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AM-10-154 Impact of Processing Heavy Coker Gas Oils in Hydrocracking Units

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Impact of Processing Heavy Coker Gas Oils in Hydrocracking Units

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Abstract

The hydrocracking process unit is one of the most versatile refinery upgrading units that produces a wide range of products including ultra-low sulfur, low aromatics diesel fuel and high smoke point kerosene. Chevron Lummus Global's (CLG) hydrocracking experience began with Chevron's invention of modern hydrocracking, ISOCRACKING, more than 50 years ago. As an entity since 1993, CLG has repeatedly been the first to introduce technologies and catalysts that enable refiners to economically, safety and reliably meet today's tough new standards for producing cleaner transportation fuels.

With the onset of new grass roots refineries configured with delayed coking as the primary low cost residuum upgrading unit and hydrocracking as the gas oil upgrading unit, hydrocracking of coker-derived products becomes a key factor in refining operations. When faced with inquiries from the refining industry, licensors of delayed coking technologies are challenged to maximize liquid yields and, as such, typically employ low to ultra-low recycle rates and high recycle cut points in the design of the delayed coking unit. However, these designs result in a very high boiling incremental liquid yield of heavy coker gas oil (HCGO) which contains very high concentrations of polycyclic aromatic compounds and other contaminants. These compounds tend to rapidly deactivate hydrocracking and/or hydrotreating catalysts and significantly reduce the catalyst cycle time. Hydrocracker licensors have responded to this by emphasizing a lower HCGO TBP end point, lower asphaltenes, lower Conradson carbon, and lower metals (Ni+V) content. These properties are directly related to the end point of the HCGO. Despite extensive planning, quality of coker gas oils can vary significantly with drum swings. As a result, the hydrocracker will routinely see some amount of coker gas oil with a quality significantly worse than planned. If catalyst lives are to be maintained at a given run length, hydroprocessing design parameters must be adjusted, resulting in directionally higher costs.

Because of this effect, the coker operating parameters have to be optimized to balance coker and hydrocracking costs against the incremental overall product yield and reduced coke production. In essentially every case such an optimization will reduce the recycle cut point and increase the recycle rate relative to a design based solely on coker considerations. The savings in overall investment and operating cost pay for the slight loss of liquid yield and increase in coke production. Directionally, the optimization is aimed at balancing the overall liquid yield against total investment and operating costs for the coker/hydrocracker combination.

Over the years, CLG has developed innovative process configurations to effectively process the high boiling vacuum gas oil (VGO)/HCGO gas oils while maximizing distillates yield with optimum hydrogen utilization via the ISOCRACKING and ISOTREATING processes and catalysts.

This paper outlines the strategies employed by CLG to hydrocrack high boiling VGO/HCGO blends. Reference to commercial operation is included in this paper.

Introduction

Globally, the refinery product slate has gravitated toward maximizing high-quality middle distillates fuels, including kerosene and diesel. New grass roots refineries are expected to meet the Euro V specifications as a requirement for clean fuels. Given the increasing global demand for clean fuels and crude source, many new and upgraded refineries are employing coking and hydroprocessing technologies to maximize middle distillates yields.

Delayed coking continues to be the primary low cost bottom-of-the-barrel residuum upgrading process worldwide, with new capacity installations reaching epic proportions in the first decade of the 21st century. Although the demand for delayed coking has declined somewhat in 2009 as a result of the economic crisis and the relatively low light/heavy crude spread, this is expected to recover as the demand for crude and refined products recovers. This increase will continue to challenge existing hydrocracker utilization and make grassroots hydrocrackers essential.

Challenged to maximize liquid yields, delayed coking licensors offer designs that incorporate ultra-low recycle conditions and/or low pressure. While these conditions achieve a high yield of heavy coker gas oil (HCGO), the HCGO has a high boiling range, typically >565^{o}C, which rapidly deactivates catalyst in hydrocrackers and hydrotreaters.

