Repurposing Existing Hydroprocessing Assets to Maximize Refinery Gross Margin

by
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Abstract

With the economically challenged environment facing our industry, it is absolutely imperative that refiners evaluate their existing assets and look for creative, low capital solutions to identify gross margin improvement opportunities.

Chevron Lummus Global (CLG) with the expertise that comes from its parent companies (Chevron and CB&I as operating and engineering companies) has developed a number of significant revamp opportunities for North American and overseas refiners. In each of the case studies presented, we highlight significant gross margin value capture by utilizing hydroprocessing units with significant catalyst volumes that are repurposed to produce higher margin products. The case studies include the following: (1) Implementing mild hydrocracking catalyst in an existing FCC feed hydrotreater to produce diesel. (2) Increasing conversion on a two-stage recycle hydrocracker with an innovative configuration solution. (3) Converting a hydrocracker that was in Single Stage recycle operation geared for naphtha production into a single stage through operation at higher rates with conversion to middle distillates. (4) Converting a Residuum Desulfurization unit (RDS) into the first stage of a two-stage hydrocracker that maximizes diesel production.

Introduction

The current worldwide economic environment has imposed a reduction in capital expenditure budgets for new expansion. However, despite this economic environment, refiners are still being challenged to meet stringent clean fuels regulations to maintain product quality requirements. Any non-regulation compliance projects are even further scrutinized due to the limited capital available.

Refiners have to think creatively to develop projects that are profitable with return on investments that are subject to a higher level of scrutiny with restrictions on capex. Revamps of existing units can provide the refiner the ability to generate excellent return on investments with restricted and non-regret capital investments.

Chevron Lummus Global (CLG) finds itself in the unique position as a leader of hydroprocessing technologies and catalysts, and as an experienced operator of hydroprocessing units worldwide. CLG is able to offer creative and innovative solutions to aid the refiner in developing revamp projects that achieve the task of meeting future environmental regulations and increase conversion capacity.

Chevron invented the modern hydrocracking process in 1959 and has had an unwavering commitment to the development of all hydroprocessing technologies. The CLG joint venture between Chevron USA and CB&I marries two companies that provide the hydroprocessing technology, operating and engineering experience unmatched in the industry. CLG is a world leader in licensing their technologies including: ISOCRACKING, ISOTREATING, ISODEWAXING, ISOFINISHING and a full suite of resid upgrading options (Delayed Coking RDS, VRDS, LC-FINING, LC-MAX, and LC-SLURRY).

An important part of developing a low capital revamp is minimizing changes to the high capital outlay of a unit, specifically the high pressure reactors and the recycle gas compressor. This involves creatively looking at the existing assets with the use of process and catalytic technologies. This is a strategy that Chevron USA has incorporated in its own refineries for decades, taking existing reactor assets and placing them in more advantageous processing positions to improve gross margin.

In a similar fashion, CLG has creatively revamped a number of existing hydroprocessing units to improve refinery gross margin.

This paper will discuss four different revamp configurations that CLG has designed for ISOTREATING or ISOCRACKING units. All of the unit revamps have been successfully implemented commercially.

Case Study 1: Conversion of FCC Pretreatment unit to Mild Hydrocracking Service.

A low capital opportunity that should be widely considered is the conversion of a FCC pretreat unit to mild hydrocracking service. The beauty of this revamp option is that it typically involves very low capital and often requires only a catalyst change and upgrades to reactor internals and/or reactor thermometry in the high pressure reaction system. With the availability of cheap hydrogen, gross margin improvements (diesel production and improved FCC feed quality) can be substantial. If the FCC pretreat unit is designed for moderate pressure (1200 to 1500 psi) and high purity hydrogen is available, there is sufficient hydrogen partial pressure to provide acceptable run lengths and good product qualities (diesel cetane uplift and higher quality FCC feed).

A small refinery within the Chevron refining system started up a grass roots FCC pretreat unit in the mid 2000's as part of a major Clean Fuels implementation at the refinery. Following the first cycle, the unit was converted to mild hydrocracking service.

In prelude to the implementation, extensive research unit testing was conducted with a number of ISOCRACKING and ISOTREATING catalysts at Chevron's Richmond Technology Center. The reactor contains four beds and a number of different hydrotreating to hydrocracking ratios were tested to determine the optimum mix to balance catalyst run length, desired diesel yield targets, and hydrogen consumption. The refiner began with 15 % hydrocracking catalyst and has since increased the hydrocracking catalyst ratio to 30 % (the entire fourth bed) in order to achieve maximum distillate production. The testing and commercial operation has shown the excellent nitrogen tolerance of the ISOCRACKING catalysts. By placing the ISOCRACKING catalysts higher in the bed it is exposed to higher nitrogen levels but the catalysts have proven to be robust, offering excellent stability to meet the desired catalyst run length targets.

