SPECIAL SUPPLEMENT TO
HYDROCARBON PROCESSING®

MOVING THE OPERATING WINDOW

An in-depth look at some high-performing revamping and upgrading projects that are helping refiners to capture additional margin from existing assets

Shell Global Solutions

INTRODUCTION

WHY REFINERY REVAMPS OFFER COMPELLING INVESTMENT OPPORTUNITIES IN TODAY'S VOLATILE MARKETS

For most refiners, the need to enhance margins and remain competitive has never been greater. Industry overcapacity, crude price volatility, the implementation of environmental regulations in new markets, the desire to reduce fuel oil production and changes in feedstock availability are combining to make this one of the most challenging periods that the industry has ever known.

Investment can be key to maintaining competitiveness, but large programmes requiring substantial capital expenditure are likely to be difficult to justify to shareholders.

In most parts of the world today, a proposal for a grass-roots refinery, for example, is extremely unlikely to get off the ground. At a cost of $10–$20 billion, depending on the scope and the size of the refinery, and with gross refinery margins being viewed as poor to average at best, such a project is likely to be out of reach for most investors. In fact, in many cases, the project cost escalates further with the need to integrate with petrochemicals production.

Refiners can often achieve better payback with less risk by improving or upgrading their existing assets. That is why, in this supplement, we are focusing on revamping and upgrading opportunities. The business case for such projects, which will typically cost $100–500 million, is usually far more compelling.

The cost per tonne of the capacity installed during a revamp is about 20–50% of that for a grass-roots facility. The extreme range reflects the flexibility a refinery has in a revamp project. A feasibility study for a revamp project can identify costs with a greater degree of certainty, thereby enabling a refiner to make easier decisions on how much scope to take on in a project. In addition, there is the gestation period to consider; a revamp will deliver returns far quicker than a grass-roots project.

Smaller, incremental investments can be extremely suitable in today's market and revamps are key elements of many of our customers' investment strategies. They carry a smaller investment risk, generate credibility with investors and, as many of our case studies demonstrate, provide the ability to respond flexibly to differing situations as market conditions change.

At Shell Global Solutions, we have always advised customers not to overlook their existing assets. Operational excellence should be your first consideration. Then, you should generate as much value as possible from your existing assets through revamps, for example. These can provide big gains for a relatively modest investment and the returns can help to fund any larger capital projects that you may require. This is the basis of the Shell Global Solutions Multiplatform Pentagon model (see Figure 1).

Shell Global Solutions' revamp projects are, by definition, low in capital expenditure. We seek to reuse existing equipment and find synergies with the conversion units already on the ground. We try to minimise major equipment; the kit that needs to be acquired is usually limited to items that have a modest capital cost such as new reactor internals, heat exchangers and small furnaces (for a more detailed list of actions that are typically taken in a revamp, see Technology focus, page 7).

However, revamp projects are also more complex in the implementation phase than grass-roots initiatives. The project planners have to ensure that they do not disrupt the continuing operation of the existing facility. They have to design within the existing units' precise boundary conditions, such as the size and duty of the existing reactors, and the tie-ins during project execution have to be carefully planned.

Fortunately, these issues can be mitigated by working with an experienced strategic licensor that has experience of delivering such projects internally and externally. Shell Global Solutions has delivered a wide variety of value-adding revamping and upgrading projects around the world, some of which are described in more detail in the pages that follow.

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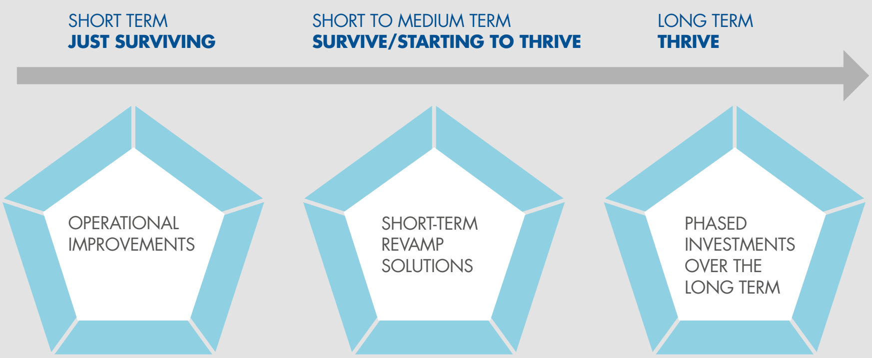

Health, safety and environmental issues are of great importance to Shell Global Solutions and thus central to all Pentagon options.

Figure 1: The Shell Global Solutions Pentagon Model. Pentagon I advocates a focus on operational improvements that do not require capital expenditure. These are short-term initiatives and can help to fund Pentagon II initiatives, which are short-to-medium-term revamp solutions. In turn, the cash generated from those initiatives can be used for the more capital-intensive projects of Pentagon III. Each of the three pentagons has investment options on all five sides. ▶

ABOUT US

- Shell Global Solutions can undertake the full range of revamp projects, which it generally designs for shorter delivery and payback periods.
- A dedicated, highly experienced team manages our revamp projects and draws on the years of experience that Shell has gained in revamping and operating refineries and petrochemical complexes around the world.
- When revamping hydrocrackers and hydrotreaters, Shell Global Solutions offers proprietary state-of-the-art reactor internals and works with two of Shell's catalyst companies, Criterion Catalysts & Technologies (Criterion) and CRI Catalyst Company.
- Shell Global Solutions licenses a wide range of industry-leading technologies across all refinery processes, from distillation and separation, through hydrocracking and hydrotreating (including for dewaxing, lubricant base oil and enhanced aromatic saturation) to technologies for treating sour gas such as the CANSOLV* SO_2 Scrubbing System.
- The alliance of Shell Global Solutions with KBR enables both companies to offer a broad range of refining technologies aimed at helping customers to unlock margin improvements while meeting their environmental mandates. This covers hydrocracking, hydrotreating, deep-flash, high-vacuum technology and bottom-of-the-barrel upgrading.

*CANSOLV is a Shell trademark.

SELECTED REFERENCES

REVAMP TYPE	CUSTOMER
Increase hydrocracker conversion for increased middle distillates yield	Grupa LOTOS's Gdańsk refinery, Poland
Reduce hydrocracker conversion for base oil production	Hyundai Oilbank's Daesan refinery, South Korea
Maintain hydrocracker conversion; increase middle distillates capacity	Valero's St Charles refinery, USA Valero's Louisiana refinery, USA Marathon's Garyville refinery, USA PREEM AB's Preemraff Lysekil refinery, Sweden
Increase hydrotreater middle distillates yield	TAIF-NK's Nizhnekamsk refinery, Russia
From full conversion to partial conversion for ethylene cracker feed	Shell Deer Park Refining Ltd's Deer Park refinery, USA
Convert diesel hydrotreater to mild hydrocracker for increased middle distillates capacity	OJSC Naftan's Novopolotsk refinery, Belarus
Add distillate dewaxing to produce winter diesel	S-Oil Corporation's Onsan refinery, South Korea Gazprom Neft's Omsk refinery, Russia

DESIGNING A REVAMP TO MEET YOUR SPECIFIC BUSINESS DRIVERS:

7 SEVEN SCENARIOS

A review of more than half a dozen recent revamp projects demonstrates that they are driven by a broad range of business objectives, some of which are described below.

SCENARIO A: INCREASING CONVERSION TO INCREASE MIDDLE DISTILLATES YIELD

Maximising the middle distillates yield is a goal many refineries worldwide share. Many, though, cannot increase their hydrocracker feed rate, so they will likely look at improving the conversion instead.

