OUT OF UNCERTAINTY COMES OPPORTUNITY: THRIVING IN THE NEW REALITY WITH A HYDROCRACKER REVAMP

- **Shift the yield pattern**
- **Process advantaged crudes**
- **Process difficult feeds**

The refining landscape has shifted in unprecedented ways in recent years. The global pandemic brought a reset in energy demand, utilisation challenges and pressure on margins. And, although the sector has somewhat rebounded, conditions will remain highly challenging.

Because of this, it is business critical for most refiners to take steps to improve their short-term performance. Failing to invest carries the risk of competitive vulnerability, though capital discipline is key. So, in this set of articles, we reveal a wide range of low-capital revamp opportunities that will help refiners to unlock high returns quickly.

Refiners seeking to adapt their assets to the prevailing situation can exploit the inherent flexibility of a hydrocracker to:

Shift towards petrochemicals. With industry commentators asserting that demand growth for gasoline and diesel is set to weaken in the long term, some refiners are evaluating how they can repurpose their facilities. Though most hydrocrackers commissioned in the past 15 years have traditionally been designed as diesel-producing machines, they are now increasingly being reconfigured towards naphtha. Many refiners are pulling naphtha out of gasoline and then redirecting light naphtha to the ethylene cracker and sending heavy naphtha through additional processing units to produce paraxylene. If desired, it is also possible to continue to produce jet fuel, for which long-term demand is expected to remain strong.

Improve residue conversion. The need to respond to the IMO 2020 fuel-sulphur cap and invest in residue conversion projects remains strong for many. By revamping a hydrocracker, repurposing it and integrating it with another fuel conversion technology such as solvent deasphalting, delayed coking or thermal cracking, refiners can cost-effectively reduce their exposure to high-sulphur fuel oil.

Produce lubricant base oil feed. There is a global trend away from Group I products based on solvent technology towards group II and III lubricant base oils produced using catalytic dewaxing and hydrofinishing technology. In some regions, lubricant base oil feed can command a higher margin than middle distillates, so refiners are revamping their hydrocrackers to enable the right feed quality. The hydrocracker's catalyst system and configuration are key, as they have major influences on the yield and quality of the final base oil products.

Process advantaged crudes and difficult feeds. Another popular revamp objective is to facilitate the processing of lower-priced opportunity crudes such as West African, Mexican, Colombian and Venezuelan, and non-standard feeds such as heavy coker gas oil and deasphalted oil (DAO).

WHAT DO WE OFFER?

- Process configurations to suit your objectives, including single-stage designs (once-through and recycle mode) to produce lubricant base oils or fluidised catalytic cracker (FCC) or ethylene cracker feedstocks, and both single- and two-stage designs to maximise middle distillates.
- A wide range of hydrocracker pretreatment catalysts, including CENTERA GT, which offers up to a 25% increase in hydrodenitrification performance and similar improvements in hydrodesulphurisation and aromatic saturation.
- A wide range of zeolite hydrocracking catalysts through our joint venture with silica and zeolite specialist PQ Corp. This includes a new nano-engineered technology, Shell's Molecular Access Catalysts for Hydrocracking (MACH), which offers improved conversion efficiency of heavy molecules and could unlock up to $30 million per cycle. **Click here to learn about Shell's Molecular Access Catalysts for Hydrocracking.**
- Latest-generation reactor internals.
- Technical services and advice on unit optimisation.

NEXT

HOW DO WE IMPLEMENT?

We begin a hydrocracker revamp with a feasibility study that aims to find the "sweet spot" for the project, whereby increases in unit capability are balanced with economic factors.

This begins with a formal kick-off meeting so that we can align with you on objectives and understand your constraints in terms of capital availability, turnaround duration, timing and so on.

The experience of our engineers, our kinetic model (which allows us to efficiently review the impact of changing feed rates and qualities on reactor yields and properties) and our catalyst and reactor internals technologies, are all key to our ability to unlock value here. Part way through the feasibility study we discuss options with you and align on the best solution, before finalising the study.

We follow the feasibility study by delivering a design package for the selected option, and the deliverables are tailored to your situation and preferences.