A key aspect to consider in the reactor system when converting a unit to mild hydrocracking service is to be cognizant of the larger exotherms that hydrocracking catalysts exhibit. Adequate reserve recycle gas compressor capacity for additional quench, superior reactor internals and the ability to quickly depressurize the unit are all very critical components to consider.

For this specific unit, the revamp modifications required for the implementation was very minor as the unit was already equipped with high performance ISOMIX® internals, sufficient recycle gas compressor capacity and a robust automatic emergency depressuring system.

On the fractionation end, the unit was pre-built with a diesel side stripper and fractionator feed heater. This allowed for minimal revamp requirements which were limited to tray upgrades in the sidestripper.

Since the implementation of mild hydrocracking service operation, the unit has regularly achieved 30 LV% yield of diesel (fresh feed basis) that meets EPA ULSD quality.

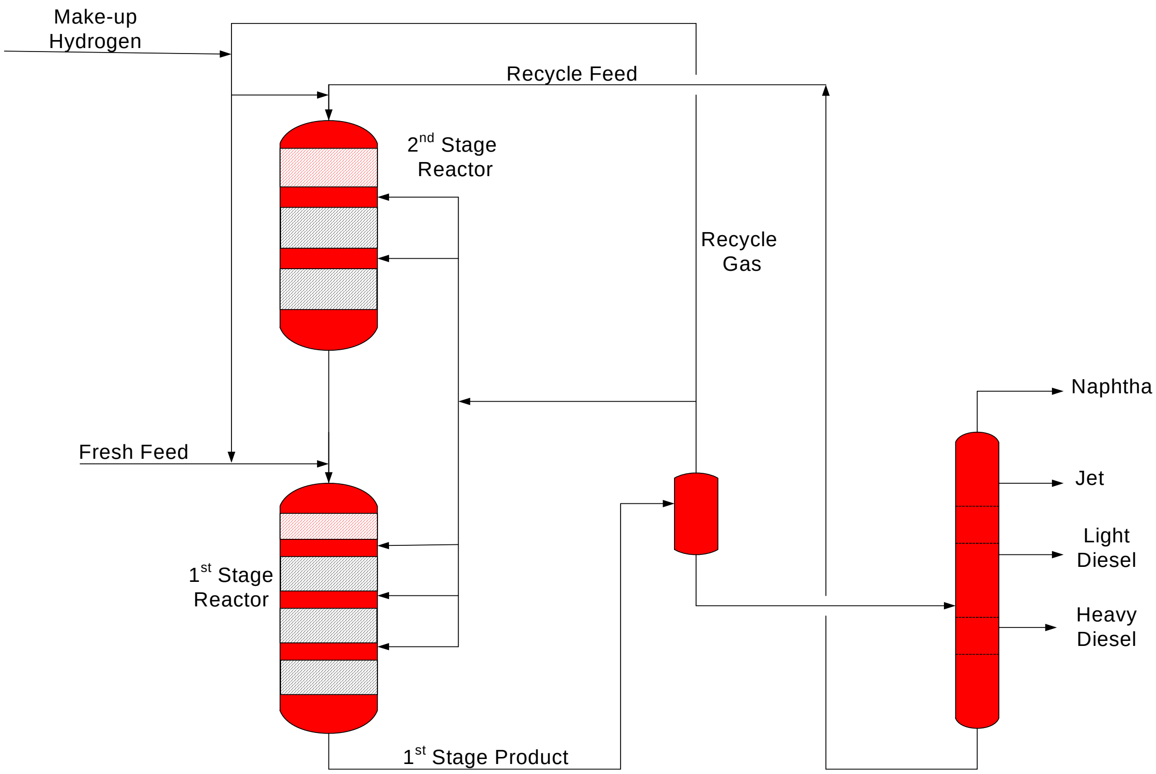
Case Study 2: Two-Stage Hydrocracker Revamp using The SSRS Process (Single Stage Reverse Sequencing)

A CLG licensee in Southeast Asia that originally commissioned a Two-Stage Recycle (TSR) unit in the mid 1990's with selectivity towards middle distillates was evaluating a project to increase unit capacity and extend run length significantly. A traditional revamp would necessitate additional reactor volume and recycle gas compressor modifications. However, CLG offered a novel solution that allowed the client to achieve their goals with substantially less capital expenditure using a process recently commercialized by CLG, Single Stage Reverse Sequencing (SSRS).