That was the situation for the Grupa LOTOS refinery in Gdańsk, Poland. In its first cycle, the refinery increased the conversion rate of its hydrocracker from 60 to 85% to produce more jet fuel and Euro 5 diesel. In this case, there was much more value in converting the bottoms to distillates than in selling it as feed to a fluidised catalytic cracking unit.

SCENARIO B: REDUCING CONVERSION TO EXPLOIT HIGH LUBRICANT BASE OIL MARGINS

Although middle distillates often provide a higher-value product stream, the economics in some regions are better for lubricant base oils. So, while Grupa LOTOS was revamping to increase conversion, Hyundai Oilbank was revamping the hydrocracker at its Daesan facility in South Korea to reduce it. The plant had originally been designed and started up at full 98% conversion. It subsequently reduced the conversion to 70% and sold the bottoms product as base oil feed. However, the margins that it was recouping on its own lubricant base oils business prompted Hyundai Oilbank to reduce this further to 50% to accommodate the shift from middle distillate production to its own new base oil plant (see page 10).

In China, CNOOC realigned routing of the hydrocarbon streams at its refinery in Guangzhou Province to take advantage of the premium on base oils. In this case, the operator was switching away from petrochemical products. Shell Global Solutions had originally installed an 80,000-bbl/d, dual-service hydrocracker at 85% conversion where the bottoms were running to the ethylene cracker at the Nanhai petrochemicals complex. Now, the bottoms are routed to the base oils plant across the fence because there were better margins in base oils than in chemicals. A key enabler to this was the high quality of the hydrowax that comes from the Shell hydrocracker.

SCENARIO C: PROVIDING ADDITIONAL PETROCHEMICAL FEEDSTOCKS

Like CNOOC's Guangzhou refinery, many other refineries are also integrated with a neighbouring petrochemical facility. One Shell refinery had a 98%-conversion, two-stage diesel hydrocracker, but management commissioned a revamp to respond to the enhanced petrochemical margin. It is now running at twice the capacity and a lower percentage conversion to make ethylene cracker feedstock (see page 13).

SCENARIO D: MAINTAINING CONVERSION; ADDING MIDDLE DISTILLATES CAPACITY

In the previous scenarios, the refiners were adjusting the conversion of their hydrocrackers but, of course, other parameters can be tuned instead. For example, Valero, North America's largest refiner, originally built a 50,000-bbl/d, two-stage hydrocracker at each of its refineries in St Charles, Louisiana, and Port Arthur, Texas. Subsequently, it has revamped both of them to increase capacity towards 75,000 bbl/d to benefit further from the booming market for distillate products.

Marathon Oil Corporation has responded in a similar way. It revamped the hydrocracker at its Garyville refinery in Louisiana, to increase its capacity from 77,000 to 115,000 bbl/d. Marathon Oil maintained the same conversion level (80–85%) but increased the feed rate to generate more barrels of jet and diesel. Both of these expansion projects solved their hydraulic and heat balance constraints through cost-effective, low-cost revamps involving replacing the heat exchangers, small heaters and pumps. ▶

SCENARIO E: INCREASING MIDDLE DISTILLATES CAPACITY BY CONVERTING A MILD HYDROCRACKER

To increase capacity at minimum capital cost, reusing redundant equipment can often be a highly effective response. For instance, OJSC Naftan's Novopolotsk refinery in Belarus added an available reactor to one of its hydrotreating units and, with the increased catalyst volume, raised the conversion, thus creating a mild hydrocracker. Shell's state-of-the-art reactor internals were added to both reactors with new-generation pretreatment and cracking catalysts from Criterion. The revamped unit was able to achieve up to 60% conversion of the 370°C-plus heavy atmospheric gas oil and light vacuum gas oil fractions.

SCENARIO F: COST-EFFECTIVELY RESPONDING TO MARKET DEMAND FOR WINTER DIESEL

Many refiners are keen to produce winter diesel that has specific cold-flow properties, as it can attract a price premium. This can be achieved in several ways, but the economics can vary substantially. A revamping project that involves the installation of catalytic dewaxing capability can often provide a better economic return than additivation or kerosene blending, for example. That was certainly the case at the Gazprom Neft refinery in Omsk, Russia. Reusing a redundant reactor as a second-stage dewaxing reactor enabled it to produce higher-quality winter and extreme-winter-grade diesel fuels at minimum capital cost and with minimum changes to the process configuration.

SCENARIO G: ADAPTING TO PROCESS HEAVIER FEEDS WITHOUT COMPROMISING ON CYCLE LENGTHS

Many refiners are having to run heavier feeds such as heavy coker gas oil, heavy vacuum gas oil and deasphalted oil. This is due to the industry trend for increased fuel oil conversion and processing crudes with higher portions of 370°C-plus fractions. However this can lead to operational problems such as fouling that can curtail cycle lengths. Nevertheless, S-Oil was able to avoid such problems at its Onsan refinery in Ulsan, South Korea by adding Shell's state-of-the-art reactor internals to both reactors, along with new-generation pretreatment and cracking catalysts from Criterion.

KEY TAKEAWAY

These examples demonstrate that every revamp project is unique and should be carefully tailored towards a refiner's specific situation. Should you process heavier feeds? Should you increase conversion or reduce it? Could you improve the yield of middle distillates, petrochemicals or lubricant base oils? The answer will depend on your business objectives, assets and the dynamics of the markets you serve. Moreover, your margin drivers are likely to change over time.

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REVAMPING NEW UNITS

Many of the projects described in this supplement are revamps of newly installed hydrocrackers. Why would a refiner invest additional capital in a new unit that is still in its first cycle?

As much as six years can elapse from completing the configuration study to the unit starting up and much can change in that time. Market conditions may have shifted or there may have been changes in emissions legislation or product-quality specifications. For example, if the market demand for middle distillates has outstripped the initial forecasts, the owner may be keen to increase capacity or, if some product streams are achieving an unanticipated margin, modify for a different product slate.

Shell Global Solutions has worked with several refiners, including, for example, Valero and Marathon, to revamp their newly started up hydrocrackers. These projects made relatively small adjustments but their impacts were substantial: they ensured that the new assets continue to be relevant to the prevailing market conditions and provide substantial bottom line benefits.

TECHNOLOGY FOCUS

Revamping an existing hydrocracker or hydrotreater is substantially more complex than building a new one and is a highly specialised area that calls for advanced process engineering skills and wide-ranging operating experience. A selection of the actions taken during a revamp is shown below.

New technologies may be installed, including:

- state-of-the-art reactor internals that can enable a greater catalyst volume to be loaded into the reactor;
- latest-generation catalysts to help improve product yields and cycle lengths;
- high-capacity distillation trays to help improve throughput cost-effectively;
- additional rotating equipment, such as turbines, pumps and compressors, to support the increased capacity; and/or
- higher-capacity relief valves to help remove hydraulic constraints.

A revamp may require operational changes, for example:

- realigning the process configuration to modify the conversion;
- optimising the feedstock selection and preparation; and/or
- running the unit to the limit of its design constraints to achieve capacity creep.

Studies and reviews often are required, including:

- dynamic simulations for reactor thermal stability checks during normal and upset conditions; and/or
- material reviews of corrosion rates in, for example, wash-water loops and fired equipment.

Existing equipment is not replaced unless there is a strong economic case, so recycle gas compressors and recycle gas turbines, for example, are rarely replaced. Moreover, care is taken to avoid the additional duty triggering the need for more steam-raising capacity.

HOW TO MAKE ROBUST INVESTMENTS IN TODAY'S VOLATILE, CAPITAL-CONSTRAINED MARKET

Amid the backdrop of today's harsh refining landscape, most refiners have a clear aspiration of where they want to get to, but many are often less clear about what they need to do to get there. For instance, there is a wide range of options for them to consider when evaluating what project they should select, what kit they should install and what configuration changes they should make. Moreover, the economics of each option may ultimately prove to differ enormously, depending on how the mid- to long-term market dynamics play out.