TAKE THE NEXT STEP

Schedule a revamps consultation

CUSTOMER CASE STUDIES

In recent years, Shell Catalysts & Technologies has revamped hydrocrackers for a wide variety of objectives. For example, we have helped refiners to increase capacity, increase or decrease conversion to adjust the yield profile, and to extend cycle length by increasing crude flexibility or mitigating fouling.

Click on the links to find out how:

Case study: Hyundai Oilbank's refinery
shifted to a heavier, lower-cost crude blend. →

Case study: Shell's Pernis refinery
revamped its HYCON residue hydroprocessing unit to a DAO hydrocracker. →

Case study: Shell's Norco refinery
revamped its hydrocracker to maximise diesel instead of naphtha. →

Case study: SASREF
increased diesel yield, cycle length and safety with a low-cost hydrocracker revamp. →

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HOW HYUNDAI OILBANK'S REFINERY SHIFTED TO A HEAVIER, LOWER-COST CRUDE BLEND

DRIVERS

Hyundai Oilbank identified an opportunity to improve margins at its Daesan, Korea, refinery by moving from a medium-sour Middle East crude blend towards super-heavy crudes such as Maya and Basrah Heavy. These low-priced crudes can provide high margins but are extremely challenging to process.

ABOUT THE PROJECT

To enable such a crude slate while minimising capital investment and maximising returns, Hyundai Oilbank made a series of changes to the refinery configuration in a carefully designed combination of adding new hardware and revamping existing assets. The changes include:

- Installing a new C5 solvent deasphalting (SDA) unit (a residuum oil supercritical extraction, or ROSE™, unit licensed by KBR);
- Converting atmospheric residue desulphurisation (ARDS) Module 2 to deasphalted oil (DAO) mild hydrocracking (MHC) service to process 100% DAO from the SDA unit;
- Revamping the delayed coker to enable it to process pitch from the SDA unit instead of vacuum residue; and
- Revamping the ARDS Module 1 to increase capacity.

One of the key constraints for processing a more difficult crude slate had been the maximum allowable metals content that the existing ARDS modules 1 and 2 could process. The new configuration lifts this constraint significantly for module 2 because the SDA unit concentrates the crude impurities, such as sulphur, nitrogen and metals, in the asphalt stream that is routed to the delayed coker.

PHASING THE INVESTMENT – AN IMPERATIVE IN THE NEW REALITY

"As refiners are likely to adopt a more conservative approach to capital investment in the new reality, it may become more important to take a phased approach to projects. This is exactly how Hyundai Oilbank executed these projects. It followed a staged approach to generate cash through a series of small investments and then used that cash to fund additional investment in small increments."

John Baric, Licensing Technology Manager, Shell Catalysts & Technologies

PHASE 1

During Phase 1, Hyundai Oilbank revamped both ARDS modules:

- ARDS Module 1 was revamped to process 50% more AR above original design, at 20% conversion, producing residue fluidised catalytic cracker (RFCC) feed (0.5% sulphur, 4.5% micro-carbon residue);
- ARDS Module 2 was converted to MHC service and the capacity increased by 50% above original design, processing 100% DAO at 50% conversion. It produces feeds for the existing RFCC and the future petrochemicals complex.

In addition, Hyundai Oilbank installed a new C5 SDA unit, the largest-capacity ROSE unit ever licensed by KBR, and revamped the existing delayed coker to enable co-processing VR and ROSE pitch feed.

In order for the project to begin to generate returns, speed of implementation was also important. It took the Hyundai Oilbank / Shell Catalysts & Technologies project team just 30 months from the beginning of the feasibility study to startup.

PHASE 2

During Phase 2, Hyundai Oilbank further revamped the ARDS module and MHC unit:

- ARDS Module 1 was revamped from a single train to two parallel trains and added more fixed-bed reactors, which increased capacity by an additional 30% and the cycle length by 50%;
- The MHC was revamped by adding more fixed-bed reactors, which increased capacity by an additional 10% and the cycle length by 50%.

These changes also enabled the refinery to be further integrated with a new heavy feed petrochemical complex that was being built.

The updated refinery flow scheme is shown in Figure 1.

