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AM-11-19 Refinery Configurations for Maximum Conversion to Middle Distillates

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REFINERY CONFIGURATIONS FOR MAXIMUM CONVERSION TO MIDDLE DISTILLATES

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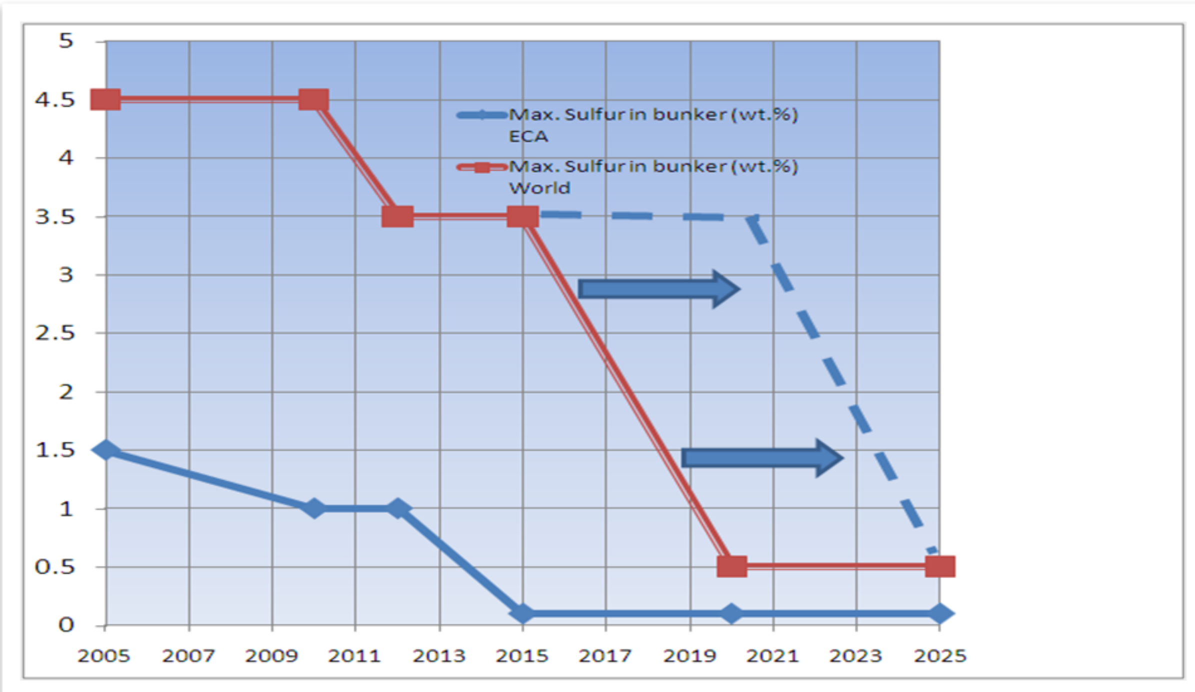
Abstract

The International Maritime Organization's (IMO) newly proposed limits of 0.5 wt % sulfur in bunker fuel implies that refiners will have to either replace the traditional bunker fuel oil (3.5% S) with diesel or increase conversion capability to convert low value fuel oil to diesel. In either case, the spread between diesel and fuel oil is likely to increase. Gasoline demand is dropping relative to diesel even in traditionally gasoline-oriented markets such as North America, and this trend is expected to continue. The trend has led to most recent major grassroots projects selecting distillate-oriented conversion technologies; very few, if any, refineries have its entire conversion strategy focused on FCC and many FCC units are operating at low severity ("distillates mode") or occasionally converting to a propylene producer. Therefore, modern conversion strategy is based on reducing or eliminating production of fuel oil, maximizing diesel and only producing the amount of gasoline that makes strategic sense in the local context.

Chevron Lummus Global (CLG) explores several configurations including some novel process configurations developed by CLG that are based on commercially proven technologies to maximize conversion to diesel in grassroots units and in revamp situations. Implications of eliminating traditional gasoline-oriented units such as reformers and FCC are examined. A brief discussion on phasing in investments is also included. These strategies will permit a refiner to remain competitive even in periods of depressed margins.

Residual Fuel – An Increasing Challenge

Refiners globally continue to face numerous challenges as environmental laws become increasingly stringent; principal among them in the near future will be to meet the International Maritime Organization (IMO) proposed changes in bunker fuel oil sulfur limits from the current 3.5% down to 0.5% globally and from 1% to 0.1% in Emission Control Areas (ECA), as shown in Figure 1. Global demand for high sulfur residual fuel oil is steadily declining; since 1995, the demand for the residual fuel has declined by 35%. The specification changes and the decreasing demand for residual fuel oil will significantly impact a refiner's ability to market any significant quantity of HSFO at a price that will maintain refinery profitability. Refineries currently making a significant amount of fuel oil and lacking complexity to upgrade the residual oil to premium products (middle distillates) will have to face two difficult options – either invest in commercially proven and reliable solutions to convert HSFO to more valuable liquid products (i.e., Euro V diesel) to greatly improve the refinery profitability or face a threat to shut down the refinery as the operation becomes uneconomical to continue.