So what steps should a refiner take to make a robust investment? At Shell Global Solutions, we typically deliver more than 10 investment planning studies per year for refineries and petrochemical plants around the world. The first step, according to our methodology, is to have a view of the future market. What crude price should you use in your calculations? Which products will be in highest demand? Will the product specifications in your markets and environmental legislation tighten further?

For instance, in 2020 for Europe and in 2025 for the rest of the world, the sulphur specifications for bunker marine fuels will shift from 3.5 to 0.5%. The potential consequences of this are that demand for high-sulphur fuel oil may collapse, which will have an immediate impact on its price. Clearly, market trends and events such as this must be considered in any investment scenario. The impact on different businesses will vary according to, for example, their asset base and the markets they serve. Consequently, the solution will be different too. In that respect, it is particularly important to establish the so-called margin drivers of a site. Why are we doing business? Which products, units and supply and trading options generate the most value?

The client's overarching strategic considerations and objectives are built into this analysis. Once there is an agreed set of

> "IT IS PARTICULARLY IMPORTANT TO ESTABLISH THE SO-CALLED MARGIN DRIVERS OF A SITE. WHY ARE WE DOING BUSINESS? WHICH PRODUCTS, UNITS AND SUPPLY AND TRADING OPTIONS GENERATE THE MOST VALUE?"

premises and we have defined the sensitivities to be tested and the desired flexibility, we work with them to develop a list of all the investment options that could help the customer to achieve their objectives: a task that calls for considerable experience and industry insights.

Let us take a simple example in which a refiner has determined that it must respond to market changes by increasing middle distillates capacity. It could build a new unit, revamp an existing unit, upgrade to a higher-activity desulphurisation catalyst or improve the refinery's hydrocarbon management in another way. But which option would be the best fit for that specific refinery?

Screening those options requires detailed technical and economic evaluations. Capital cost estimates are made using an extensive projects database. Operating costs are estimated using operating experience and best-in-class benchmarks. A scenario-based approach is applied so that the selected option is robust under a wide range of economic circumstances. This is then taken for development into a firm investment proposal: one that aligns with the client's long-term vision and overarching strategic objectives.

If a business were to launch a capital project without such an in-depth evaluation of what each option involves, substantial value could be at risk. A seemingly value-adding project could potentially turn into a poor investment decision, especially if integration opportunities are overlooked during the early phases. A key consideration is whether all the existing units will be able to cope with the streams coming from the new assets. For instance, can an existing gas oil hydrotreater deal with some light coker gas oil or is a new unit required?

Likewise, additional hydrogen is likely to be required, but how much and from where will it come? Can you expand the hydrogen plant or implement hydrogen recovery, or should you contract a hydrogen supplier? There are usually many different options, but the economics can vary substantially.

Similarly, although most revamps do not significantly increase the demand on utilities, it is important to confirm that the existing utilities system has sufficient capacity. For example, there have been cases in which owners have discovered at a very late stage that the existing boilers could not cope with the extra demand. Consequently, the owners had to either dial down their operations or add an additional boiler at considerable expense.

In recent years, many refiners have had to reduce the sulphur levels in their diesel from 50 to 10 ppm. This often requires a revamp of the hydrodesulphurisation unit involving the replacement of the existing reactor internals with state-of-the-art reactor internals for improved catalyst utilisation and using a more active catalyst. That, however, is only part of the story. The refiner must also look carefully at the impact on the rest of the refinery. For instance, the higher concentration of hydrogen sulphide in the reactor section means that the wash-water facilities may need upgrading and that the amine treating and sulphur recovery units need checking and possibly revamping. It is vital that all these changes are also included in the evaluations.

Substantial value can be won or lost during front-end development. No matter what your business objectives are, there is likely to be a wide range of potential responses and it is important to consider them through a range of operational and strategic lenses.

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BACKWARD INTEGRATION MOVES HYUNDAI FORWARDS

When striving to increase the throughput of a hydrocracker or other conversion unit, the amount of vacuum gas oil (VGO) that the high-vacuum unit (HVU) can generate is often a critical constraint. To overcome this, some refiners lift more from the short residue into the VGO, but that brings with it metals and other contaminants that can affect the conversion unit's reliability. Fortunately, with Shell's deep-flash technology, the VGO yield of an HVU can often be increased substantially without affecting the downstream units' reliability through a low-cost revamp, as a recent project for Hyundai Oilbank demonstrates.

> WE WERE VERY IMPRESSED WITH THE QUALITY OF THEIR SOLUTION AND THEIR RESPONSIVENESS.

When Hyundai Oilbank conceived the notion of building a 20,000-bbl/d Group II base oil manufacturing plant, its integration with the adjacent Daesan refinery in South Korea was key. To make the project work, Hyundai Oilbank needed to revamp the hydrocracker to provide the right amount of feed at the right quality. However, even after doing that, the hydrocracker would be short by about 5,000 bbl/d, but the Shell Global Solutions team identified an opportunity to produce additional feedstock for the hydrocracker by going further back into the processing stream and revamping the HVU.

"We identified various ways in which Hyundai Oilbank could get more VGO to the hydrocracker," explains Kaushik Majumder, Team Lead and Licensing Technology Manager – Distillation, Shell Global Solutions. "Essentially, these centred on two main options. The first was a major revamp of the existing vacuum distillation unit (VDU) to convert it to a deep-flash HVU. The second involved a minor revamp of the VDU and adding a new deep-flash HVU in parallel to co-process atmospheric residue (AR) and vacuum residue (VR) from the VDU."

Shell Global Solutions conducted cost–benefit analyses of these options. Hyundai Oilbank then selected the option involving a major revamp, as this provided the lowest-capital-cost option, but, says Majumder, it was also the most technically challenging and the riskiest in terms of the project economics owing to the potential for significantly extending the planned turnaround of the crude distillation unit (CDU) and the HVU.

The changes made to the refinery configuration through the HVU revamp are explained in Figure 1 (overleaf).

"The biggest limitation was the furnaces," says Majumder. "Hyundai Oilbank had two furnaces feeding the existing HVU and to meet the project goals we needed to increase their duty significantly. So, we revamped both extensively, including adding tubes in the convection section and switching completely to gas firing instead of dual-fuel firing. This was critical to the success of the project."

Other important changes were upsizing the transfer line and the column feed inlet nozzle. The team also replaced the existing vapour horn type feed inlet device with a Shell Schoepentoeter* Plus inlet device (see boxed text overleaf) to reduce the entrainment of VR to VGO (hydrocracker feed) and to ensure better vapour distribution. "This was very important for the performance of the unit because we were almost at the maximum limit of the transfer line velocity," says Majumder.

In addition, the team took all the possible steps to minimise the vacuum column pressure drop to help maximise distillate yield. The pumparound and wash-bed packing were replaced with the latest-generation, low pressure drop structured packing and the existing chimney trays were replaced with Shell's proprietary low pressure drop draw-off trays.

The team also installed new spray distributors and made minor plant modifications outside the column to support the main revamp, such as upgrading the heat exchangers, pumps etc.

"Unlocking more barrels of VGO from the HVU was key to the economics of our lubricant base oils project because the HVU and the hydrocracker are configured to work with the new base oil plant as a value chain," says Dalho Kang, Refinery Manager, Hyundai Oilbank.

"Shell Global Solutions provided us with a detailed set of creative options that would help us to unlock more barrels of VGO from the HVU and then went on to evaluate each one against our objectives. Once we had selected our preferred option, they licensed the technology to us and guaranteed its performance. We were also very impressed with the quality of their technology solution and their responsiveness," Kang concludes.