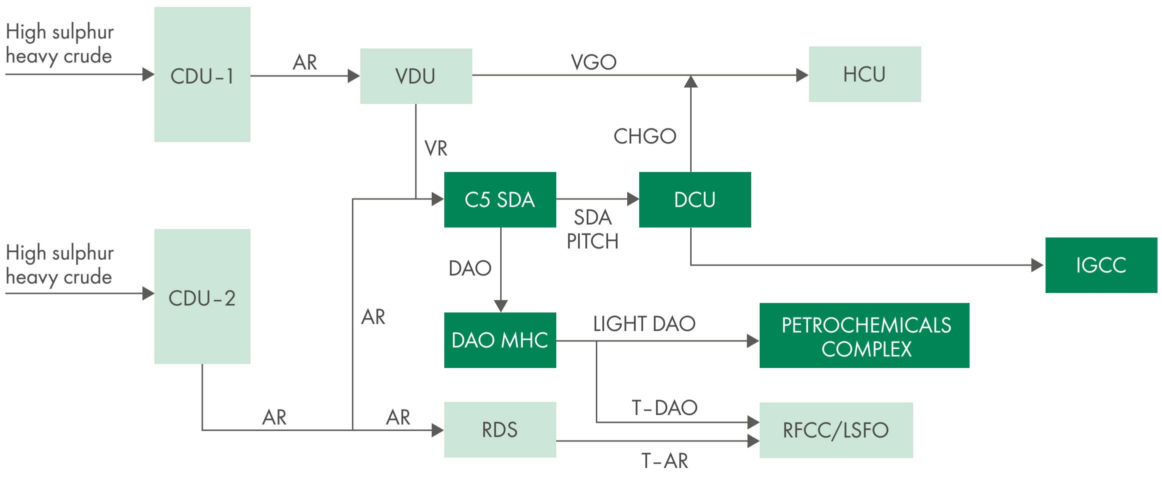


Figure 1: Block flow scheme of Hyundai Oilbank refinery after the revamps.

Read the expanded description for Figure 1 in the appendix on page 11

For this phase, it took just 20 months from starting the feasibility study to starting up the revamped unit.

VALUE DELIVERED

Enabling the processing of super heavy crudes has helped Hyundai Oilbank to unlock a major improvement in its refining margin. Crucially, it achieved this for only modest capital investment by leveraging revamps.

In 2018, Hyundai reported that it has the nation's highest heavy oil upgrading ratio, and in 2019 it posted the industry's highest ratio of net income to sales. The Phase 1 project, which concluded in 2018, was a key contributor to these achievements.

TAKE THE NEXT STEP

Schedule a revamps consultation

HOW SHELL'S PERNIS REFINERY REVAMPED ITS HYCON RESIDUE HYDROPROCESSING UNIT TO A DAO HYDROCRACKER

DRIVERS

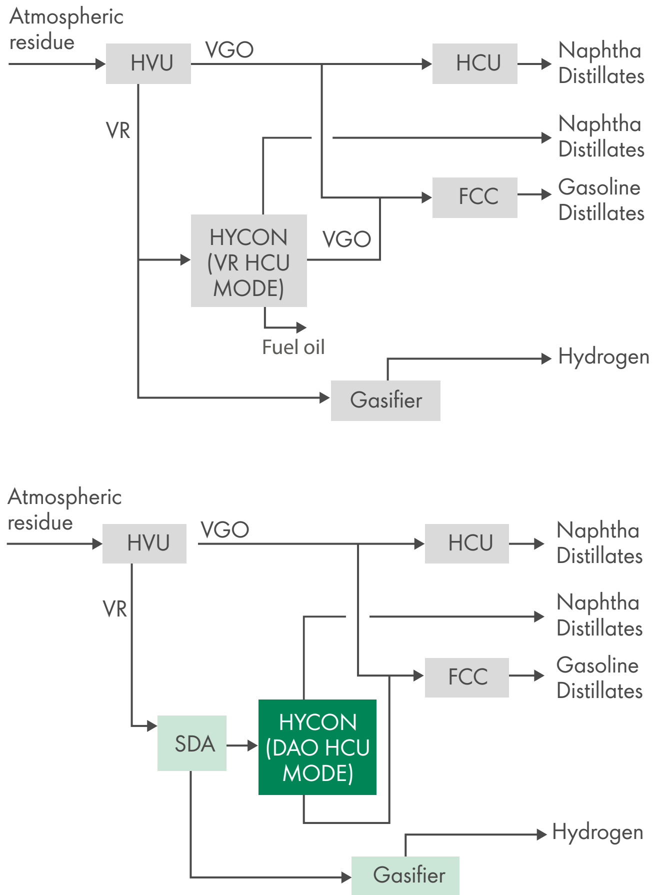
Ahead of the IMO 2020 marine fuel oil mandate, it was business critical for Shell's Pernis refinery in the Netherlands to find a way to reduce its fuel oil production. To improve margins further, it also wanted to enhance the yield of ultra-low-sulphur diesel and increase its crude flexibility.