A schematic of CLG's SSRS flow scheme is shown in Figure 1. Like a TSR unit, the SSRS also takes advantage of a clean second-stage environment with overall rate constants much greater than the rate constants from the first stage. This clean environment permits full conversion of difficult feeds with less than half the reactor volume needed compared to a Single-Stage Once-Through (SSOT) or Single Stage Recycle (SSREC). The obvious difference between the traditional TSR configuration and the SSRS configuration is the effluent from the second stage flows directly to the inlet of the first stage, which provides the following benefits over a conventional TSR configuration:

- Effluent from the second stage provides a heat sink for the first stage, reducing first-stage quench gas demand by up to 40%.
- Excess hydrogen from the second stage is used to supplement the gas-to-oil requirement for the first stage.
- Reduction in the overall recycle gas compressor load typically by up to 70%.
- Only one reactor furnace is required.

Figure 1 - SSRS ISOCRACKING

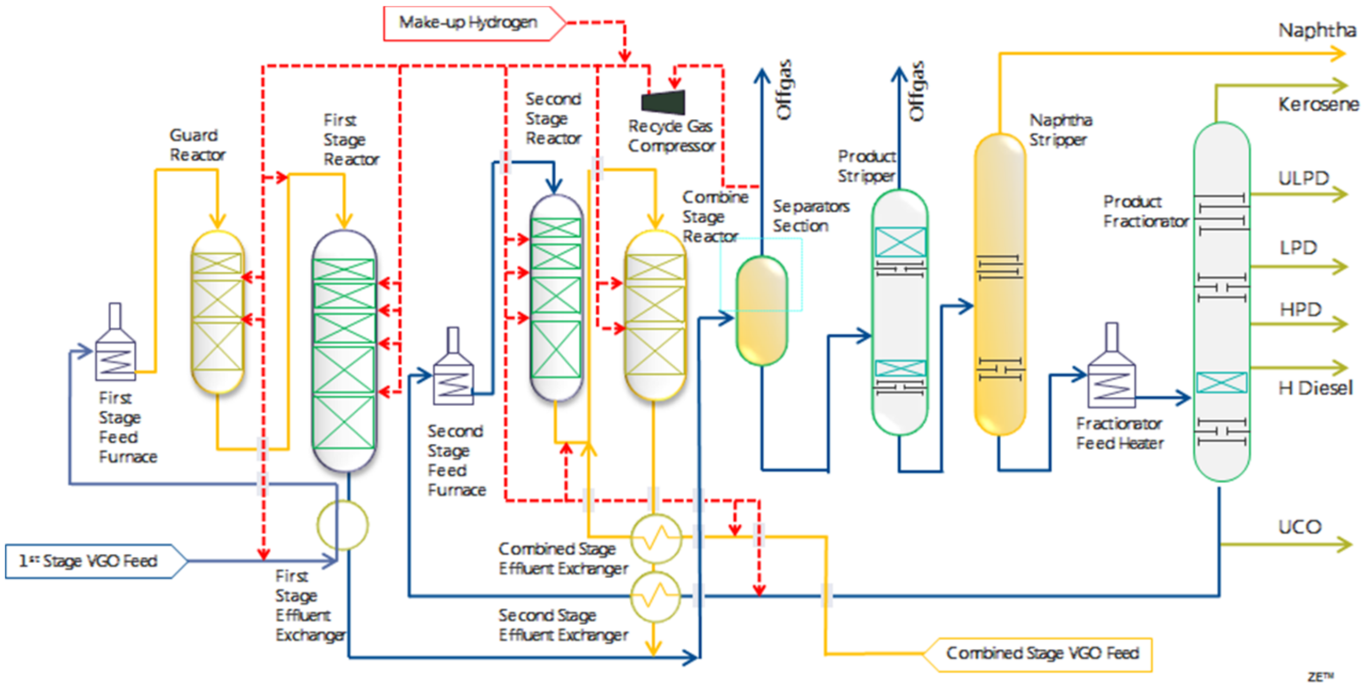


SSRS Revamp Application

High pressure hydroprocessing revamp economics are largely influenced by whether recycle gas compressor modifications to either the compressor or turbine driver are required. The SSRS flow scheme is ideal for revamp consideration due to the small incremental load on the recycle gas compressor. This is fairly intuitive for consideration of a SSOT (Single-Stage Once Thru) or SSREC (Single Stage Recycle) revamp to a two-stage unit, but less intuitive for a TSR revamp. CLG recommended this innovative solution for the aforementioned licensee as shown in Figure 2. In the TSR configuration, a guard bed is added to the first stage, and an additional first-stage reactor added between the second-stage effluent and the product fractionator. The guard reactor was added to increase demetallation and overall first-stage reactor volume to extend catalyst run length. The unit (pre-revamp) was running at 38 MBPD. The addition of the two new reactors allowed the unit to increase throughput by 42% to 50 MBPD and extend run length by 30%. This allowed a 170 % increase in processed barrels per catalyst fill compared to prior to the revamp, all with the existing recycle gas compressor. The existing fractionator was also untouched other than some minor tray modifications with the addition on a naphtha stripper to offload the main column.