ECA: Emissions Controlled Area

Figure 1 (Source – IMO)

Shift in Product Demand

The IMO's looming specification changes, as shown above in the Figure 1, is likely to accelerate the decline in demand of HSFO by the year 2020, if not earlier. Worldwide, including emerging markets like China, India and the Middle East, there is a shift in the product demand from gasoline to diesel. Ethanol substitution in gasoline and improvements in engine technology are some of the reasons driving the diesel demand, which continues to outpace gasoline. IMO regulation will indirectly increase the diesel demand further as refiners are forced to blend in additional low sulfur diesel to meet fuel oil sulfur specifications. Worldwide mid-distillates production is projected to account for 55% of the rise in oil demand expected over the next 20 years[6]. The shift to diesel puts emphasis on bottom-of-the barrel processing.

Growing Demand

The worldwide demand for refined products is projected to increase significantly in the next 20 years, driven by population growth and the transition of emerging markets into the global economy, with the majority of growth coming from China in particular and Asia in general[5]. According to OPEC, global demand for diesel fuels is expected to grow by 10 mb/day by 2030, driven by an increased share of diesel driven vehicles in Europe and developing countries[6].

Current refining investment is predominantly in Asia, the Middle East, Russia and Latin America, regions with growing demand for refined products. Tightening of product quality specifications will accelerate implementation of deep conversion units in existing refineries but often these refineries are constrained by plot space, hydrogen and other infrastructural issues; grassroots export-oriented refineries are all geared towards high conversion to mid-distillates.

For the strategically-oriented refiner the stringent high quality product requirements actually present an opportunity to invest in the right technologies to significantly improve refinery margins. Based on increasing product demand and the closure of multiple non-performing refineries, refining margins are expected to recover by 2015. According to HART a shortage of refining capacity is expected after 2020.

Wider and more intense deployment requirement of emissions reduction technologies may also act as catalyst for new investments; modern hydroprocessing technology will eliminate the need for expensive downstream remediation technologies.

Finally, it is our view that refining should be viewed as an ongoing business where long-term average margins and product price differentials will support the investments that are needed.

Residue Upgrading Technologies

In view of the increasingly stricter regulations expected in the near future along with the emerging product demand trends, CLG evaluated multiple combinations of residue conversion technologies, keeping the following intent of a global refiner in mind:

The conversion technology:

- Should be commercially proven and reliable with good onstream factor
- Should maximize the most valuable product (diesel) while retaining the capability to address niche product demands for the foreseeable horizon
- Should be flexible to handle more difficult feedstocks
- Should be environmentally compliant to meet future stringent specifications

- Should have enough complexity so that the refinery remains profitable when margins remain depressed for prolonged periods (based on current trends only such refineries will survive in the future)
- Ideally, should be part of a conversion platform encompassing complementary technologies

Excluded were technologies on the cusp of commercialization because CLG did not want to prescribe any solution without a reasonably long operating history. For example, there are several slurry phase residue conversion processes on the verge of commercialization but without a commercial operating history there is no data on reliability and onstream factor, a major consideration in any residue upgrading process because of the difficult nature of the feedstock.

Major refinery processes included in this evaluation were:

- Delayed Coking
- LC-FINING (a high-conversion residue hydrocracking process)
- RDS (Residue Desulfurization)
- SDA (Solvent Deasphalting)
- Combinations of the above along with secondary processes such as hydrocracking, residue catalytic cracking (RFCC) and gasification (VR and Coke), FCC feed/product desulfurization and various gasoline producing processes

In the studies we conducted for various clients residue conversion technologies that rose to the forefront were Delayed Coking, LC-FINING and Residue Desulfurization. The screening phase quickly ruled out several technologies as being too expensive such as gasification, or because they were not geared towards maximizing diesel, the product of choice. A brief description of the primary upgrading processes follows:

Delayed Coking

Delayed Coking is the most widely used residue conversion technology and is particularly valuable when a long-term off take arrangement for coke exists. Almost every major grassroots refinery in the world has considered it as a primary residue conversion process with the exception of locations like Scandinavia, Western Europe, and Eastern Canada, where coking units are not preferred. Fuels grade coke is used in infrastructure projects (cement, power) and demand remains robust in developing countries. However, with even more large coking units coming on-line, coke demand could come under pressure.

Vacuum Residue, normally destined for fuel oil, is thermally cracked to obtain nearly 70% of distillate products. All distillate products require further hydroprocessing to make finished products. Coker Naphtha requires special and more severe hydroprocessing compared to straight-run naphtha. Light Coker Gas Oil (LCGO) that boils in the diesel boiling range has a much higher nitrogen content compared to straight-run diesel and operating pressures required for hydroprocessing are relatively higher. The Heavy Coker Gas Oil (HCGO) boils in the Vacuum Gas Oil (VGO) boiling range. HCGO has much higher total aromatics, nitrogen, polycyclic aromatics, and asphaltenes and requires more severe operating conditions compared to straight-run VGO. HCGO is either sent to a FCC feed pretreater (gasoline-oriented refinery) or a hydrocracking unit (diesel-oriented refinery). The coke produced by a standalone Delayed Coker is lower value fuel grade coke. If a hydroprocessing unit such as LC-FINING precedes the Delayed Coking unit, then the coke produced from the Delayed Coking unit can be of superior anode grade quality suitable for use in the aluminum industry. Table 1 presents the main advantages and disadvantages of the Delayed Coking process.

