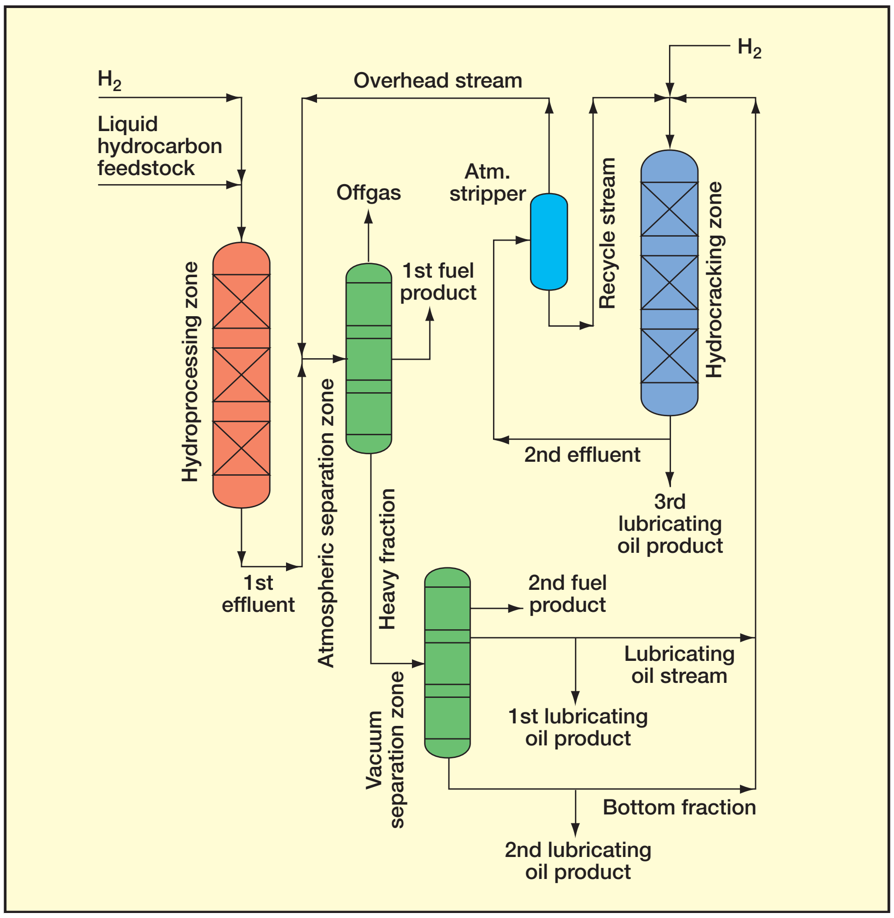

Figure 7 Isocracking for fuels and lubes

limitations. The conversion needed by the refiner to fulfill its fuels quantity/quality requirements set, without much flexibility, the viscosity range and V.I. possible of the base oil feedstock. Here is where the TSR configuration, with its innate advantages for making fuels described earlier, can provide a highly flexible platform to produce a range of lube base oil viscosities and qualities.

The patented principle is shown in Figure 7, where the configuration can be set up to produce three different lube base oil feedstocks while largely maintaining the predetermined overall conversion level for fuels. The three lubricating oil streams are of different qualities and boiling ranges. Investment to recover each stream for further dewaxing/hydrofinishing steps can be phased to match market requirements.

BPCL, a refiner in India, saw the potential in a TSR-configured hydrocracker. Using CLG's process, it designed an integrated dewaxing hydrofinishing unit, taking advantage of the flexibility available in its TSR to meet its forecast lube base oil market. "Catching" the hydrocracker project before all the major equipment had been ordered enabled BPCL and CLG to design further cost-saving ideas. For example, obviating the need for several major pieces of equipment normally required for a lubes hydroprocessing unit. BPCL's lubes plant is expected to start up about one year after feed in to the hydrocracker in early 2005.

This article is based on a more detailed manuscript originally presented at the 2003 Asia Refining Technology Conference (ARTC) in Singapore. Isodewaxing (ISODEWAXING) LC-Fining (LC-FINING), TSR, OCR, OPC, UFR, Isocracking (ISOCRACKING) are proprietary trademarked ChevronTexaco technologies.

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