This unit revamp was commissioned in 2010 and continues to operate successfully at the higher capacity and runs in a maximum mid-distillate mode.

Figure 2 - Revamp Configuration Using Reverse Staging



Case Study 3: Conversion of Naphtha Selective Hydrocracker in Recycle Operation to More Distillate Selective Once Thru Hydrocracker

CLG was contacted in 2010 by a North American refiner to increase the fresh feed capacity of their North American naphtha selective single stage recycle hydrocracker (SSREC) from 28 MBPD to over 38 MBPD. The other overarching goals for the revamp were to substantially increase middle distillate production from the unit and produce additional high quality FCC feed (essentially turn down the hydrocracker conversion from 90% to 70%).

With one of the stated goals of producing more FCC feed (effectively reducing conversion), the CLG approach was to convert the unit from SSREC to a Single Stage Once Thru Unit (SSOT). With substantial advances in catalyst technology, achieving a 30 month+ catalyst life with superior yields with distillate selective catalysts at 70% conversion in a once through environment is now readily achievable. Switching to once through operation eliminates the liquid recycle stream which provides inherent advantages in a revamp scenario. The liquid recycle rates can be supplemented with fresh feed without negative impacts on reactor loop pressure drop and any hydraulic limits through the reactor system. This significantly reduces the capital cost for a project as the reactors and recycle compressor do not require expensive capital modification.

The fractionator was modified by repurposing side stripper columns to recover jet and diesel rather than heavy naphtha and jet. The naphtha from the system is sent overhead in the fractionator to another column to recover and separate light and heavy naphtha.

The following figures show the basic process flow configuration of the unit before and after the revamp.

Figure 3 - Single Stage Recycle Configuration (before revamp)