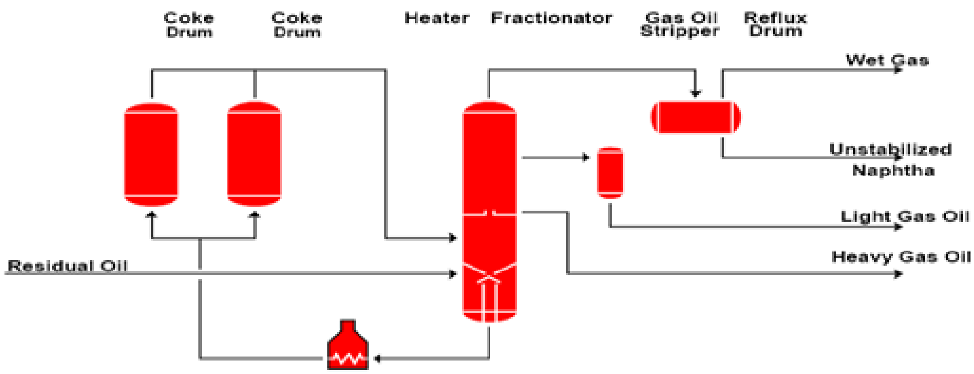


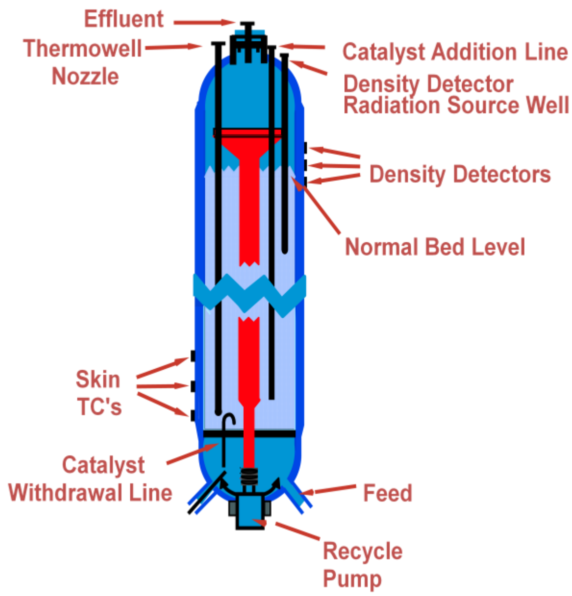
Figure 2: Schematic of a Delayed Coking Unit

Table 1

Advantages of Delayed Coking	Disadvantages of Delayed Coking
Lower “on plot” capital investment compared to hydrogen addition processes	Coke handling, plot area limitations, and transportation and logistics
Can handle very poor quality (high in contaminants) feeds	Additional Environmental Health and Safety (EHS) requirements
Widely used with many references	Hydrogen addition still required to upgrade products and the process does not share the same process platform as other hydroprocessing units
Favored in low crude oil price environment	Loss of liquid yield compared to hydrogen addition processes
No residual liquid product to deal with	Coke disposition is a major issue

LC-FINING

The LC-FINING process is a residuum conversion process that hydrocracks the most difficult, heavy, lower-value hydrocarbon streams such as petroleum residua, heavy oils from tar sands, shale oils, etc., to lighter more valuable products such as VGO, diesel, and naphtha. The process involves an ebullated bed reactor that completely mixes oil and hydrogen. Because of continuous addition and withdrawal of small quantities of catalyst, the run lengths between shutdowns, are long. Unconverted oil from the LC-FINING unit can be used as fuel oil, or as feed to power plants, or a Delayed Coking unit. Maximum conversion is dependent on feedstock. Operating unit conversion ranges from 60 to over 80%.



Reactor Temperature	410–440°C
Reactor Pressure	110–180 bar
Resid Conversion	55–80%
Hydrogen P. P.	75–125 bar
Chem H_2 Consumption	135–300 Nm^3/m^3
Desulfurization	60–85%
CCR Reduction	40–70%
Demetallization	65–88%

Figure 3: Schematic of a LC-FINING Reactor With Typical Operating Conditions

The LC-FINING unit operates at pressure levels similar to high-pressure hydroprocessing and therefore offers excellent opportunities for capital reduction by permitting integration of either hydrotreatment (Shell, Canada) or complete hydrocracking (Neste, Finland).

The conversion of Conradson carbon is economically important if LC-FINING vacuum bottoms are fed to a downstream coking unit. A lower carbon-content resid product to the coking unit means less coke-make and thus a higher yield of liquid fractions that can subsequently be converted to transportation fuels.

The LC-FINING unit has great inherent flexibility to meet variations in feed quality/throughput, product quality and reaction operating severities (temperature, space velocity, conversion, etc.). This flexibility is a direct result of the ebullated catalyst bed reactor system. In an ebullated bed unit, if the metals or sulfur content of the feed increases, the product quality is maintained by increasing catalyst consumption. Conversely, the catalyst consumption is reduced if the feed quality improves.

There are only two ebullated bed processes in the world which have been proven by long commercial history, LC-FINING and H-Oil. The LC-FINING process has benefitted enormously from the unmatched success in the last 10 years of commercialization of process and catalyst concepts and access to the vast amount of operating and pilot plant data. LC-FINING has demonstrated high on-stream factors and reliability in the operating units (in many units 3+ years between turnaround have been observed). Table 2, below provides the list of LC-FINING units running successfully.