The execution of the HVU revamp by Hyundai Oilbank was exceptionally efficient. The full scope was delivered within the budgeted days and cost, which confirmed that the full revamp option was the best decision for this project. After start-up, all the performance guarantees, including VGO yield and quality, were fully met.

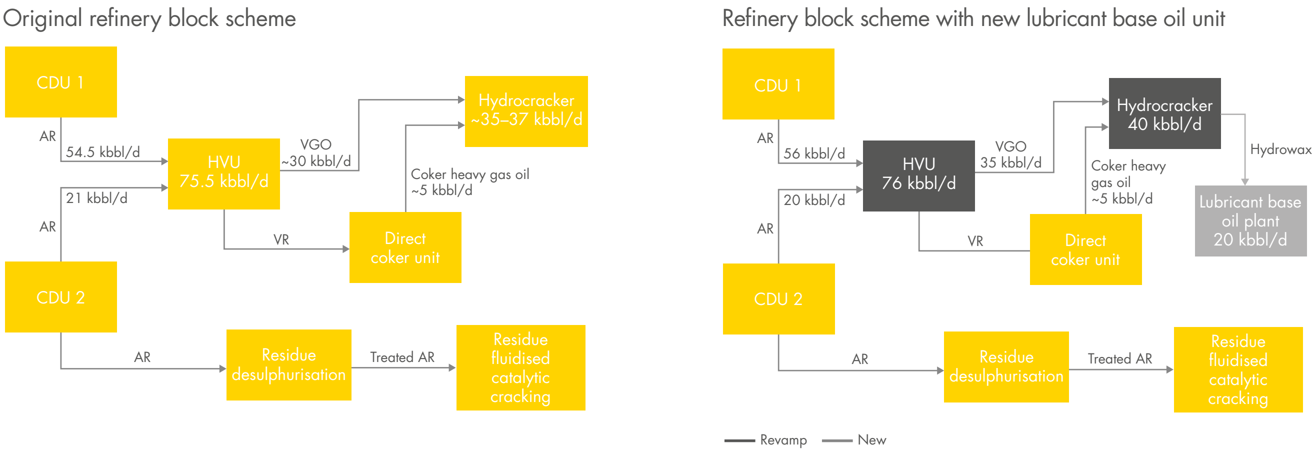


Figure 1: The refinery block scheme before (left) and after (right) the HVU revamp.

MINIMUM-SCOPE VERSUS MAXIMUM-SCOPE HVU REVAMPS

Many refiners have a strategic need to maximise the throughput of their conversion units and an HVU revamp can often be an extremely attractive solution. But some are often unaware that the scope of such a project can vary enormously according to the unit's current bottlenecks and the customer's specific objectives, writes Kaushik Majumder, Team Lead and Licensing Technology Manager – Distillation, Shell Global Solutions.

"In my opinion, no HVU could be revamped more than Hyundai Oilbank's. We really pushed at the limits of what is achievable. But some projects do not need to push as hard and can achieve their objectives through a relatively simple revamp in which we only introduce a new feed inlet device and change the wash bed. We would call that a minimum-scope revamp.

For example, we recently worked with a non-Shell refinery in India where the VGO yield was limited owing to excessive entrainment of metal from the short residue. Unlike at Hyundai Oilbank, we found that changes would not be required to the furnace and most of the packing could stay. They wanted to produce more VGO and had the capacity in the column, furnace and transfer line to do so. Revamping this unit only required modifications to the column internals and replacing the existing feed inlet device with a Shell Schoepentoeter Plus.

We implemented these changes within the turnaround window, and our customer has reported that the unit now generates 8% more VGO of the desired quality.

Whether the project involves maximum scope, minimum scope or something in-between, an HVU revamp can often be an extremely compelling project. Typically, the capital cost is relatively low, the payback time is short and the hardware changes can often be made within an existing refinery turnaround window.

Having said that, HVU revamps can often be very challenging and, if they are not engineered properly, it may be impossible to meet the desired revamp objectives. At Shell Global Solutions, we have delivered almost 50 new designs or revamps since 1985 and that track record brings with it invaluable experience."

For more on minimum-scope HVU revamps, see page 22.

THE SHELL SCHOEPENTOETER PLUS

The Shell Schoepentoeter Plus is a key component that Shell Global Solutions has introduced in most of its HVU revamps since the device was developed in 2010. This is an advanced version of the Shell Schoepentoeter, a versatile, low pressure drop, vane-type feed inlet device. The conventional device has proven to be one of the most effective technologies available on the market for efficient de-entrainment in critical services such as deep-cut vacuum distillation and the new "plus" device provides yet more efficient de-entrainment, especially at higher vapour loadings, owing to its innovative vane design for minimising liquid re-entrainment.

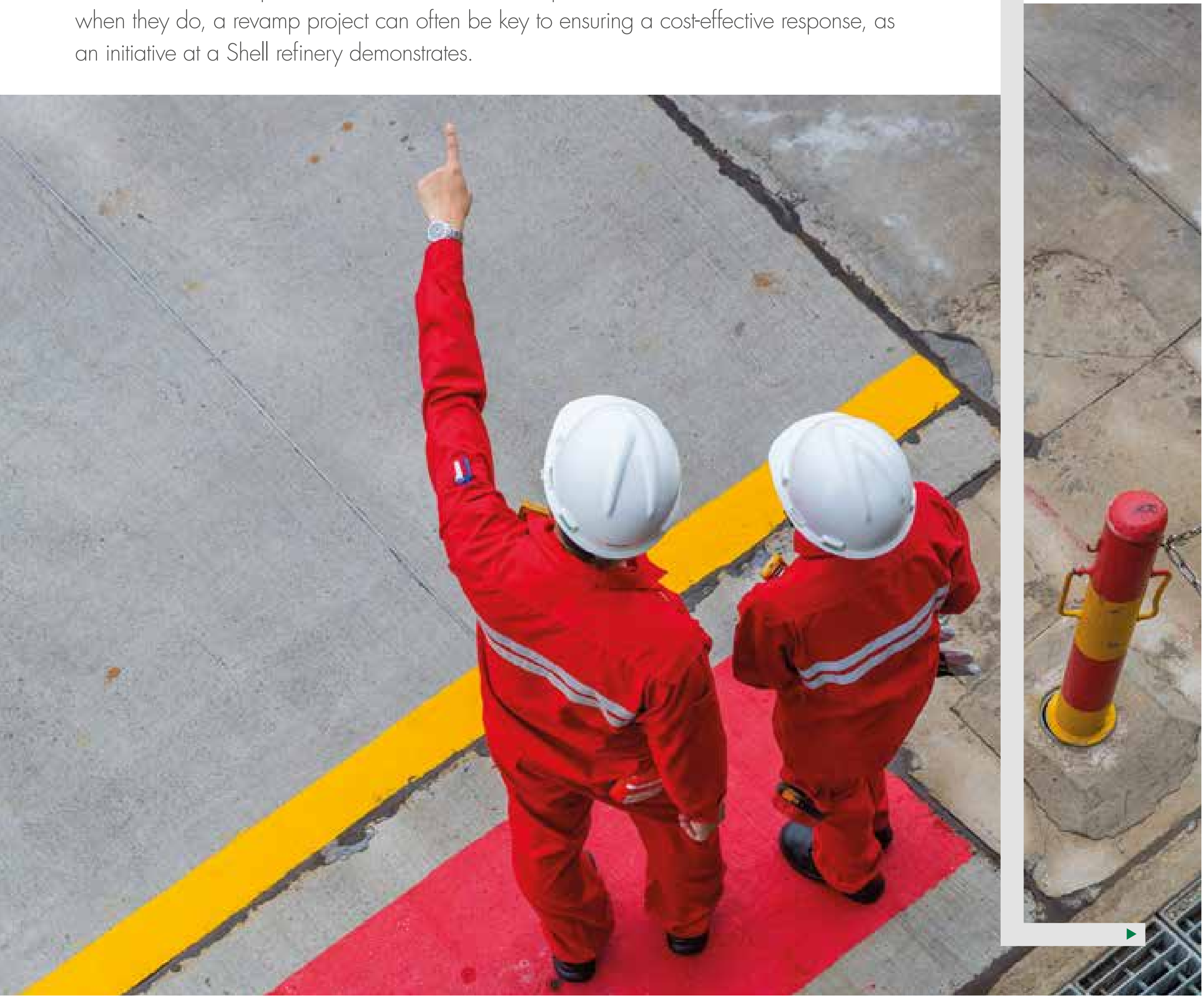
This technology has an excellent track record. For example, a recent inspection of a Shell Schoepentoeter Plus in a deep-cut vacuum column in 2010 revealed it was mechanically and functionally robust after five years of on-target performance.