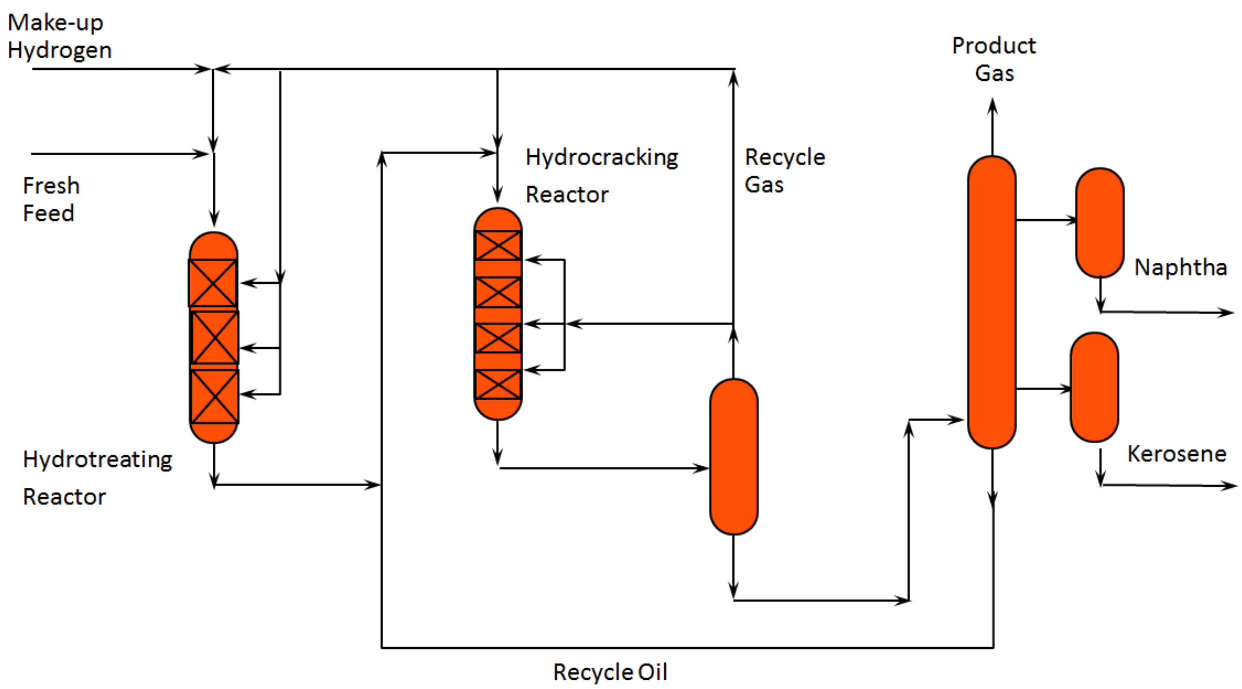
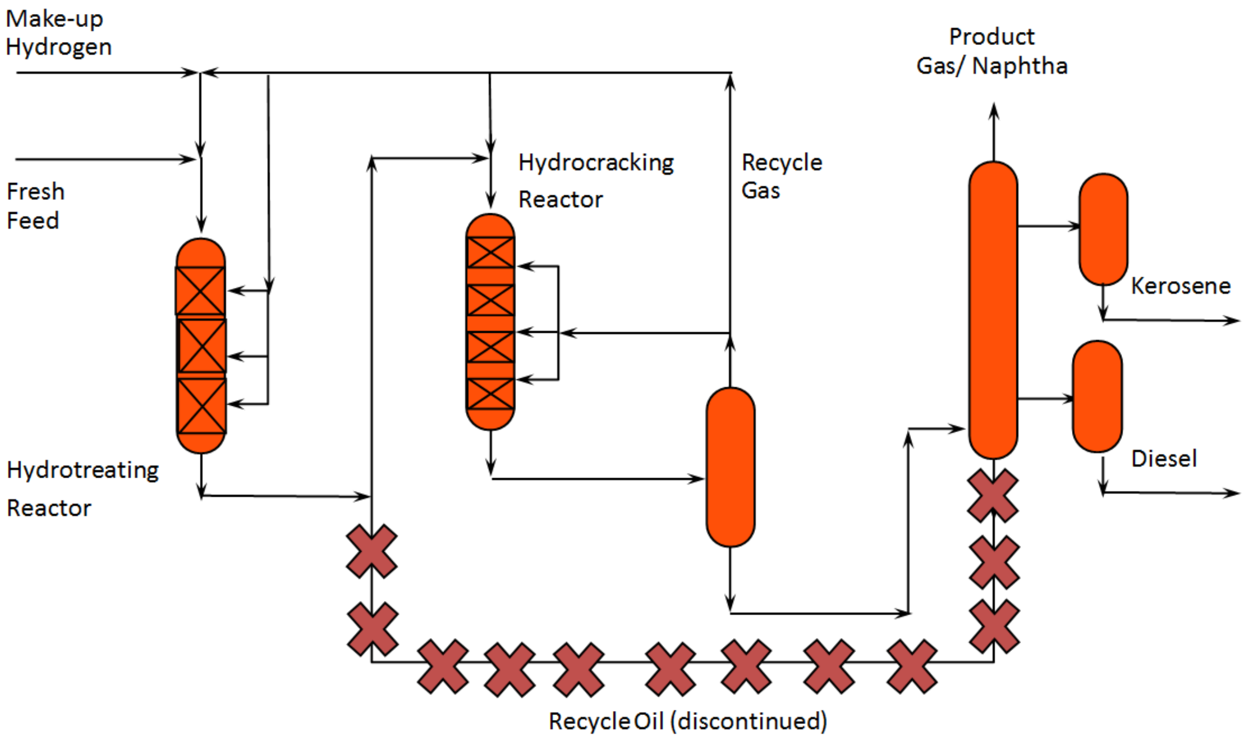


Figure 4 - Single Stage Once Through with Fractionator Side Strippers Repurposed



The revamped unit was put into service in 2015 achieved and even exceeded guaranteed mid-distillate yields and overall unit feedrates. The overall mid-distillate make (factoring in higher feedrates and higher MD yield selectivity) has increased 70 LV% from the cycle before the revamp versus afterwards.