Table 2

Start-Up	Client	BPSD	Unconverted Oil
2011	Shell Canada	47,300	Stable HSSC
2010	GS Caltex	60,000	Stable FO
2007	Neste Oil	40,000	Stable FO
2003	Shell Canada	79,000	Stable HSSC
2000	Slovnaft	23,000	Stable LSFO
1998	AGIP Petroli	25,000	Stable LSFO
1988	Syncrude Canada	40,000	Coker Feed
1984	BP-Amoco	75,000	Coker Feed
Total	**8 Units**	**389,300**	

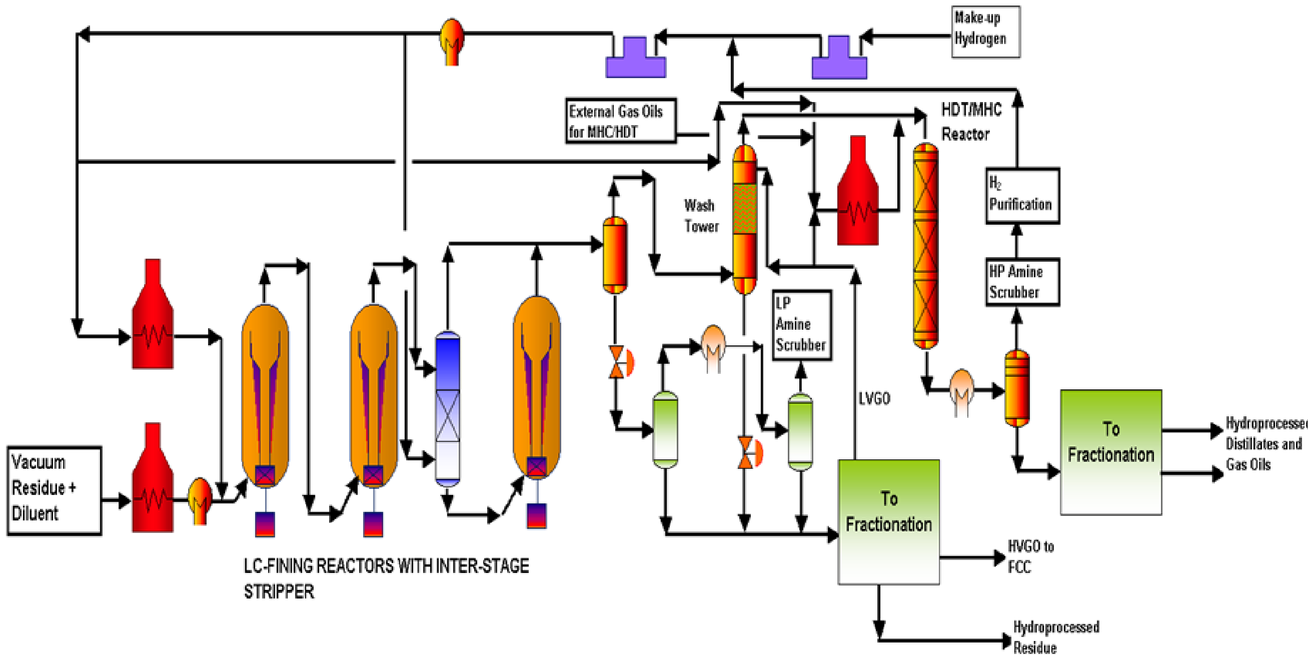


Figure 4: LC-FINING Process With Integrated Hydroprocessing

Table 3

Advantages of LC-FINING	Disadvantages of LC-FINING
Higher liquid gain compared to Delayed Coking	On plot investment is higher than Delayed Coking units
Can handle feeds higher in metals and other contaminants compared to fixed bed processes	Residue stability may become a concern at high conversions (Feed dependent). Middle Eastern feeds, for example, have no stability concerns even at high conversions (proven commercially)
Long run lengths	More complex process compared to Delayed Coking and requires better operator training
Can be integrated easily with other hydroprocessing units	Not as much commercial experience as Delayed Coking units but adequate
Ebullated Bed technology is a mature technology and 30+ years operating experience has led to many technological advances and made the process very reliable	Spent catalyst disposal (trucks, rail car) has to be considered. Spent catalyst normally sent to metals reclaimer.
Requires less plot space compared to Delayed Coking units	Unconverted oil disposition can become an issue depending on sulfur /stability specifications

The unconverted oil from the LC-FINING unit is normally used as fuel oil. When combined with a Delayed Coking unit downstream, the unconverted oil is converted to distillates and anode grade coke which fetches a far higher price compared to fuels grade coke. While LC-FINING can handle a relatively high metal content in the feed, the high level of nickel and vanadium in the unconverted LC-FINING bottoms could limit the production of anode grade coke in the downstream Delayed Coking unit. LC-FINING by itself produces significantly more liquid yield compared to Delayed Coking and improves the refiner's volume gain.

The LC-FINING process is also easily integrated with a solvent deasphalting unit either upstream (Figure 5), downstream (Figure 6) or, as recently invented by CLG, as an interstage process.