*Schoepentoeter is a Shell trademark.

ADJUSTING THE MODE OF OPERATION:

HOW AND WHY THE HYDROCRACKER AT A SHELL REFINERY WAS REVAMPED FROM A TWO-STAGE TO A SINGLE-STAGE CONFIGURATION

Excellence in refining is dynamic. When external conditions change, as they inevitably will, refiners need to adapt to ensure that their mode of operation continues to be relevant. And when they do, a revamp project can often be key to ensuring a cost-effective response, as an initiative at a Shell refinery demonstrates.



The hydrocracker was originally designed by Shell in the 1980s as a full-conversion unit with a two-stage configuration geared towards middle distillate production. In response to growing demand for middle distillates, the unit's capacity was later increased to about 167% of the design capacity, though it still operated as a two-stage unit.

However, increasing demand for petrochemicals and an enhanced petrochemical margin provided the triggers that led to Shell changing the hydrocracker's mode of operation.

To increase its petrochemicals capacity, the company intended to build an ethylene cracker in the adjacent petrochemicals plant, so it commissioned Shell Global Solutions to help plan the investment and to understand and evaluate its technical and operational options.

It was during this review that Shell Global Solutions' strategic planners identified that the economics of the refinery and the petrochemicals site could be greatly enhanced by adapting the hydrocracker to produce large amounts of unconverted oil (hydrowax), which could be used as ethylene cracker feedstock.

So, working with the refinery's management, Shell Global Solutions devised a plan to revamp the hydrocracker into two parallel, single-stage reactors (see figures 1 and 2) operating at reduced conversion, but with an increased fresh feed capacity of some 300% of the original design capacity and a catalyst cycle length of two years. The revamped hydrocracker has retained the common recycle gas compressor, the high- and low-pressure-separators, and the common distillation section.

As with any revamp, it was critical to explore the impact on the existing major equipment. Consequently, Shell Global Solutions undertook a technical feasibility study to understand the impact of these changes on the unit's hydraulics and heat and material balances. The study concluded that the project was viable, although there were concerns regarding hydrogen partial pressure, recycle gas purity, recycle gas compressor performance and sour water corrosiveness.

Further investigations confirmed the requirement for a recycle gas hydrogen sulphide scrubber and increased wash-water make-up flow. The engineering study concluded that several generally low-cost modifications were necessary. For example, in the hydrocracking reactor the project team:

- fitted an additional feed filter to accommodate the higher feed rate;
- installed Shell reactor internals to increase the catalyst volume and utilisation;
- increased the fresh gas compressor capacity to cope with the increase in hydrogen consumption;
- modified the water booster pumps and increased the wash-water make-up to minimise the ammonium bisulphide concentration in the sour water phase of the cooled reactor effluent;
- adapted the recycle gas compressor and turbine to increase the recycle gas flow, which was required to meet minimum gas–oil ratios; and
- installed a new recycle gas amine scrubber to improve recycle gas hydrogen purity and ease hydraulic constraints.

"THIS HYDROCRACKER REVAMP PROJECT PROVIDES AN EXCELLENT EXAMPLE OF HOW MAKING THE MOST OF EXISTING ASSETS CAN SUPPORT A CHANGE IN A REFINER'S BUSINESS DRIVERS."

OVERCOMING CHALLENGES

Robert Karlin, Hydrocracking Team Lead, Shell Global Solutions, has extensive experience of hydroprocessing design. He and his team have executed several hydrocracker revamps. He explains that the second-stage feed system and high-pressure reactor circuit can present significant challenges when converting to a new service. "These had originally been designed to process 'clean' fractionator bottoms that contained almost no sulphur or nitrogen contaminants," he says. "The second-stage reactor had originally been designed with a cracking catalyst system for conversion, so it was going to see a major change in feedstock: fresh vacuum gas oil containing sulphur, nitrogen, Conradson carbon and metals."

"It was a major challenge to design a functional demetallisation, pretreatment and cracking catalyst system within the existing second-stage reactor," Karlin continues. "And, because of the significantly higher level of sulphur and nitrogen entering the unit, we carefully evaluated the entire wash-water system to ensure that the cold section of the unit (from reactor effluent air cooler through to the fractionation system) is adequately protected against corrosion."

In support of the process revamp study, a pilot-plant testing programme was carried out at Shell Technology Centre Amsterdam to compare the performance of the original design basis catalyst system against three alternatives that Criterion Catalyst & Technologies had proposed. From these results, the refinery's management was able to select the option that provided the best fit for its objectives.

Since the unit started up in the new single-stage mode in 2010, it has delivered both the quantity and quality of hydrowax required for the ethylene cracker.

"This hydrocracker revamp project provides an excellent example of how making the most of existing assets can support a change in a refiner's business drivers," says John Baric, Licensing Technology Manager, Shell Global Solutions. "In this case, we adapted the mode of operation of a hydrocracker that had been in operation for nearly 30 years in order to support the economics of a major new project. Consequently, this cost-effective revamp has had a major impact on the economics of the wider enterprise."

Pre-revamp two-stage configuration

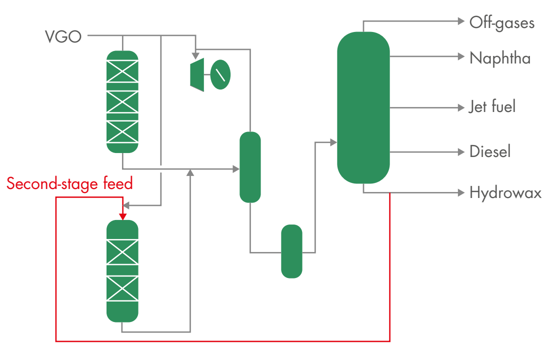


Figure 1: Before the revamp, the hydrocracker had a two-stage configuration. It was operating at 167% of the original design capacity and focused on middle distillate production.

Post-revamp single-stage configuration

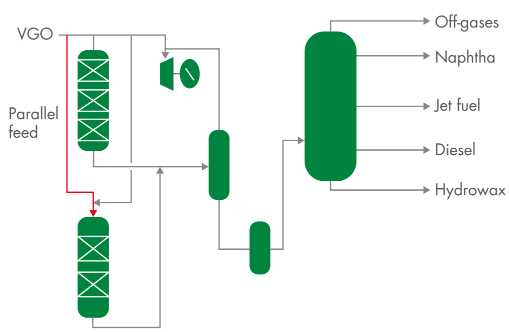


Figure 2: The revamped hydrocracker operates with the two original reactors in parallel. It has a feed rate of 300% of the design capacity and about 70% of its output is hydrowax, which is fed to the ethylene cracker.