This paper will overview the configurations of hydrocrackers to process HCGO, typically blended with vacuum gas oil (VGO), but often with light cycle oil (LCO) and medium cycle oil (MCO) to maximize middle distillates. The information provided will be of use for potential new and upgraded refineries aimed at maximizing middle distillates while processing heavy VGO and HCGO.

Chevron, a leading refiner and innovator of hydroprocessing technologies, combined resources with Lummus Technology (now a CB&I company), a leading technology and engineering company, and formed Chevron Lummus Global (CLG) in 2000. CLG has a depth of experience in designing, building and operating hydroprocessing units unmatched in the industry. Today, CLG offers a full spectrum of technologies and catalysts designed for optimizing the production of clean transportation fuels from even the most difficult feeds.

Heavy Coker Gas Oil Quality

Typically, licensors of delayed coking respond to refiners’ inquiries for maximum liquid yields by offering designs that incorporate low coke drum pressure and ultra-low recycle conditions. While these operating conditions result in a minimum quantity of coke production and a maximum quantity of liquids, the latter is accomplished by recovery of a larger quantity of HCGO product. Unfortunately, as the quantity of HCGO increases, the quality of this material deteriorates rapidly as a result of the increase in heavy, higher boiling, higher molecular weight components that would have otherwise remained in the coke drum at higher pressure and/or higher recycle, converting to coke and lighter liquid products. This quality can deteriorate even further as a result of drum swings causing disruption to downstream units like hydrocrackers and hydrotreaters.

In many refineries, the HCGO is processed in hydrocrackers to produce high-quality middle distillate products. The impact of processing the higher boiling components in HCGO on hydrocracking catalysts in existing hydrocrackers is significant, resulting in increased catalyst deactivation and shortened run lengths. HCGO is a very refractory feed which requires careful choice of process configuration, catalyst selection, and operating conditions for new designs.

Figure 1 shows a simulated distillation of the variation in the end point of HCGO for various coker unit recycle rates. The increase in the end point of the HCGO results in a significant increase in the polynuclear aromatics and asphaltenes, both of which are coke precursors for hydrocracking/hydrotreating units. CLG recommends an optimal TBP cut point between the HCGO and the coker recycle at approximately 950°F. At this cut point, the D1160 end-point of the HCGO is approximately 995-1,010°F. This is more critical for existing hydrocracking units as new hydrocrackers can be designed to handle higher HCGO end-point.