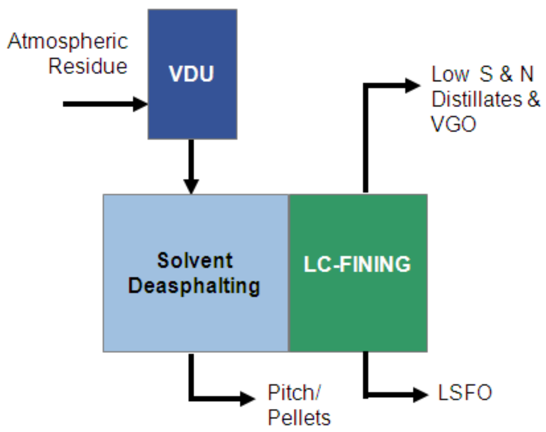


Figure 5: SDA Upstream of an LC-FINING Unit

An upstream SDA significantly reduces metals, CCR, and asphaltenes. Operating conditions required in the LC-FINING unit become less severe and conversions can be pushed much higher. The yield slate shifts towards lighter products and catalyst consumption drops significantly. Without the heavy asphaltenes in the process, unit operating factors improve as well. The obvious disadvantage is the loss of global conversion as a significant volume of residue is removed as pitch and without a dedicated disposition of the large volume of pitch (such as a gasifier); the economics may not be favorable. The option becomes very attractive in those situations where an SDA is already in operation and there is a need to upgrade the DAO to diesel rather than routing to an FCC for conversion to gasoline.

The SDA process can also be integrated downstream where the deasphalting removes the heaviest asphaltenic residue from the unconverted oil. The DAO can be recycled back to the LC-FINING process while the pitch can be blended in with incremental VR to an existing Delayed Coking unit (BP, Texas City). Conversion is boosted and the volume of pitch to be handled is reduced very significantly.

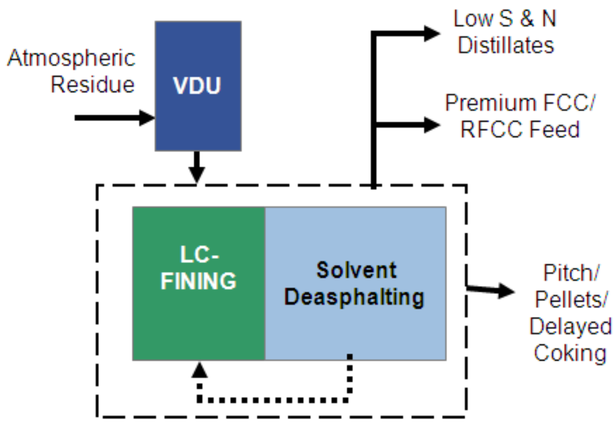


Figure 6: SDA Downstream of an LC-FINING Unit

The Residue Desulfurization (RDS) Process

Residue Desulfurization is a fixed bed process that has multiple beds of catalyst to remove metals, nitrogen and sulfur from petroleum residua in the presence of hydrogen. Conversion is resultant from the level of desulfurization required and is not by itself a target. The process is normally used to produce low sulfur fuel oil or to produce a feed stream that is suitable for cracking in a residue FCC (RFCC) unit.