S-OIL'S JOURNEY TO

HYDROCRACKING HIGH PERFORMANCE

Some revamp projects can be triggered by a strategic need to change the product mix, but often the trigger is more straightforward, for example, the desire to enhance performance. This was the case at S-Oil's Onsan refinery in Ulsan, South Korea. This leading refiner was dissatisfied with the cycle length of its hydrocracker, and installing Shell reactor internals and next-generation catalysts from Criterion Catalysts & Technologies (Criterion) proved to be a robust, high-value solution. S-Oil calculates the value to its operations as in excess of $20 million a year.

S-Oil's Onsan facility is the fifth largest refinery in the world[1] and has an extremely complex configuration that includes a hydrocracker, a residue fluidised catalytic cracking unit, an aromatics complex and a state-of-the-art lubricants base oils plant. This enables it to produce high-value light oil products such as gasoline, diesel and kerosene, as well as petrochemicals and group 2 and 3 lubricants base oils.

With a corporate goal of becoming the most competitive oil refiner in Asia Pacific, S-Oil is continually striving to maximise its performance and profitability. So, when the cycle length of its hydrocracker was curtailed, management took steps to rectify the situation by working with Criterion and Shell Global Solutions.

The single-stage, two-reactor, 170-bar, 75,000-bbl/d hydrocracker was originally licensed from another vendor. The unit's most valuable output is unconverted oil, which is routed to the wax hydroisomerisation unit and then the hydrofinishing unit to make Group 3 base oils. It also produces large amounts of middle distillates and smaller quantities of less-valuable liquefied petroleum gas and naphtha.

S-Oil had desired a cycle length of 36 months but the unit had only achieved 32 months in the previous cycle and other cycles had been even shorter. Pretreatment limitations meant that, at the end of run, the unconverted oil quality tended to decline. Consequently, S-Oil had to derate the base oil unit to maintain product quality and there was little opportunity for deeper processing of vacuum gas oil (VGO).

[1] www.hydrocarbons-technology.com/features/feature-top-ten-largest-oil-refineries-world

Meng Loong Chua, Senior Technical Service Engineer, Criterion Catalysts & Technologies, was part of the team that investigated the unit. He explains that, on the pretreatment portion, the existing catalyst was suboptimal in stability and losing activity too quickly over the cycle. There was also suboptimal catalyst utilisation that resulted in the short cycle length. "We found that there was a high radial temperature spread over the catalyst beds," he says. "This indicates low uniformity of vapour–liquid distribution and suggests that the catalyst bed is not being used efficiently, which can shorten cycle life." In the cracking reactor, there was extra activity left in the last cycle and this provided the opportunity to optimise the cracking catalyst towards more middle distillate production and better hydrogenation for the unconverted oil production.

To address these issues, the team replaced the internals in both the hydrocracker's reactors. The new hardware that it fitted included Shell high dispersion (HD) trays, Shell ultra-flat quench (UFQ) interbed internals, Shell catalyst support grids and Shell bottom baskets (see box, Reactor internals for S-Oil's Onsan refinery, page 19).

In addition, Criterion tailored a stacked-bed catalyst system that was designed to deliver balanced activity and selectivity, an optimal product slate and significantly better-quality unconverted oil. This was informed by a series of pilot plant tests that used S-Oil's actual feeds (see box, Stacked-bed catalyst system for S-Oil's Onsan refinery, page 19).

VALUE DELIVERED

Since the change to Criterion catalysts and Shell reactor internals, conversion at the unit can be lowered to increase the yield of unconverted oil, which is more valuable, while meeting the required product quality.

The unit has demonstrated exceptional selectivity towards the products that are most important for S-Oil. As shown in Table 1 (overleaf), compared with the previous cycle, the yield of the less valuable products, liquefied petroleum gas and naphtha, decreased by 0.5 and 6.8% respectively. Unconverted oil from the hydrocracker (which is fed to the base oil plant) increased, which increased the yield of base oil products by 7.1%. The distillate yield remained similar. In addition, hydrogen consumption fell and catalyst stability improved.

Key to these results is the unit's improved temperature performance and the catalyst package. As shown in Figure 1, the weighted average bed temperature (WABT) is substantially lower in the post-revamp cycle than in the pre-revamp cycle.

Mr Tae Sung Yang, Process Engineering Manager, S-Oil, is responsible for the unit's operations. He says, "The combined team of technologists from S-Oil, Shell Global Solutions and Criterion unlocked major benefits for the economics of our refinery. We have calculated it to be more than $20 million a year."

"After installing the new catalyst system and reactor internals, the unit achieved the 36-month cycle length that we had targeted – the first time that it had ever done so," he continues. "In addition, we have been able to increase base oil production and to treat heavier feeds. Based on the success of this project and on the excellent working relationship that we have established, we are currently evaluating launching another revamp project with Shell Global Solutions and Criterion." ▶

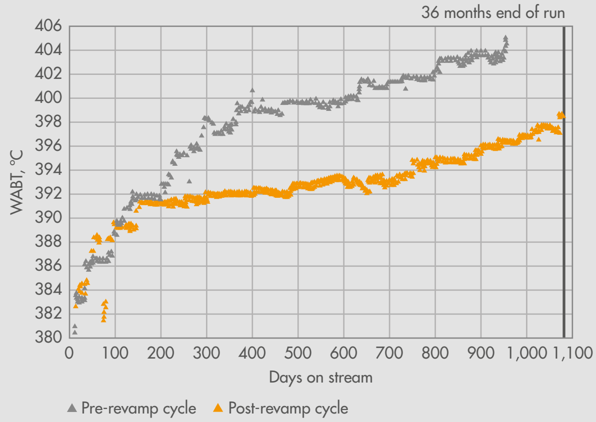


Figure 1: The revamped unit has displayed enhanced temperature performance in its first cycle compared with the last cycle before the revamp.

VOL% YIELDS	POST-CYCLE REVAMP
Liquefied petroleum gas	Base –0.5
Naphtha	Base –6.8
Kerosene	Base –2.4
Diesel	Base +1.9
Base oil – light grade #1	Base
Base oil – light grade #2	Base +0.6
Base oil – medium grade	Base +3.9
Base oil – heavy grade	Base +2.6
Base oil product yields	Base +7.1

Table 1: After the new reactor internals and catalysts were installed, naphtha yield decreased by 6.8% while the yield of base oil products increased by 7.1%.

> AFTER INSTALLING THE NEW CATALYST SYSTEM AND REACTOR INTERNALS, THE UNIT ACHIEVED THE 36-MONTH CYCLE LENGTH THAT WE HAD TARGETED – THE FIRST TIME THAT IT HAD EVER DONE SO.

STACKED-BED CATALYST SYSTEM FOR S-OIL'S ONSAN REFINERY

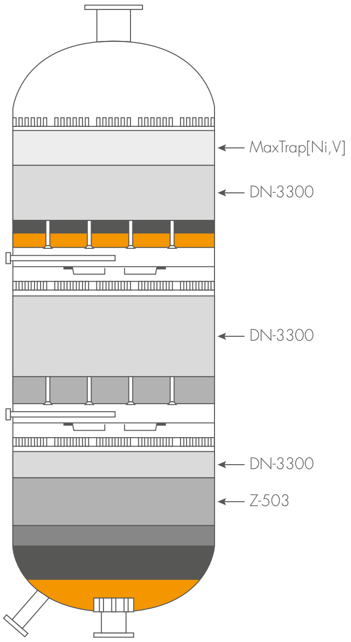


Figure 2: The pretreatment reactor.

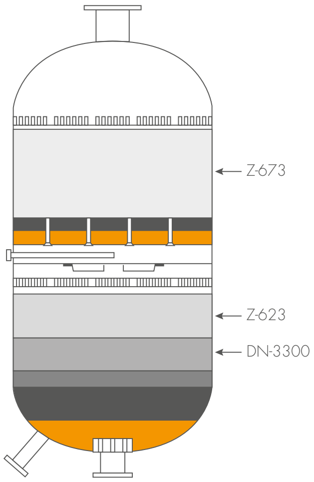


Figure 3: The cracking reactor.