A secondary but very important objective of the revamp was to improve the performance of the existing reactor internals which were replaced with CLG state of the art ISOMIX®-e proprietary internals. Prior to the revamp, the hydrocracking unit was prone to large radial temperature deviations sometimes as high as 45°F in one bed in the hydrocracking reactor which contains high activity zeolitic catalysts. With ineffective reactor internals performance, the catalyst effectiveness is significantly reduced which negatively impact liquid yields and can lead to a premature catalyst run due to excessive hot spot formation.

ISOMIX®-e internals were installed in both reactors as part of the revamp effort and the results have been very favorable as demonstrated below. Figures 5 and 6 show the radial temperature performance before and after the revamp of the bed which exhibited the highest radial temperature deviations.

Figure 5- Radial Temperature Deviations Pre-Revamp

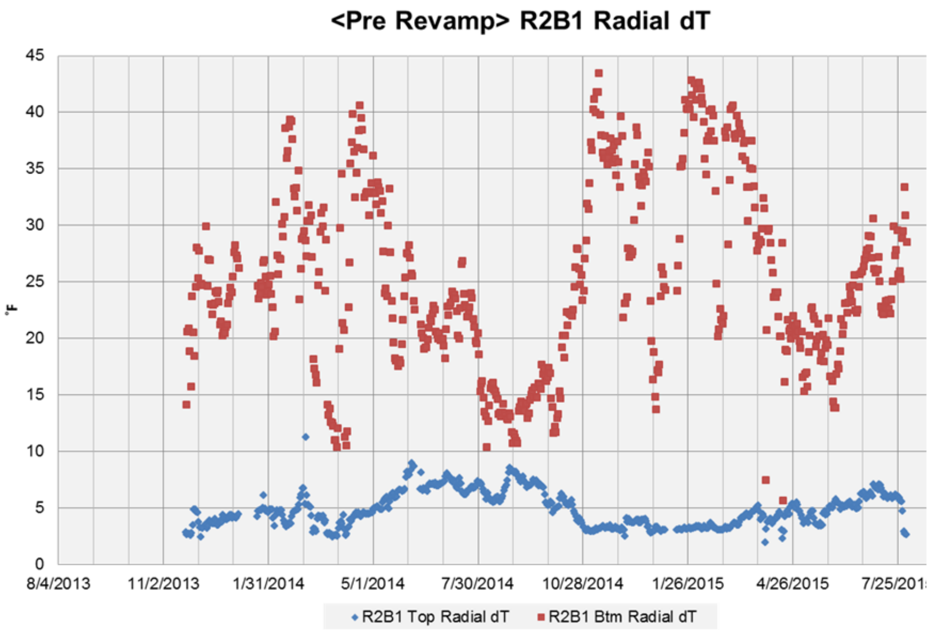
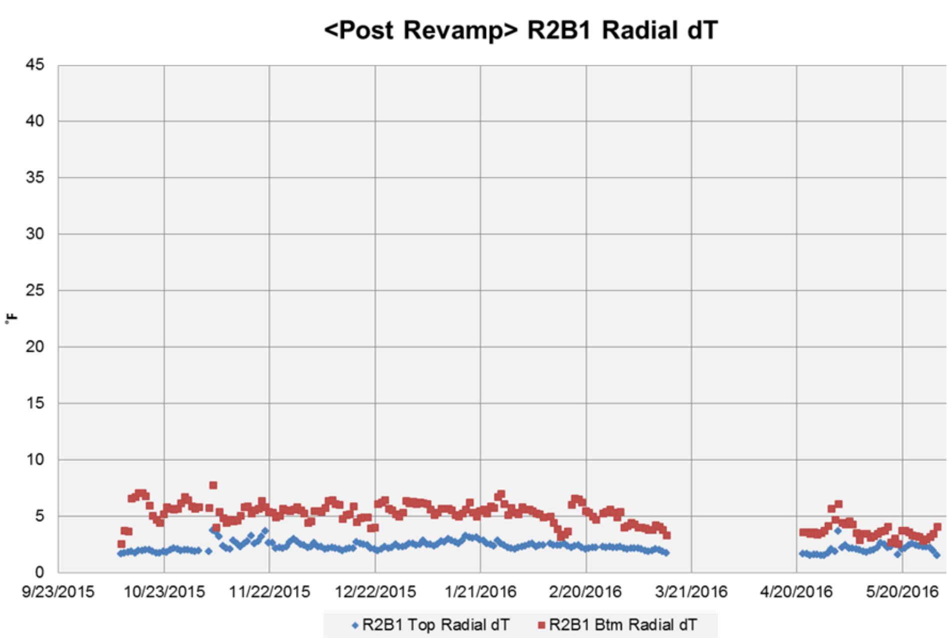