ABOUT THE PROJECT

In 2018, Shell's Pernis refinery brought an integrated project online that involved:

- The construction and startup of a solvent deasphalting (SDA) unit (a residuum oil supercritical extraction, or ROSE™, unit licensed by KBR) that typically produces high-quality deasphalted oil (DAO) that is suitable as a fixed bed hydrocracker feedstock;
- A revamp of the HYCON unit from vacuum residue hydrocracking to DAO hydrocracking mode featuring Shell Hycon Moving Bed technology upstream of the fixed-bed reactors to enable it to process 100% DAO; and
- Minor modifications to the gasification plant to enable it to handle a heavier stream.

Figure 2 shows a simple flow scheme for the Pernis refinery bottom of the barrel before and after project implementation.



Read the expanded description for Figure 2 in the appendix on page 11

Figure 2: Block flow scheme of Pernis refinery's residue upgrading scheme before and after the revamp.

KEY RESULTS

The design DAO feed quality is given in Table 1.

Feed quality parameter	Design Case Urals	Check Case I Arab Light	Check Case II WAF
Specific gravity	0.960	0.973	0.953
Sulphur, wt%	2.48	3.45	1.67
Nitrogen, ppm wt	4,000	2,709	4,273
Vanadium, ppm wt	32	13	19
Nickel, ppm wt	10	5	10
Metals (Ni+V), ppm wt	42	18	29
CCR, wt%	7.4	8.7	6.5

Table 1: DAO feed quality.

Shifting the feed from vacuum residue to DAO reduced the levels of all the feed contaminants, especially metals. This enabled changes in the design and operation of the HYCON unit. The lower metals level resulted in only the single moving-bed lead reactor being necessary for demetallisation. This enabled conversion of the next two three-bed reactors from moving to fixed mode. Overall, optimisation of the entire catalyst system has resulted in higher conversion (up to 75%) for the same two-year catalyst cycle length while producing on-specification, ultra-low-sulphur diesel. The site is now evaluating minor unit changes to the HYCON unit that would help to increase future cycle lengths to three years.

In DAO hydrocracking mode, the unit has achieved the targeted higher conversion and an increased yield of high-value products.

In addition to much-improved refinery yields, the DAO hydrocracker generates high-quality finished products, as Table 2 shows.

VALUE DELIVERED

The project helped the site to:

- Reduce fuel oil production by 35%;
- Increase middle distillate yield; and
- Process heavier, cheaper crudes that contain high concentrations of nickel and vanadium.

Revamping existing units and tight integration with the rest of the refinery meant that the project could achieve a return on investment above 15%, a factor of two higher than the prediction for the industry-standard solution, a delayed coker.

The project was fully commissioned and started up in July 2018, one month ahead of schedule and 30 months after the final investment decision. Modular construction was successfully used for the new SDA unit; the modules were fully tested in China before shipping to Netherlands.

CUSTOMER QUOTE

"Pernis refinery is now ready to meet the anticipated demand growth for cleaner transport fuels that will help keep to Europe's people and economy moving. This unit pushes the boundaries of refining technology and seamlessly integrates with almost every part of the site to unlock the full value of each barrel of oil."

Robin Mooldijk, Executive Vice President for Manufacturing, Shell

Download the HYCON Moving Bed technology white paper to learn more.