Criterion developed a tailored, stacked-bed catalyst system for the unit. At the top of the pretreatment reactor (Figure 2), MaxTrap[Ni, V] is used to trap the nickel and vanadium in the VGO. Then a combination of CENTINEL Gold DN-3300 and Z-503, specially selected for their ability to remove nitrogen and to provide a viscosity index boost, are used for pretreatment.

In the second reactor (Figure 3), Z-673 was selected for its excellent hydrogenation properties and Z-623 for its selectivity towards distillates.

REACTOR INTERNALS FOR S-OIL'S ONSAN REFINERY

S-Oil installed a set of state-of-the-art reactor internals from Shell Global Solutions that includes:

- **Shell HD trays**, which help to optimise catalyst utilisation by achieving enhanced vapour–liquid and thermal distribution, and utilise nearly 100% of the catalyst inventory (Figure 4);
- **Shell UFQ interbed internals,** which provide uniform gas–liquid redistribution and quench mixing between catalyst beds;
- **Shell catalyst support grids,** which feature support beams and a grid screen that utilises a wedge-wire construction that is less prone to foulant build-up and clogging; and
- **Shell bottom baskets,** which are designed to be extremely flat in order to increase the loading of catalyst in the bottom dome.

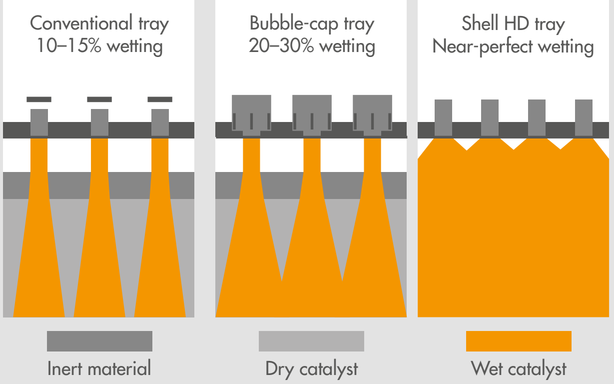


Figure 4: Shell HD trays incorporate proprietary nozzles that can help to maximise catalyst utilisation.

HYDROTREATER REVAMP

PUTS TAIF REFINERY AHEAD OF DIESEL REGULATIONS

Upgrading an existing hydrotreater boosts capacity by 50% and enables refinery to produce Euro 5 quality diesel

When new diesel quality specifications were on the horizon in Russia, the TAIF-NK refinery in Nizhnekamsk, Tatarstan, needed to find a way to adapt its operations cost-effectively to produce ultra-low-sulphur diesel. "We were driven by the need to produce low-sulphur diesel to meet forthcoming environmental legislation and by the economic benefits of improving the quality of the fuel," says Rashit Shamgunov, General Manager, TAIF-NK. "Taxes on poorer quality diesel were increasing, while those for the higher-quality, lower-sulphur product were falling."

"We were keen on utilising our existing assets to minimise investment costs and delivery timescales, so sought an experienced licensor to help us revamp our atmospheric gas oil hydrotreater," adds Igor Bogomazov, Chief Engineer, TAIF-NK.

The Russian government was also gearing up to including domestic heating oil on its list of excisable goods, which enhanced TAIF's desire to eliminate the fuel from its production line-up and to replace it with ultra-low-sulphur diesel.

The original hydrotreater contained Criterion Catalysts & Technologies (Criterion) catalysts. The strong performance of these catalysts led TAIF refinery to approach Shell Global Solutions, which is affiliated with Criterion, for the revamp of the hydrotreater.

"We had a very positive experience with Criterion and were impressed with the performance of its catalysts. These were still performing to their original specification almost 10 years after being installed, despite only having had a guaranteed cycle length of three years," says Anatoly Chekashov, Head of the Development Department, TAIF-NK.

Edmundo van Doesburg, Lead Process Engineer, Shell Global Solutions, who was heavily involved in the revamp project, explains, "We were asked to undertake a feasibility study to determine the best option for upgrading the hydrotreater while TAIF conducted a cost assessment. Following this work, TAIF decided to continue with the project, so the hydrotreater was relicensed to Shell Global Solutions on the basis of its revamp design."

Van Doesburg continues, "As part of the revamp project, we also addressed aspects such as the hydraulic constraints and corrosion problems. TAIF's desire to co-process visbreaker naphtha was a complicating factor and required an extensive revamp of the work-up section to maximise the diesel yield while meeting the flashpoint specification without defaulting to a costly, energy-intensive atmospheric fractionator."

Utilising as much of the existing equipment as possible and ensuring that any work would fit in with the normal operations of the refinery were key considerations for the revamp project. "We needed to keep investment costs down and to tie the upgrade into the operation of the refinery to prevent having to shutdown the hydrotreater and lose valuable production time," Chekashov explains.

Consequently, the work was split into two phases so that it could be carried out during the scheduled 20-day shutdowns of the hydrotreater or while it was still operating. The first stage of the revamp involved installing a new hydrogenation reactor to achieve deeper desulphurisation, new Shell reactor internals, a vacuum stripping column to remove any remaining moisture from the product and new heat exchangers to reduce the thermal input of the unit. This phase of the project was commissioned in June 2012.

The project's delivery timescale was of utmost importance for TAIF, as the environmental conditions, such as weather constraints, had the potential to affect the project development severely. Therefore, the detailed engineering started before the issue of the final basic engineering package, which consequently required adjustments to the standard project schedule.

"A 300-t reactor was ordered that could only be delivered by sea, which put time pressure on the delivery schedule owing to the risk of the river freezing over during the winter months. It was vitally important that the reactor was on-site before the winter, otherwise, the project would have been held up until the following spring," explains Chekashov.

Following the first phase, the team achieved a 30% increase in the unit's capacity to reach 2.015 Mt/y of feedstock. The sulphur content of the diesel produced met the Euro 5 specification of less than 10 ppm.

The second stage renovation kicked off in 2013. This was geared towards making the unit capable of processing all the middle distillates from the refinery and excluding domestic heating oil from the product range. The feedstock pumps at the unit boundary and the pumps for supplying feedstock from the tank farm were replaced. Additional recuperative heat exchangers were included in the circuit and the vacuum splitter column condenser and filtering elements were replaced in the feedstock stream.

This phase of the work lifted the unit's capacity by almost 50% to 2.3 Mt/y while maintaining the same natural gas and steam consumption for the unit. Despite the increased capacity and significant improvement of the fractionation sharpness between the diesel and the naphtha, the overall thermal energy consumption has not increased owing to the improved heat integration.

A strong working relationship between TAIF and Shell Global Solutions, with constant sharing of ideas and plans, was a key factor in delivering these results.

"This was a challenging project that required a lot of internal planning from the refinery with a strong focus on safety," says Bogomazov. "Working together as one team meant that we were able to take a flexible and creative approach to the revamp to overcome space and time constraints."

Finding ways to keep or improve existing pieces of equipment wherever possible also required special planning. TAIF wanted to utilise its existing furnace, so Shell Global Solutions devised a plan to keep it in operation and improve the heat recovery. "As a result of some minor changes to the flow scheme of the heat exchanger, we can now use the heat for other units around the refinery," says Chekashov.

"The level of expertise of Shell Global Solutions' technical specialists was tremendous and we were very impressed with their creativity and advice. For instance, they introduced some interesting ideas, including a furnace bypass, a recycle gas circulating reflux cooler and a vacuum splitter column. When they discussed these ideas with our technical experts, the results were fantastic. That strong working relationship is ongoing," he concludes.