Figure 1: HCGO Product Distillation

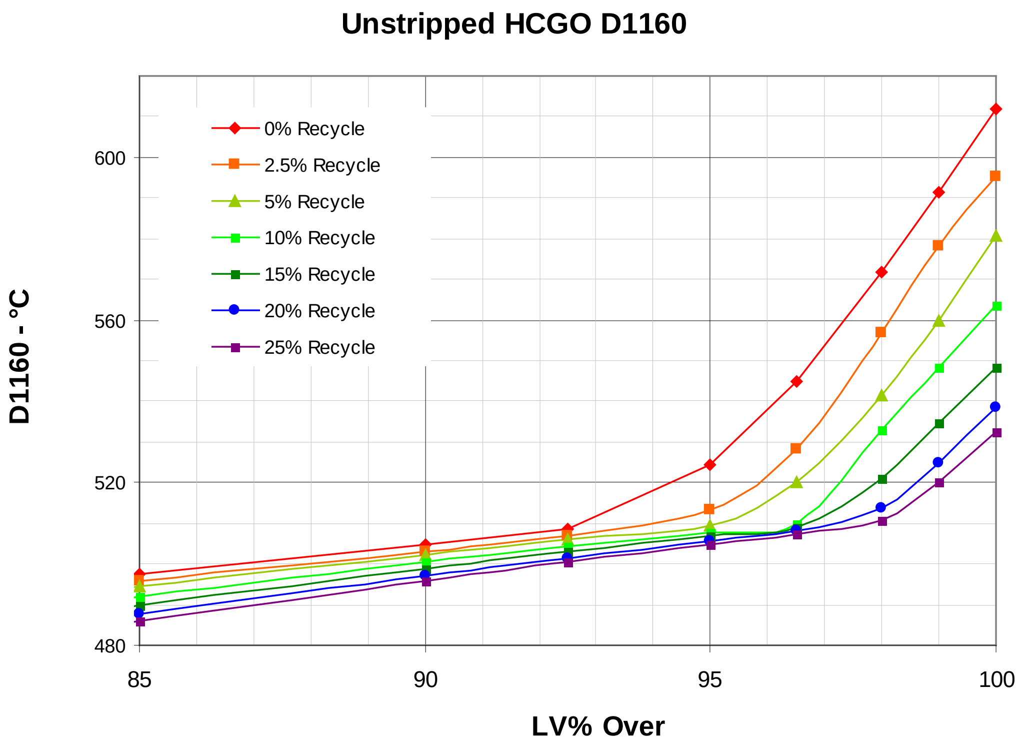


Table 1 summarizes typical quality of HCGO.

Table 1: Typical Properties of HCGO

API	10.8-11.9
Nitrogen, wppm	3,500-9,000
Sulfur, Wt %	2.5-5
Metals, wppm	2-3
C_7 Asphaltene, wppm	350-700
PCI (Polycyclic Indicator)	7,000-10,000
Distillation, D1160, LV %	°F
10	655-739
30	737-800
50	790-864
70	848-936
90	926-1,025

Other contaminants include CCR, Silica, and Olefins (Bromine Number).

All of the feed characteristics contribute to increased catalyst deactivation in hydrocrackers and hydrotreaters. The impact of the feed quality requires a careful selection of the grading, catalysts, and process configuration to protect the downstream catalyst and assure a stable operation.

Hydrocracker Process Configurations

The global demand for clean fuels has driven the need for increased diesel yield which has prompted an increase in the implementation of new hydrocrackers. The designs of new hydrocracking units are challenged by the difficult feeds from heavy sour crudes and residuum upgrading units. CLG has developed innovative process schemes aimed at processing difficult VGO and HCGO feeds to maximize the distillate yield and optimize the hydrogen consumption. The following outlines the innovative strategies employed by CLG to process difficult, high boiling refractory types of feeds using CLG's ISOCRACKING and ISOTREATING technologies.

Optimized Partial Conversion ISOCRACKING Technology

The Optimized Partial Conversion (OPC) scheme was developed in 1998 to process difficult feeds while achieving high quality FCC feed and ULSD. The processing objectives are aimed at achieving the following:

- High conversion of refractory, high nitrogen feed at minimum reactor and catalyst volume
- Flexibility to produce high quality FCC feed and distillates
- Feed flexibility

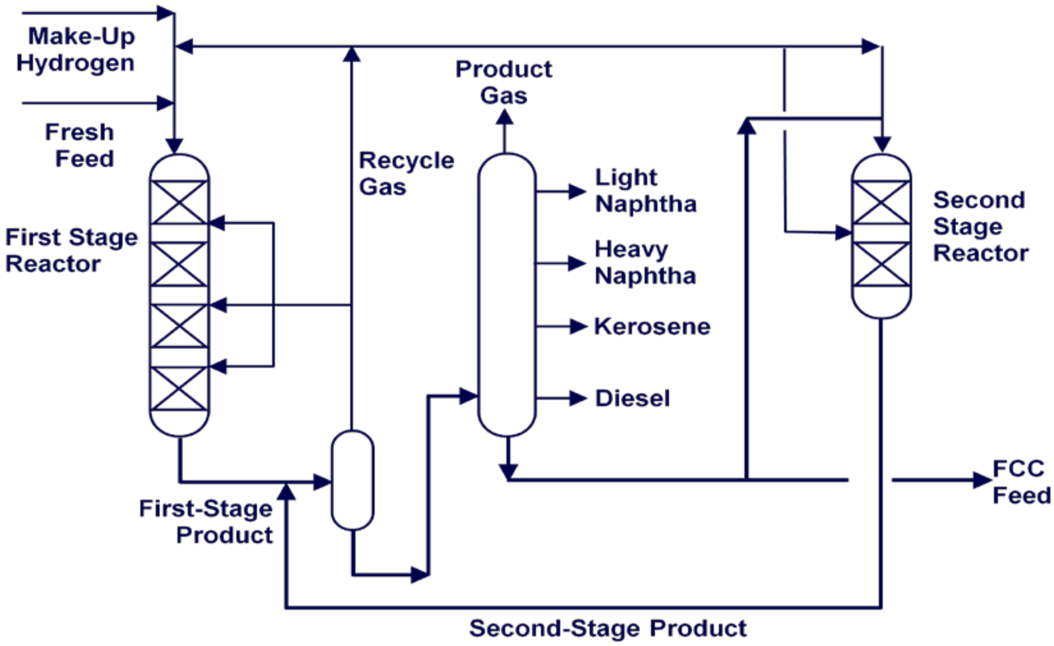
The OPC process scheme achieves the required FCC quality while minimizing hydrogen "giveaway" and maximizes the middle distillates yields with an implementation of a "clean" second-stage reactor. The advantages of the OPC scheme are:

- Conversion in the clean second stage
- 2-3 times lower reactor volume addition:
  - Second stage offers significantly higher reaction rate constant than first stage (approximately 10 times higher)
- Improved product quality and yields
- Products (kero, diesel) can be recycled to:
  - Alter yield distribution without impacting FCC feed quality
  - Improve product quality
  - Minimize hydrogen content of FCC feed while making ULSD

The OPC scheme is similar to a two-stage ISOCRACKING unit; however, the feed blend (high concentration of HCGO), processing objectives (partial conversion for FCC feed, ULSD) and optimizing hydrogen consumption are the key drivers for the OPC scheme. The OPC process scheme has been commercially demonstrated by CLG since 2004.

Figure 2 depicts the OPC process scheme.

Figure 2: Optimized Partial Conversion Process Scheme



The following outlines the benefits of the OPC scheme:

The feed components include HVGO and HCGO from heavy Mexican crude. The typical blended properties are summarized below.

API Gravity	13-15
Nitrogen, ppm	2,500-3,000
Sulfur, Wt %	3.0-3.5
Polyaromatic Indicator, ppm	8,000-10,000

The typical yields and product properties are summarized below.

Naphtha, LV %	25-35
Middle Distillates, LV %	40-45
Bottoms, LV %	30-40
Kerosene	
Sulfur, wppm	<10
Smoke Point, mm	15
Freeze Point, °C	<-50
Diesel	
Sulfur, wppm	<10
Cetane Index	43-48
Pour Point, °C	<-15
Bottoms	
Nitrogen, wppm	5-20
Sulfur, wppm	50-200