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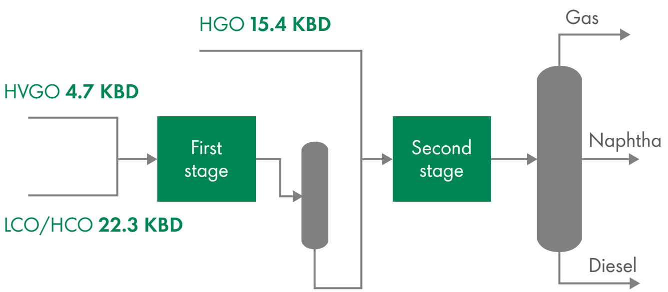
Product quality parameter	Naphtha (C_5–160°C)	Kerosene (160–225°C)	Gas oil (225–360°C)	DAO hydrowax (360°C +)
Sulphur, mg/kg	3–10	3	5	20
Cetane number			58	
Cetane index			60	
Smoke point, mm		20		
Cold flow pour point, °C			−10	

Table 2: DAO hydrocracker product qualities.

HOW SHELL'S NORCO REFINERY REVAMPED ITS HYDROCRACKER TO MAXIMISE DIESEL INSTEAD OF NAPHTHA

DRIVERS

The two-stage hydrocracker at Shell's Norco refinery in Louisiana, USA, was originally designed to convert distillates to naphtha for motor gasoline production via the reformer. Over time, however, demand for distillates increased and the refinery reacted by using the bottom product from the second-stage fractionator as a diesel component (Figure 3).



HGO: Heavy gas oil
HVGO: Heavy vacuum gas oil
LCO: Light cycle oil
HCO: Heavy cycle oil

Figure 3: Original hydrocracker configuration.

Read the expanded description for Figure 3 in the appendix on page 12.

However, the quantity of heavy vacuum gas oil (HVGO) that could be incorporated into the unit feed was constrained by the final boiling point requirement of the diesel product draw.

ABOUT THE PROJECT

The refinery was keen to explore ways to unlock this constraint and significantly increase the unit's diesel yield, so commissioned a masterplanning study.

After evaluating several options, the team opted for a solution (Figure 4) that involved:

- Rerouting distillates (light cycle oil and diesel range material) from the hydrocracker to the diesel hydrotreater (DHT);
- Increasing the DHT's utilisation through backing out imported cold feed and replacing with hydrocracker distillates via a separate project; and
- Revamping the hydrocracker to process significantly more HVGO and maximise diesel yield.

This required:

- Adding a new fractionation column with diesel draw so that the distillate end point could be controlled independently of the feed quality;
- Modifying the catalyst system in the second-stage reactors to enable the processing of fresh HVGO feed with higher nitrogen and other contaminant contents (see boxed text, "New catalysts, new possibilities");
- Installing latest-generation reactor internals and catalysts; and
- Rerating equipment (see boxed text, "Using HITLOP to minimise the capital cost").

NEW CATALYSTS, NEW POSSIBILITIES

"To enable the second-stage reactors to handle the increased nitrogen and other contaminants in the new feed, it was necessary to modify the catalyst system significantly. This involved moving from 100% cracking catalyst to a stacked system of pretreatment and cracking catalysts.

"Underlying this is that the state of the art in pretreatment catalysts is continuously improving. Typically, a new-generation catalyst is developed every four years that is about 20% more active. This provides many improvement possibilities for old units; in this case, Norco is using some of the catalyst volume for pretreating the heavier feed that it wanted to introduce."

Simon Cackett, Licensing Technology Manager, Shell Catalysts & Technologies

USING HITLOP TO MINIMISE THE CAPITAL COST

"We had to rerate the equipment in the first and second stages to enable the heavier feed to be charged; much of the equipment was only rated for 400°C (750°F) maximum allowable working temperature, but processing the additional HVGO required operating at up to 425°C (800°F) maximum allowable working temperature.

"To achieve this cost-effectively, we leveraged the high-temperature, low-pressure (HITLOP) technique, which involves evaluating each piece of equipment for the actual combination of operating temperature and pressure and replacing only the items that cannot be safely run at these conditions. It is a challenging technique that requires high-quality interaction between the process operations and inspection functions, but it can have a major impact on project cost because it minimises the equipment that has to be replaced. For this project we achieved a full 28°C (50°F) increase in design temperature window in each stage by reducing the maximum pressure rating by only 2.8 barg (40 psig) in the first stage and 3.1 barg (45 psig) in the second stage."