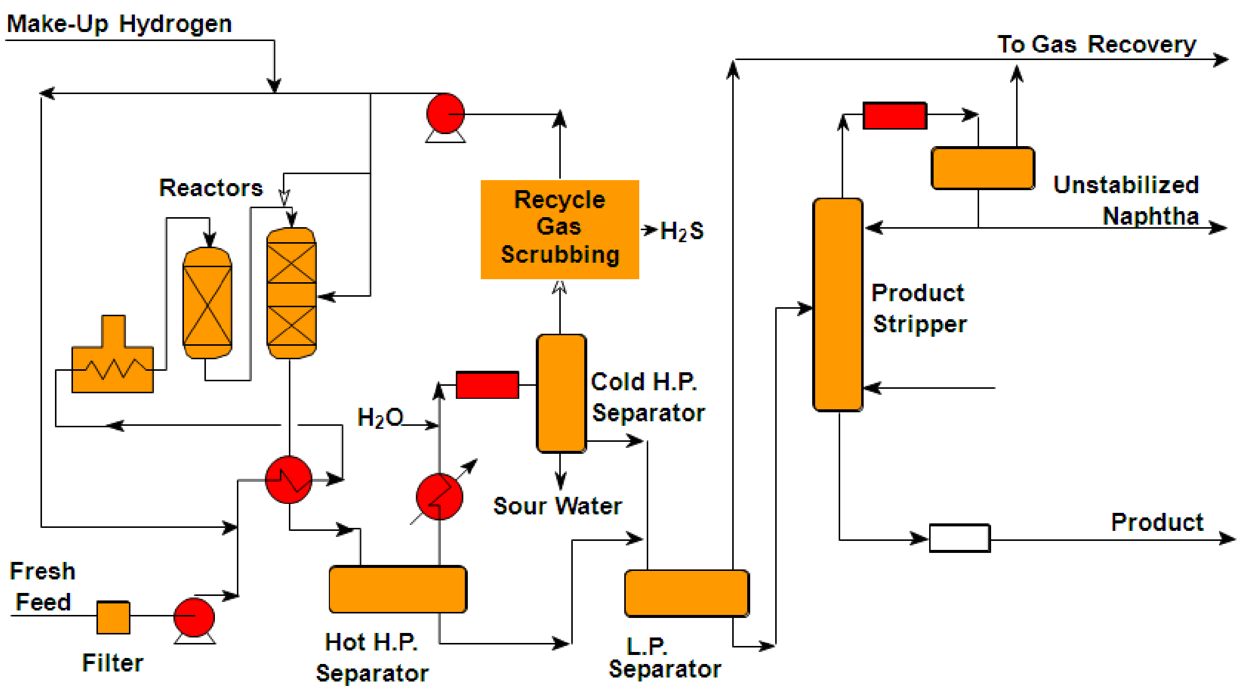


Figure 7: Schematic of RDS Process

The RDS process has benefitted from the combined experience of Gulf and Chevron corporations (when Chevron acquired Gulf) and is by far the most widely used residue upgrading process. Over the years CLG has invested heavily in both catalyst and process innovations including such unique process as Upflow Reactor (UFR) and Onstream Catalyst Replacement (OCR). UFR is typically used in revamp situations or when metals level and catalyst pore mouth plugging concerns might shorten traditional downflow reactor run lengths due to excessive pressure drop. OCR is used when metal level in the feed is excessive.

RDS is a widely used technology especially in the Far East. RDS is the only technology that can produce < 0.5 wt% sulfur fuel oil. The technology is used in this context in Japan but the most prevalent use of RDS is as a unit feeding a RFCC unit for the production of gasoline.

Attractive Upgrading Configurations of Choice

CLG explored several configurations including some novel process configurations that are based on the above commercially proven residue upgrading platforms along with other major processes like hydrocracker, hydrotreater and FCC to maximize conversion to mid-distillates. The configurations explored are presented below:

Refinery With Delayed Coking as Primary Upgrader

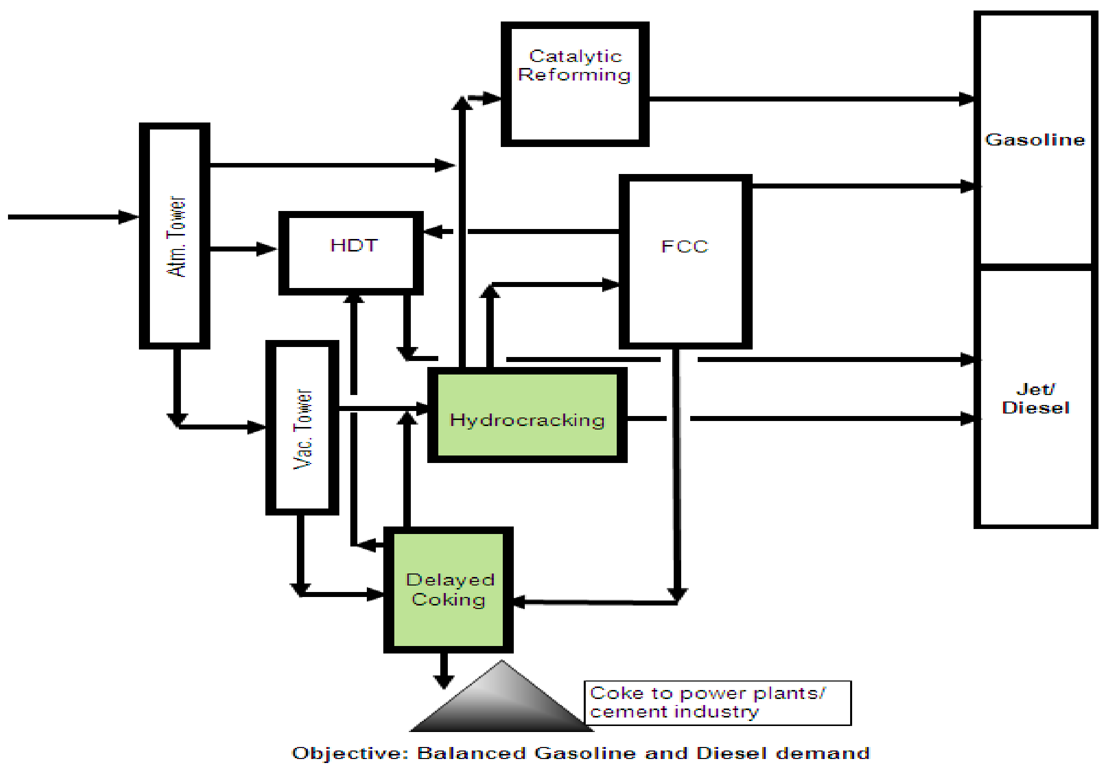
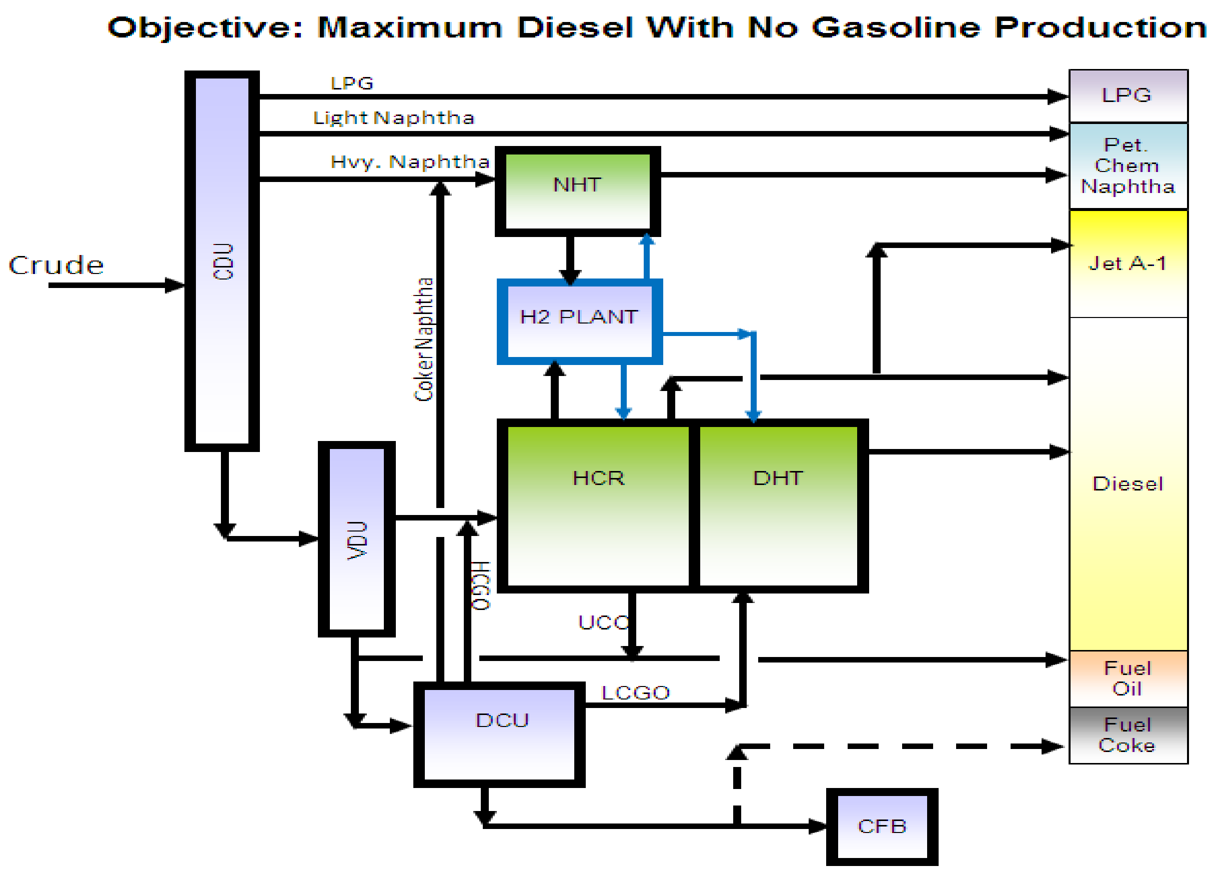