Selective Staging Hydrocracking ISOCRACKING Technology

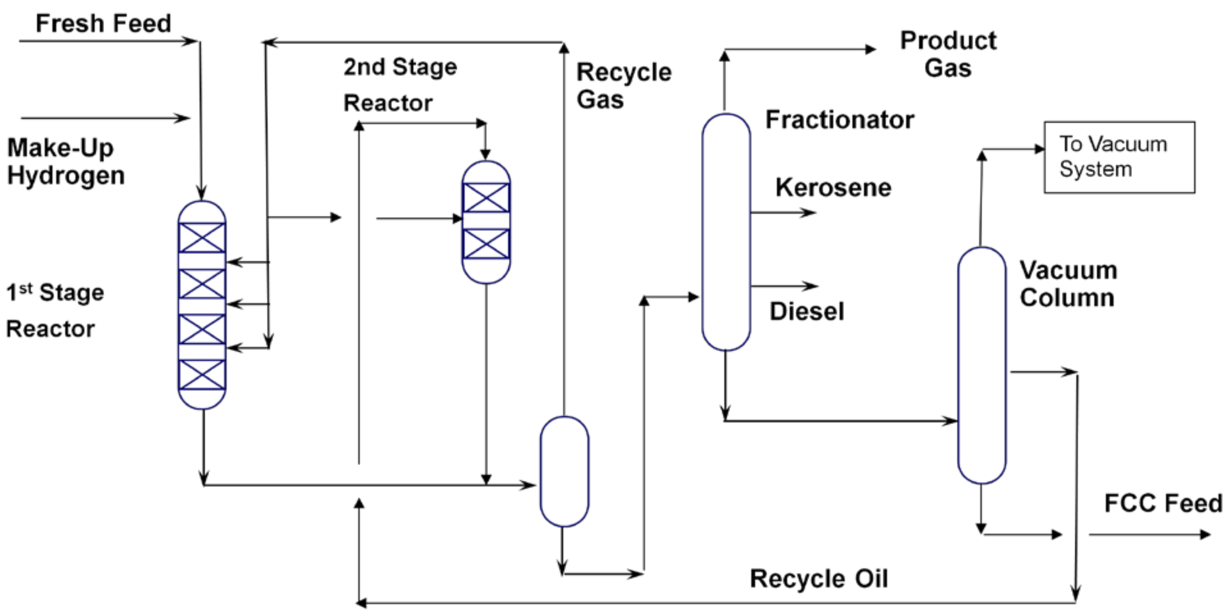
The Selective Staging hydrocracking process configuration was developed to process very high boiling HVGO and refractory feeds, such as HCGO to produce clean fuels (middle distillates) and high-quality FCC feeds with optimum hydrogen consumption. This process scheme segregates high boiling hydrotreated VGO as feed to the FCC unit while maximizing high quality middle distillates yield.

The key features of the Selective Staging scheme are:

- Fresh feed is hydrotreated and the unconverted oil (UCO) is sent to a vacuum column; a side draw from the vacuum column is sent to a clean hydrocracking reactor and the bottoms (UCO) from the vacuum column is sent to FCC unit, based on desired overall conversion
- Flexibility to adjust severity of the hydrotreating reactor to handle relatively high-end point feed and feed variations from upstream adjustments
- Maintaining a steady feed from a vacuum column to the clean hydrocracking reactor for full conversion to ultra high quality distillate products

Figure 3 depicts the Selective Staging process scheme.

Figure 3: Selective Staging Hydrocracking



The advantages of the Selective Staging process include:

- High yield of premium quality jet and diesel products
- Avoid undesirable oversaturation of the UCO from the hydrocracking unit feeding the FCC unit, resulting in significant reduction in hydrogen consumption
- Lowest reactor volume for similar feedstocks and performance objectives

The Selective Staging hydrocracking process scheme is an extension of the OPC, but addresses high boiling range VGO/HCGO. Currently, the CLG Selective Staging process is in the EPC phase with expected startup in mid-2011.

The following outlines the performance of this innovative process scheme.

Feed Quality

Feed Type	80% HVGO / 20% HCGO
API	21.7
Sulfur, Wt %	2
Nitrogen, wppm	3,000
Metals, Ni+V, wppm	4
Distillation, D1160, °F	
10%	752
50%	923
90%	1,056
95%	1,078
FBP	1,153

Performance Objectives:

- The main objective of the new hydrocracking unit is to maximize the production of middle distillates
- Jet: S <10 ppm, Smoke Point >25 mm
- Diesel: S <10 ppm, Cetane Number >56
- Achieve 70% conversion of VGO and HCGO feed blend
- Catalyst run length: > 24 months
- UCO to be sent to existing FCC unit
- Minimize hydrogen consumption