"Many of Shell Global Solutions' suggestions to alleviate the hydraulic constraints, improve heat integration and enhance the fractionation between the naphtha and the diesel products were implemented and have proven very effective and economically stable, for which we are very grateful. Without these creative ideas, we might not have had such a great result," adds Bogomazov.

The approximately $50-million revamp project resulted in an overall increase in diesel fuel production of more than 50% between 2011 and 2014.

"Everything that Shell Global Solutions and Criterion promised is now a reality," Shamgunov concludes. "We were able to begin production of Euro 5 diesel ahead of the new regulations, which boosted our image from the political and environmental standpoints, and brought with it economic gains. The future looks very bright for us."

LOW-CAPITAL-COST REVAMPS OF HIGH-VACUUM UNITS (HVU)

With demand for diesel fuel continuing to increase in many markets, refiners around the world are keen to increase the throughput of their conversion units. Consequently, it is attractive to recover as much hydrocarbon feedstock, such as heavy vacuum gas oil (HVGO), as possible from the atmospheric residue (AR) that is routed to conversion units.

Shell Global Solutions' deep-flash, high-vacuum technology has been developed through extensive research on mass transfer and separation equipment, and has also been supported by operating experience from numerous Shell and Shell-advised units over many years. This technology includes five key design features that can be tailored to meet a refiner's specific revamp requirements. These are the:

1. proprietary furnace coil design;
2. Schoepentoeter* inlet device;
3. wash-oil section design;
4. insulated, low pressure drop draw-off trays; and
5. direct contact condensation sections.

In this article, we profile two HVU revamp projects at European refineries. When scoping these projects, it became clear that both refiners had limited capital and a strong desire to minimise unit downtime, so Shell Global Solutions' consultants, working with the refinery teams, elected to install only a selection of the key design features. This demonstrates the flexibility of the technology.

CASE STUDY 1: INCREASING HVGO YIELD

This refiner's objective was to increase recovery of HVGO from the AR to feed the hydrocracker and, at the same time, improve the reliability of the HVU so that a longer run length, a target four to five years, was achievable between maintenance turnarounds. For this project, the allowable changes were restricted to the HVU column internals. The revamp was successfully executed using Shell Global Solutions' deep-flash technology.

To increase the feed rate to a hydrocracker, more hydrocarbons must be recovered from the vacuum residue (VR). This means that the volume of the HVGO stream must increase, up to acceptable limits of heavy metals (vanadium and nickel) and Conradson carbon residue, for reliable hydrocracker operation.

The modifications were carried out during a routine refinery maintenance turnaround and are described in Figure 1.

*Schoepentoeter is a Shell trademark.

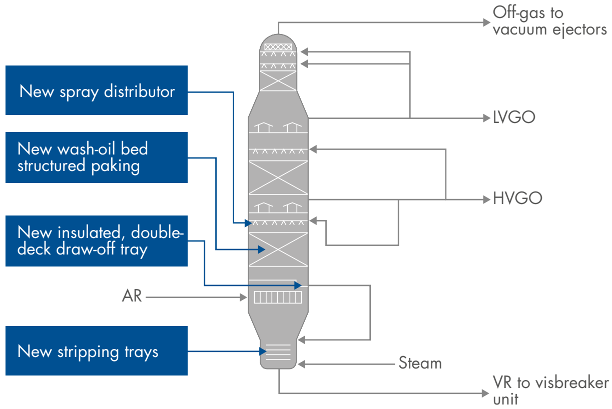


Figure 1: Modifications to the HVU included fitting a new spray distributor, new wash-oil bed structured packing and new stripping trays.

New spray distributor and wash-oil bed

A very common reliability problem for HVUs is coke formation within the wash-oil bed's structured packing. With elevated flash zone temperatures and a deep vacuum, entrainment of VR in the rising feed vapour can cause coke formation within "dry" sections of the bed. This can increase the pressure drop over the wash-oil bed. With a higher pressure drop in the wash-oil bed, the flash zone pressure increases, thus leading to loss of HVGO yield to the VR.

The coke build-up and resultant high pressure drop can only be resolved by stopping the HVU's operation to replace the wash-oil bed's structured packing. A new spray distributor was designed to ensure that there is adequate wetting of the wash-oil bed at all times. The free-passage area of the nozzles is adequate to prevent plugging and fouling. Filters were provided upstream of the spray distributor to remove any large particles that might block the spray nozzles. The spray distributor was also moved closer to the top of the wash-oil bed section to reduce re-entrainment of liquid from the nozzles.

The wash-oil bed itself was replaced with six layers of a higher-capacity structured packing to help avoid VR re-entrainment and reduce the pressure drop over the wash-oil bed.

New, insulated, low pressure drop draw-off tray
Hot vapours from the HVU flash zone rise and contact the underside of the "dirty" wash-oil draw-off tray first. The temperature difference between the draw-off tray and the rising hot vapours can cause condensation of HVGO, which will be downgraded to VR. An insulated, low pressure drop draw-off tray was installed to help minimise this effect, which is known as wild reflux.

New stripping trays
To maximise the recovery of HVGO from the VR, the amount of stripping steam applied at the bottom of the HVU was doubled. The existing ejector system was adequate to handle this higher vapour loading.

High-capacity Shell calming section sieve trays were installed within the existing column insert below the feed location. These trays were sized to handle the increased vapour loading.

CASE STUDY 2: IMPROVING HVGO QUALITY

In this case, the refiner was experiencing poor quality HVGO from the HVU: high metals content and almost daily quality fluctuations. This indicates relatively poor performance from the lower wash-oil zone, which was permitting entrainment of residue to the HVGO, so the revamp focused on this area.

The performance of the HVU lower wash-oil zone system is critical to achieving high vacuum gas oil (VGO) yields with no residue entrainment. HVGO quality is key because contaminants such as metals, Conradson carbon residue and heptane insolubles are all detrimental to the performance of a VGO hydrocracker or hydrotreater. The wash-oil zone system performance relies on the hardware (especially the spray distributor, the draw-off tray and the wash-oil bed), but it is also important to understand how to operate the system for optimum HVGO recovery.

During the planned turnaround, the lower wash-oil zone hardware was changed and post start-up the operation was optimised. Optimising the wash-oil system ensures removal of any VR entrainment in the wash-oil bed so that the HVGO yield can be maximised to ensure ongoing unit reliability.

The revamp helped to improve the HVGO quality, as demonstrated by the nickel content of the HVGO (see Figure 2).

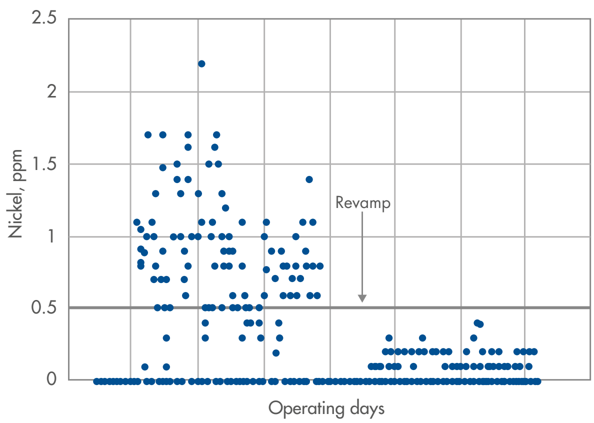


Figure 2: After the wash-oil zone revamp, the level of nickel in the HVGO fell.

KEY TAKEAWAYS

By applying Shell deep-flash, high-vacuum technology, existing HVUs can be revamped at relatively low capital costs. The simple payback times for such revamps are very attractive, and they can be undertaken within an existing turnaround window.

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