Ward Koester, Licensing Technology Manager, Shell Catalysts & Technologies

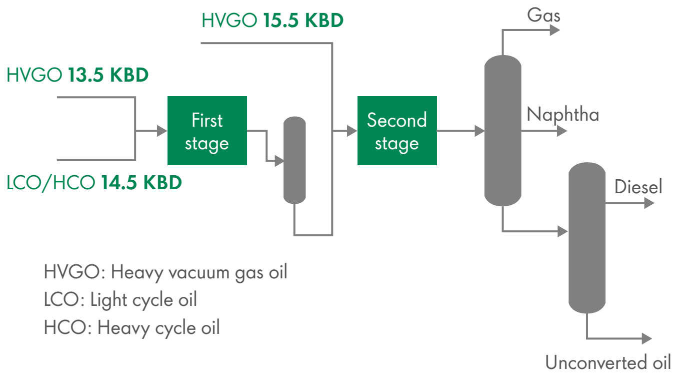


Figure 4: Revamped hydrocracker with additional fractionator and increased feed heaviness. In addition, the LCO:HCO ratio changed from 50:50 to 25:75.

Read the expanded description for Figure 4 in the appendix on page 12.

VALUE DELIVERED

The revamped hydrocracker can process a significantly higher amount of HVGO. This has increased from 4,700 to 29,000 bbl/d (13,500 bbl/d in the first stage and 15,500 bbl/d in the second stage).

The amount of diesel that the hydrocracker can produce has increased from about 14,000 to 24,000 bbl/d. The proportion of diesel that the hydrocracker produces has increased from 33 to 55 vol% now limited by the diesel cloud point specification and equipment constraints on the minimum achievable naphtha/diesel cut point.

In addition, greater utilisation of the DHT through the processing of hydrocracker distillates has allowed for elimination of 12,000 bbl/d of imported cold feed distillate.

Revamping the hydrocracker and enabling fuller utilisation of the DHT have allowed the refinery to process an extra 24,300 bbl/d of imported vacuum gas oil (VGO) and produce predominantly additional diesel, with gross margin impact of about $60 million per annum (based on typical $7/bbl VGO–low-sulphur diesel price differential).

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HOW SAUDI ARAMCO SHELL REFINERY CO. (SASREF) INCREASED DIESEL YIELD, CYCLE LENGTH AND SAFETY THROUGH A LOW-COST HYDROCRACKER REVAMP

DRIVERS

When it was built in 1982, the hydrocracker at SASREF, one of the largest in the world, was configured for maximum naphtha. By 2012, however, middle distillates, not naphtha, had become the highest-value product stream, so SASREF launched a project to repurpose the unit.

It also wanted to take the opportunity to enhance its profitability by increasing the unit's capacity and cycle length.

ABOUT THE PROJECT

SASREF installed latest-generation reactor internals throughout the unit. These include Shell HD trays, which achieve near-perfect wetting of the catalyst (Figure 5).

Other important changes that it made include modifying the bed configuration in each reactor, installing new thermometry and customising the catalyst system.

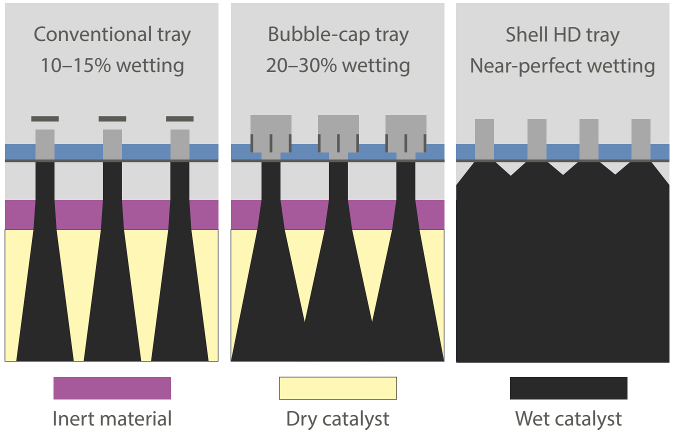

Figure 5: Shell HD trays feature proprietary customised nozzles that use the gas flow momentum to disperse the liquid as a fine mist to achieve almost 100% catalyst wetting.