Figure 8: Simplified Refinery With Delayed Coking as Residue Conversion Process

The configuration shown above is one of the most common refinery configurations and is a benchmark configuration against which other configurations are evaluated. The configuration is robust and depending on the crude slate, the capacities of the hydrocracking and FCC unit vary to obtain the right balance between gasoline and diesel production. In extreme situations where gasoline production is to be avoided, the configuration will have no catalytic reforming and no FCC unit.



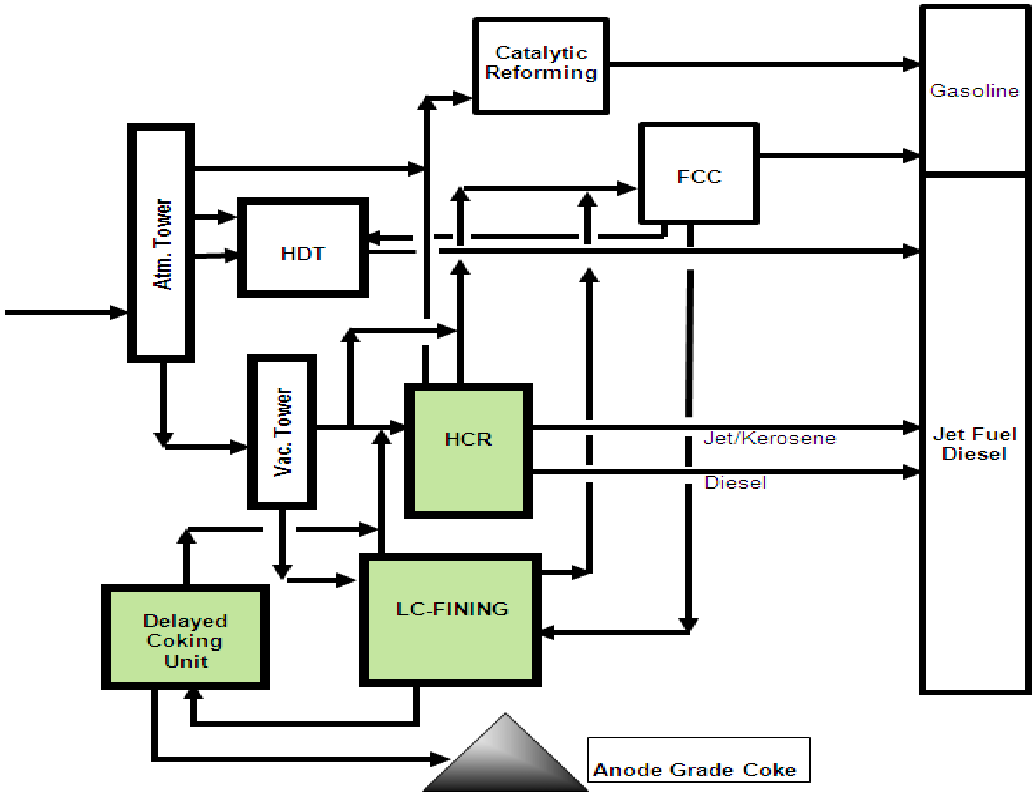
CFB: Circulating Fluidized Bed Boiler

Figure 9: A Delayed Coking Based Refinery With No Gasoline Production

Figure 9 is a modern refinery configuration developed by CLG where there is virtually no demand for gasoline and the refiner is only interested in making middle distillates and petrochemicals naphtha. Such a configuration is likely to become increasingly important in the next decade.