Combined Selective with Reverse Staging ISOCRACKING Technology

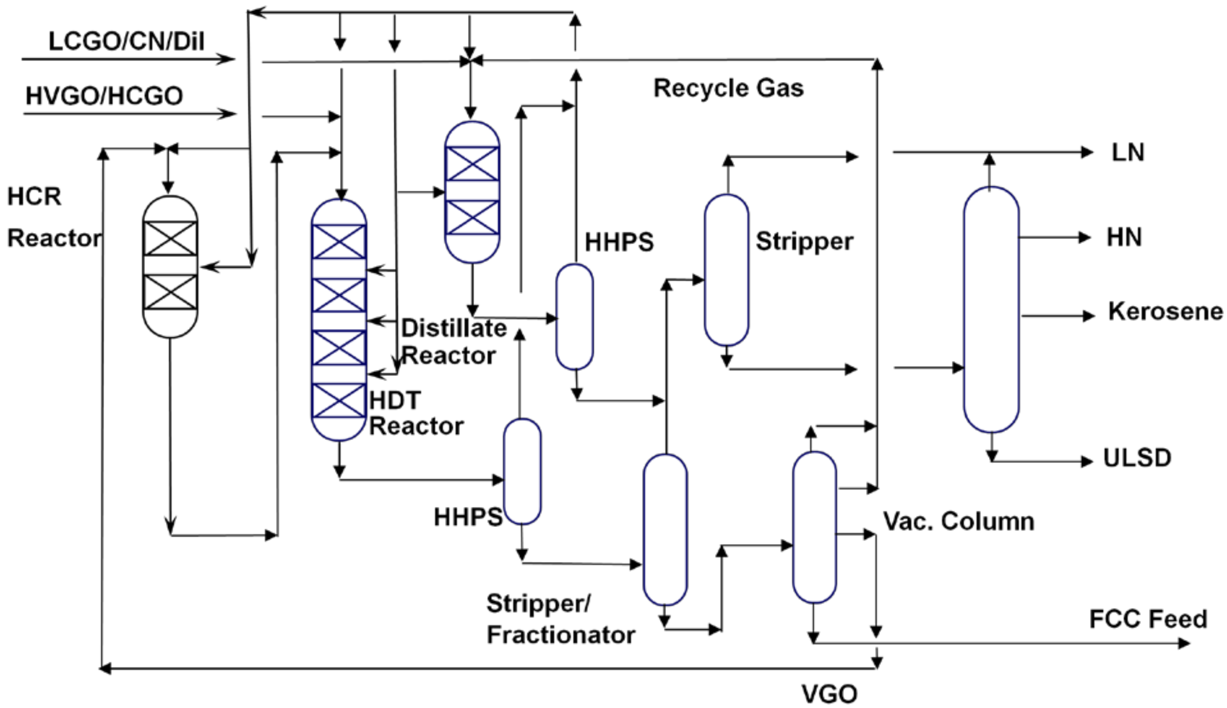
The combined CLG Selective Staging and Reverse Staging ISOCRACKING process configuration is ideally suited for the processing of high boiling refractory feeds with mid-distillates co-processing to maximize middle distillates, produce high quality FCC feed, and minimize hydrogen consumption. The key features of this process scheme are:

- Produce high quality middle distillates
- Minimize oversaturation of the UCO, thereby reduce the hydrogen content of the FCC feed
- Cascaded use of recycle hydrogen gas, hence directionally lower gas circulation
- Independent control of treating and cracking functions
- Co-process external mid-distillates
- Minimizes capital and operating costs

Figure 4 depicts CLG's Selective/Reverse Staging ISOCRACKING process scheme.

The flow scheme segregates the required processing steps (high boiling heavy feed hydrotreating, hydrocracking, and distillate treating) to allow independent control of each. This facilitates optimization in the selection of catalysts and operating conditions and thereby avoids over-cracking to light products and "giveaway" in product qualities, both of which lead to excess hydrogen consumption. Although the catalytic functions are segregated, the separation and product recovery systems are integrated to minimize investment and operating cost.

Figure 4: Combined Selective/Reverse Staging ISOCRACKING Process Scheme



The following outlines the application of the Selective/Reverse Staging process configuration.