Three types of reactor trays and their respective catalyst wetting efficiency are illustrated. On the left is a conventional tray that provides wetting efficiency of 10–15%. In the centre, a bubble-cap tray provides wetting efficiency of 20–30%. On the right, a Shell HD tray provides near-perfect wetting.

KEY RESULTS

The hydrocracker had been using conventional distribution trays, which are notorious for low uniformity of vapour–liquid distribution and undesirable radial temperature maldistribution.

Replacing these with Shell HD trays helped to improve catalyst utilisation by:

- 21% in the pretreatment reactors; and
- 52% in the cracking reactors.

Merging beds, and the hardware's slimmer profile, helped to increase the reactors' catalyst volume by:

- 16% in the pretreatment reactors; and
- 22% in the cracking reactors.

VALUE DELIVERED

The project, which required little capital expenditure, delivered value in several ways. For example, it:

- Increased middle distillates yield by 4%, which enhanced the site's profitability by over $10 million a year;[1]
- Enabled the unit to have the flexibility to swing between naphtha and middle distillates;
- Cut the time required for shutdowns by some four days, which is worth about $2.56 million per turnaround; and[2]
- Enhanced staff safety by, for example, reducing the time required for confined space entry by 75% compared with conventional hardware.

1Assumes $14/bbl diesel–naphtha price differential, 7,500 t/d intake, 350 operating days a year and 4% shift from naphtha to diesel.

2Assumes $80/t margin.

CUSTOMER QUOTE

"It was a great pleasure for SASREF to work with Shell Catalysts & Technologies on this initiative. The project is helping us to derive the intended value, which is quite timely considering the current economic conditions and tightening refinery margins."

Ali Al-Hazmi, President, SASREF

Download the New Reactor Internals and Optimised Catalyst Selection white paper to learn more.

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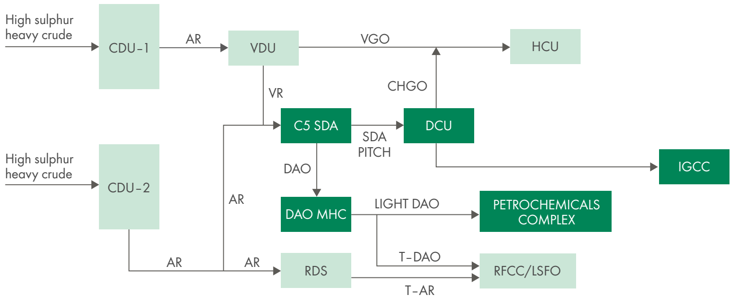
BACK

APPENDIX



The diagram in Figure 1 illustrates the block flow scheme of the Hyundai Oilbank refinery after its revamps to enable the processing of super heavy crudes. The process begins with two crude distillation units (CDU-1 and CDU-2), which distil high sulphur heavy crude oil into atmospheric residue (AR) and other fractions.

AR from CDU-1 is sent to the vacuum distillation unit (VDU) for further separation into vacuum gas oil (VGO) and vacuum residue (VR). VGO is directed to a hydrocracking unit (HCU). VR is directed to a C5 solvent deasphalting unit (SDA).

AR from CDU-2 is sent to the C5 SDA, where deasphalted oil (DAO) is separated from SDA pitch, and to a residue desulphurisation unit (RDS), where sulphur is removed. T-AR is sent to a residue fluidised catalytic cracker (RFCC)/low sulphur fuel oil unit (LSFO).

SDA pitch is directed to a delayed coking unit (DCU), where cracked heavy gas oil (CHGO) is separated and directed to the HCU. The remaining stream is sent to an integrated gasification combined cycle (IGCC) unit.

DAO is directed from the C5 SDA to a DAO mild hydrocracking unit (MHC), where it is upgraded into light DAO, which is routed to a petrochemicals complex, and T-DAO, which is sent to the RFCC/LSFO.