Further Optimization of the Delayed Coking-Based Refinery

Attractive as the configuration depicted in Figure 8 is, the overall profitability and return on investment improves significantly with the addition of the LC-FINING process to the upgrading of residue.



Objective: High middle distillate yield from heavy sour crudes, very high conversion
Eliminate Fuel Oil Production

Figure 10: Optimized Residue Conversion Using LC-FINING and Delayed Coking

The LC-FINING unit is the primary residue conversion process where conversion is pushed to maximum because unconverted oil stability is not an issue. The unconverted oil, low in sulfur and metals, is converted to high-priced anode grade coke in the Delayed Coking unit, which also converts part of the UCO to distillates to be processed in downstream hydroprocessing units. This configuration has no undesired or low valued products and is therefore truly “bottomless”.

Furthermore, the configuration is very amenable to phasing; the LC-FINING can be built first and will be profitable till such time as there is market for fuel oil. The Delayed Coking unit can be phased in after a few years.

Refinery Configuration With RDS as Primary Residue Upgrader

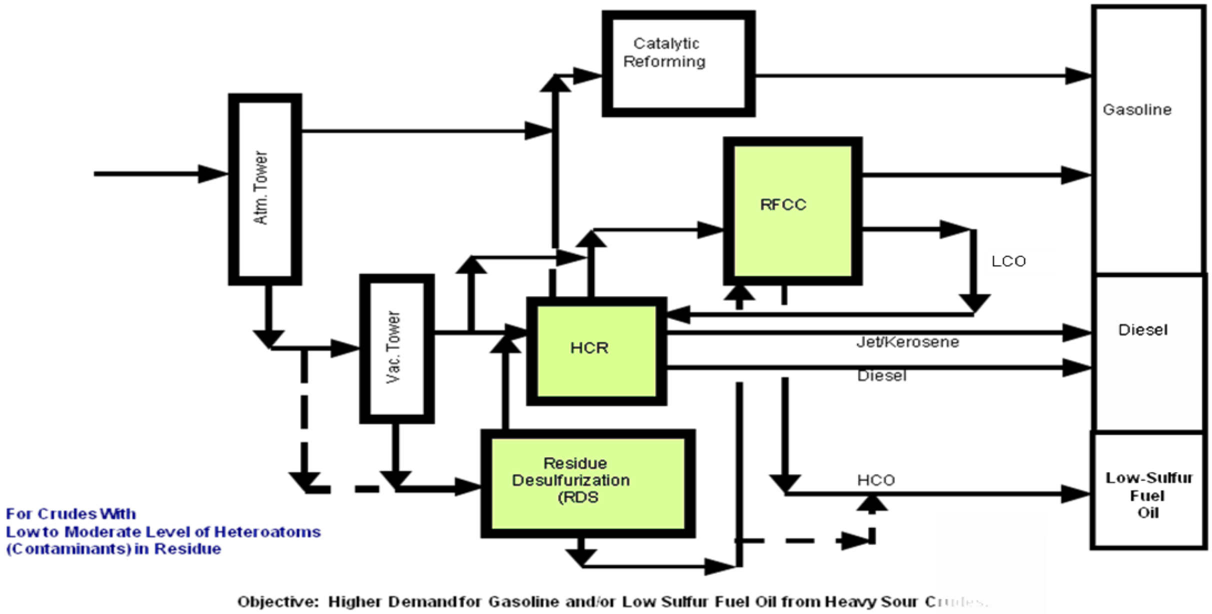


Figure 11: Refinery Scheme With RDS as Residue Upgrader

The solution with RDS becomes relevant when there is high premium for very low sulfur fuel oil and there is a fairly high demand for gasoline or alternately a market exists for incremental propylene from the RFCC. If maximizing diesel is the objective, then this configuration is not the optimum one because it will either make too much low sulfur fuel oil or too much gasoline, or significant quantities of both, at the expense of diesel. In a revamp scenario, CLG has successfully integrated RDS and hydrocracking technologies for ENI, Taranto refinery in Italy to produce Euro V diesel from residuum along with low sulfur fuel oil.

Recommended Configuration

After detailed analysis, CLG came to the conclusion that LC-FINING when combined with Delayed Coking provides the maximum returns and the highest NPV, followed by the Delayed Coking alone option. The recommended technology platform is proven and reliable and the solution is not dependent on the unreliable future of fuel oil. The solution is robust because LC-FINING and Delayed Coking can handle very difficult feeds. Furthermore, with the proliferation of Delayed Coking units worldwide, the solution will provide a refiner with a competitive edge in terms of higher volumetric gain (from LC-FINING) and the much higher priced anode grade product in most instances.

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