Figure 6 - Radial Temperature Deviations Post-Revamp

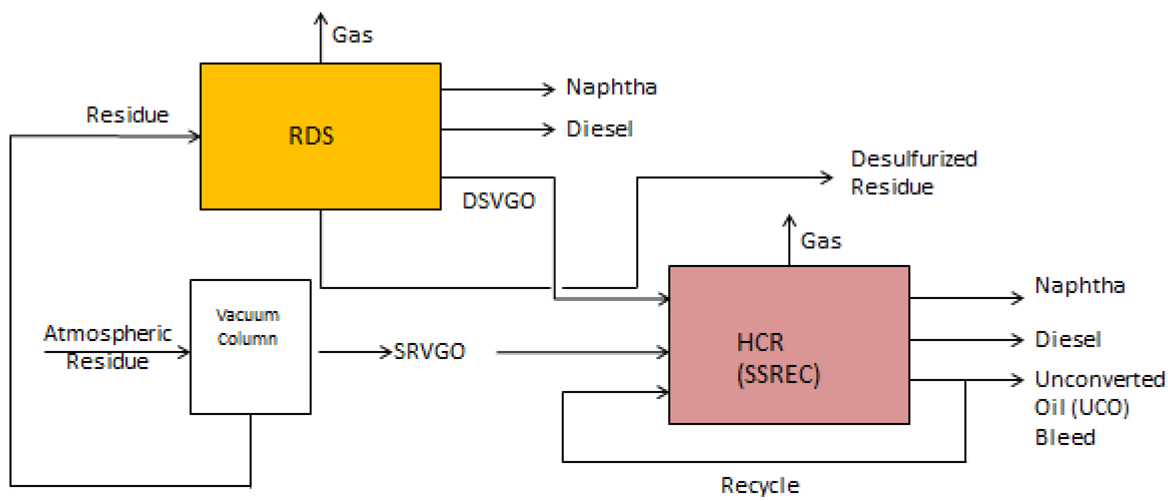


In summary, the revamp of this unit have met the refinery expectations after over 1 year in operation.

Case Study 4 - Conversion of Fixed Bed Residuum Desulfurization (RDS) Unit to Hydrocracking Service.

CLG was posed an interesting question by a valued user (European refiner) of its RDS catalysts in the mid 2000s. Can we utilize the existing reactor volume associated with the fixed bed RDS unit to incorporate VGO feed for hydrocracking to produce high quality Euro IV diesel. The RDS unit consisted of four fixed bed RDS reactors which provide ample reactor volume for hydrocracking service while still being able to maintain sufficient RDS capacity. CLG proceeded to convert one of the RDS reactors to hydrocracking service. The reactor was placed into a separate train with its own product separation and fractionation system for processing VGO (virgin and derived from the RDS). The new VGO SSREC (Single Stage Recycle) hydrocracker train shared the recycle hydrogen system and recycle gas compressor. The following block flow diagram provides a configuration of the unit after the revamp.

Figure 7 - Pre-Revamp Block Flow Configuration



A key aspect of the revamp was to install a fourth bed in the reactor which was converted to hydrocracking service and the installation of CLG ISOMIX® internals. An additional bed was necessary for proper reactor temperature control due to the higher exotherms created in hydrocracking service. The top bed was essentially divided into two equally size beds with the addition of a grid tray, nozzle tray, ISOMIX® mixing box and beams supported by a new support ring welded to the reactor cladding. An automatic depressuring logic system was also added for this service as per industry practice for reactors which contain catalysts in hydrocracking service.