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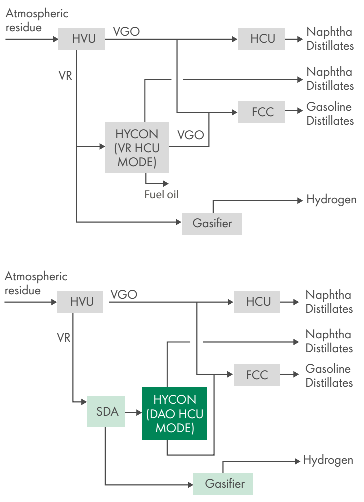

The diagrams in Figure 2 represent the block flow scheme of the Pernis refinery's residue upgrading processes before and after a revamp. They highlight how the refinery transitioned from a VR HCU mode to a DAO HCU mode.

In both configurations, atmospheric residue is fed into the HVU, which separates VGO and VR. VGO is fed into an HCU to produce naphtha and distillates and into an FCC unit to produce gasoline and distillates.

In the VR HCU mode, VR is fed into the HYCON unit to produce naphtha and distillates, additional VGO, which is directed to the FCC unit, and fuel oil. Additional VR is fed into the gasifier to produce hydrogen.

In the DAO HCU mode, VR is initially fed into an optional SDA unit before entering the HYCON unit and the gasifier. This reduces fuel oil production.

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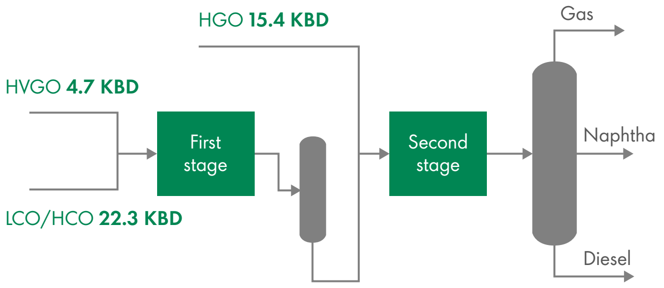
APPENDIX



HGO: Heavy gas oil
HVGO: Heavy vacuum gas oil
LCO: Light cycle oil
HCO: Heavy cycle oil

The diagram in Figure 3 illustrates Shell's Norco refinery's original hydrocracker configuration, highlighting the flow of feedstocks through the reactors.

The system starts with two feed streams: heavy vacuum gas oil (HVGO) at 4,700 barrels per day and a combined stream of light cycle oil (LCO) and heavy cycle oil (HCO) at 22,300 barrels per day. These feedstocks are processed in the first-stage reactor.

After processing, the stream, along with the addition of heavy gas oil (HGO) at 15,400 barrels per day, is directed to the second-stage reactor. The stream undergoes further processing to produce gas, naphtha and diesel.

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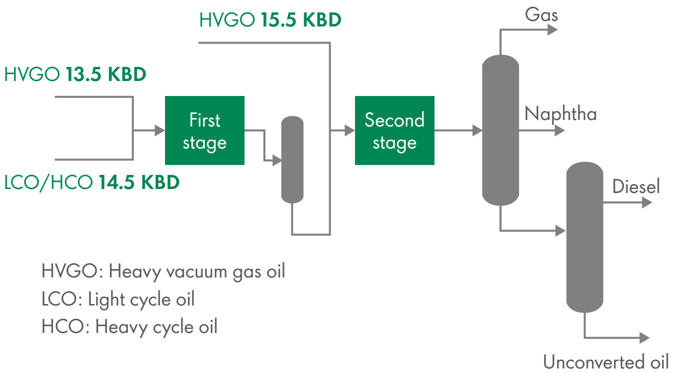

HVGO: Heavy vacuum gas oil
LCO: Light cycle oil
HCO: Heavy cycle oil

The diagram in Figure 4 illustrates Shell's Norco refinery's revamped hydrocracker configuration, including an additional fractionator and increased feed heaviness.

The feed to the first-stage reactor now consists of 13,500 barrels per day of heavy vacuum gas oil (HVGO) and 14,500 barrels per day of a mixture of light cycle oil (LCO) and heavy cycle oil (HCO). Notably, the ratio of LCO to HCO has been adjusted from 50:50 to 25:75, reflecting a greater emphasis on processing heavier components.

15,500 barrels per day of HVGO are now added to the stream fed into the second-stage reactor. Processing produces gas and naphtha. The additional fractionator produces unconverted oil as well as diesel.

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