Feed Definition

Feed Type	HCGO	HVGO	LCGO
API	13.0	20.2	30.2
Sulfur, Wt %	4.8	3.3	2.8
Nitrogen, ppm	4,900	1,600	1,600
Distillation, D1160, °F			
30%	740	824	466
50%	864	878	529
90%	1,024	1,015	637
FBP	1,081	1,121	699

Required Performance Objectives:

- Maximize the production of middle distillates
- Jet: S <10 ppm, Smoke Point >25 mm
- Diesel: S <10 ppm, Cetane Index >50
- Achieve 60% conversion **VGO + HCGO** in feed blend
- Catalyst run length: > 24 months
- UCO sent to existing FCC unit
- Hydrogen is at a premium

Existing Units

CLG is no stranger to processing ever increasingly difficult refractory feeds in existing units built many years ago. Processing coker gas oils in existing hydrocrackers presents a unique opportunity since reactor volume, operating pressure, and bed size (heat balance) are already fixed. Managing consistent feed quality and constant unit monitoring are key to achieve operating cycle goals and avoid costly surprises. Proper catalyst choice and the application of catalysts in the unit are key parameters to a successful and long cycle. By utilizing these tools it is usually possible to increase coker gas oil volumes *and* feed cut points in existing units. CLG has experience helping many customers effectively manage hydrocracker operating cycles with very high percentages of HCGO. These stocks introduce nitrogen levels in excess of 5,000 wppm and asphaltenes in high concentrations. These levels can easily be exceeded during the coker drum swings and usually are not caught with routine analytical schedules but nevertheless must be managed.

Also crucial to a successful operating cycle, especially at high severity operations as described above, are activities around catalyst loading and startup. Existing units need every pound of catalyst to be accessible and to perform as required. Over the years, working with customers and loading companies CLG has developed strong standards and requirements for proper catalyst loading and for a safe and orderly startup[1]. Typically these procedures can be incorporated into the turnaround routine with no incremental time required, and often measurably shortening traditional turnaround schedules.

Commercial Unit Reference

A commercially operating unit utilizing CLG's OPC ISOCRACKING technology process to upgrade a blend of HCGO and VGO is summarized below.

Feed Blend

Properties	Units	HCGO	HVGO
Vol %		60-70	40-30
°API Gravity	---	11.8	14.9
Sulfur	Wt %	4.30	3.5
Nitrogen	wppm	4,500	3,000
Ni + V	wppm	1.0	2.5
Si	wppm	2.0	1.0
C_7 Insolubles	wppm	100-500	100-500
PCI		9,000	4,700
Distillation		D2887	D2887
10%	°F	670	780
50%	°F	790	895
90%	°F	926	1,020
FBP	°F	1,100	1,120

[1] Dan Torchia, Gavin McLeod, Paul Cannatella, and Greg Scott, "Catalyst Loading: A Critical Variable," *Hydrocarbon Engineering,* September 2006, pp 31-33.

Processing Conditions

First Stage	
LHSV, Hr^{-1}	0.8-0.9
CAT, °F	735-750
Run Length, Months	24+
Second Stage	
LHSV, Hr^{-1}	1.7-2.0
CAT, °F	680-700
Run Length, Months	30+
Overall	
Conversion 650°F+, LV %	65-70

Conclusion

Many new (and existing) refineries are installing Delayed Cokers as the primary low cost residuum upgrading unit and aim for maximum liquid yields from the coker. As previously mentioned, Delayed Cokers designed for maximum liquid yield result in very high boiling HCGO product. Many refiners strive for maximizing coker liquid yields and processing the HCGO in the hydrocracking unit. Processing HCGO in existing hydrocrackers becomes extremely challenging which can result in significant capital investment for the hydrocracker. With the objective of maximizing total middle distillates, the HCGO can be effectively co-processed with VGO in hydrocrackers. Hydrocracking licensors have responded to this by specifying the quality of the HCGO which can be economically processed in the hydrocracker. Thus, a balance between maximizing coker liquids and maximizing hydrocracker run performance and run length while maximizing refinery profits needs to be established and managed.

However, given that refiners are continuously pushing the envelope to process the HCGO and high boiling VGO in hydrocrackers, CLG has responded to this challenge by developing and commercializing innovative process configurations and catalyst developments aimed at processing relatively high end point HCGO and high boiling VGOs. This paper has provided various process schemes which have been developed by CLG to process the challenging feeds of today with demonstrated results, thus providing refiners the options to maximize overall refinery distillates yields while processing difficult feeds.