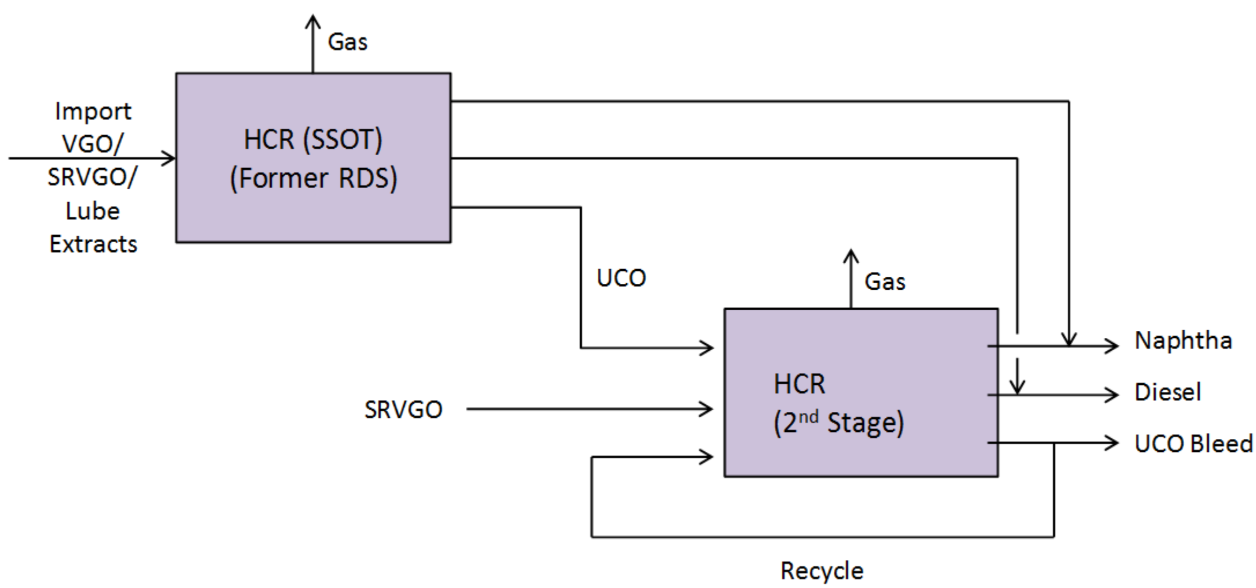
Following three successful catalyst cycles with this configuration in the SSREC hydrocracker, the refiner was faced with a business environment of reduced fuel oil and margins and steady growth in their diesel demand. This led to a decision to convert the RDS portion of the unit to hydrocracking service and increase of import vacuum gas oils for hydrocracking to Euro V diesel. The refiner had other more economic disposition of the residuum within their refinery system.

CLG performed a detailed evaluation for a full conversion of the unit to hydrocracking service. The overriding philosophy for this phase of the revamp was simplicity and expediency (refiner wanted to implement quickly on the next turnaround) with the flexibility to shift the unit back to RDS service in the future if desired.

The most straightforward and cost effective approach for this phase of the revamp was to maintain the existing process flow configuration without any significant piping changes, especially in and around the high pressure section. This approach was facilitated by converting the RDS train to essentially the first stage of a two-stage recycle (TSR) unit. In a TSR unit, the first stage hydrotreats the feed reactants (desulfurization, denitrification, and de-aromatization reactions) and mild hydrocracking. The first stage products are removed in an intermediate distillation tower and the unconverted oil is routed to the second stage. The second-stage operates in a clean kinetic environment (H_2S and NH_3 free) which favors maximum diesel production.

The reactor that was previously converted to hydrocracking in SSREC operation would now function as the second-stage in this revamped unit. The feed is unconverted oil (UCO) from the new first stage but also retains the ability to process raw feed. The following block flow diagram provides a configuration of the unit after the second revamp.

Figure 8 – Post Revamp Configuration



The unit has been operating in this configuration for nearly three years with substantial benefit to the refiner. The fresh feed capacity has increased by 44 % with nearly 48 % increase in diesel production. The other tangible benefit is a very significant increase in run length. With the substantial increase in overall residence time the unit cycle life for hydrocracking has increased two-fold, the current cycle is expected to last about three years.

The first stage conversion is not limited by reactor residence but rather by the ability to recover diesel product. The unit was originally designed for RDS service which has limited diesel recovery capacity. This bottleneck was identified and required bringing an out of service vacuum column back into service as a mechanism to increase diesel recovery capability with further fractionation system modifications.   With an ability to operate at higher conversion, the unit would be able to process a considerably higher amount of fresh feed and further increase diesel production.   The implementation of the fractionator system debottleneck is pending refinery management capital spending decision.

Summary

CLG has many demonstrated examples of successful commercial implementation of hydroprocessing solutions in a low capex manner to improve refinery gross margin.   The key in each example is to identify the constraints/bottlenecks and apply efficient cost effective solutions.

Hydrocracking has served our industry well for over half a century with rapid advancement. Continued advancement in catalyst technology and innovative configuration will ensure a prominent role for hydrocracking well into the 21st century.

Reference

1. Koldachenko, N and Yoon A, “New Hydrocracking Developments Demonstrate Lower Capex and Opex Hydrocracker Designs and Revamps” AFPM Annual Meeting Mar 22-24 2015.