The Role of Solvent Deasphalting (SDA) In Refining

Presented by Sim Romero
Coking.Com

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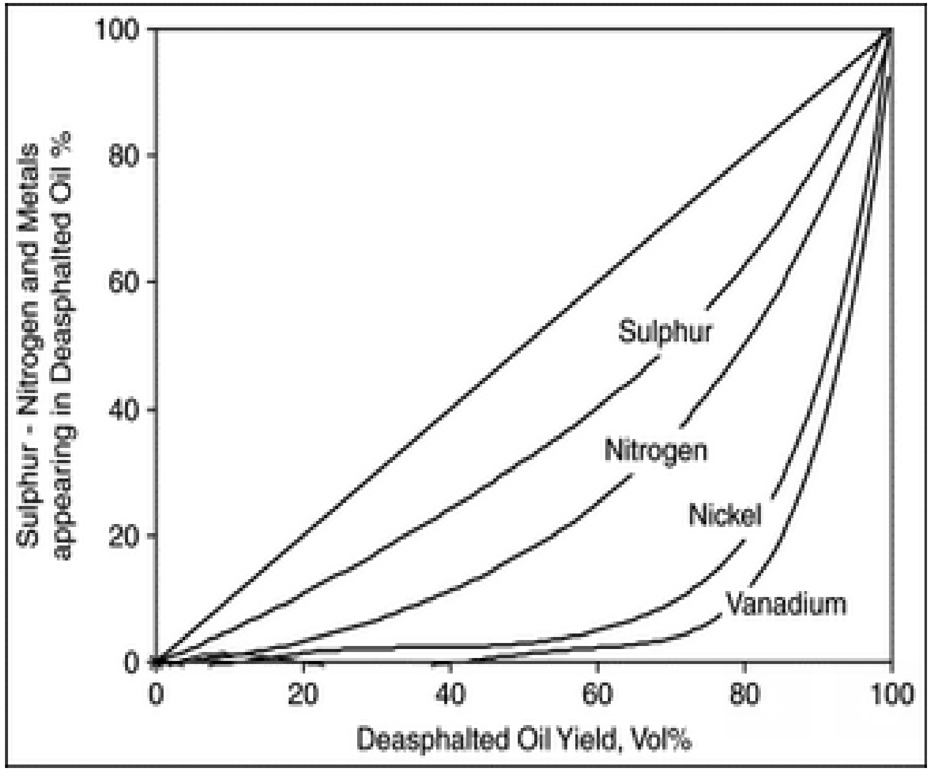
Introduction

Increased refinery margin capture is achieved by ensuring the right molecules end up in the right conversion units. This is referred to as molecular management and is typically done by producing different intermediate product boiling point cuts, i.e., Gas Oil streams are sent to the Fluid Catalytic Cracker Unit or Hydrocracking Unit while Vacuum Residue or Bottoms are sent to a Delayed Coker. A Solvent Deasphalting (SDA) unit provides a different approach to molecular management.

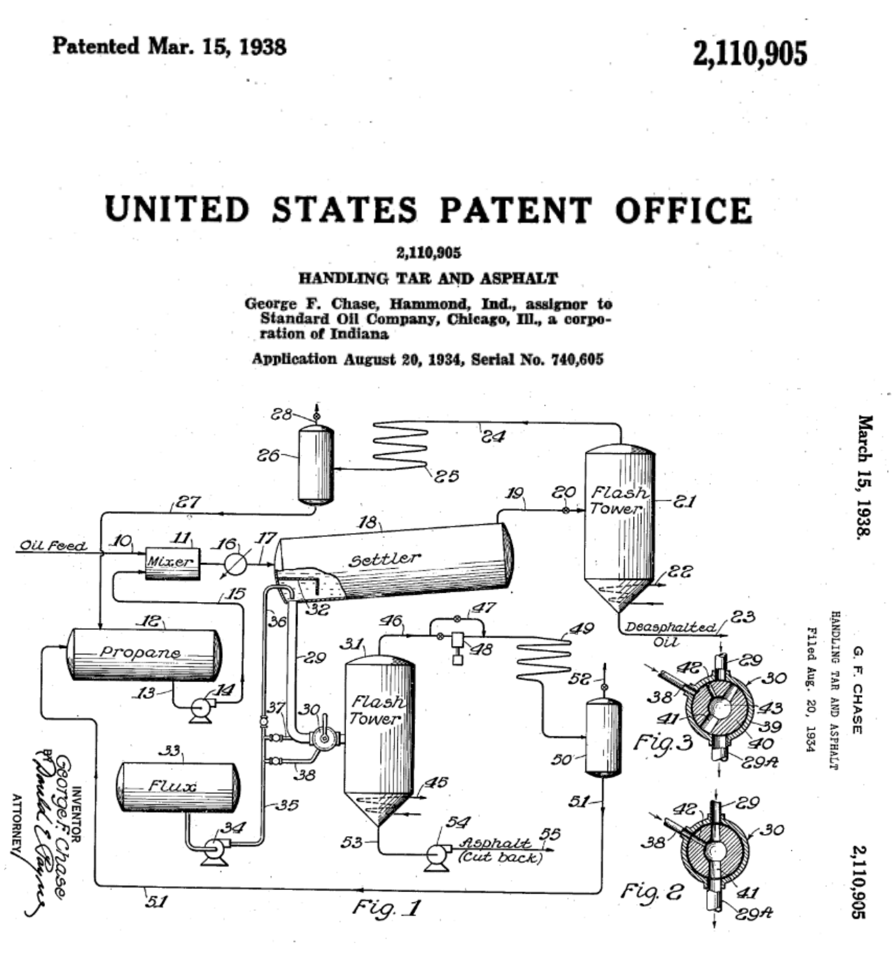
Solvent deasphalting or SDA is a separation process based on differences in molecular types rather than boiling point differences. SDA is a liquid-liquid extraction process where very heavy molecular weight asphaltenes are separated out of heavy oils. The SDA process separates the asphalt from the feedstock using a much lighter (low molecular weight) solvent hydrocarbon, which will dissolve aliphatic compounds but not asphaltenes. The output from the SDA unit is deasphalted oil ("DAO") and pitch or asphalt.

Solvent Deasphalting Basics



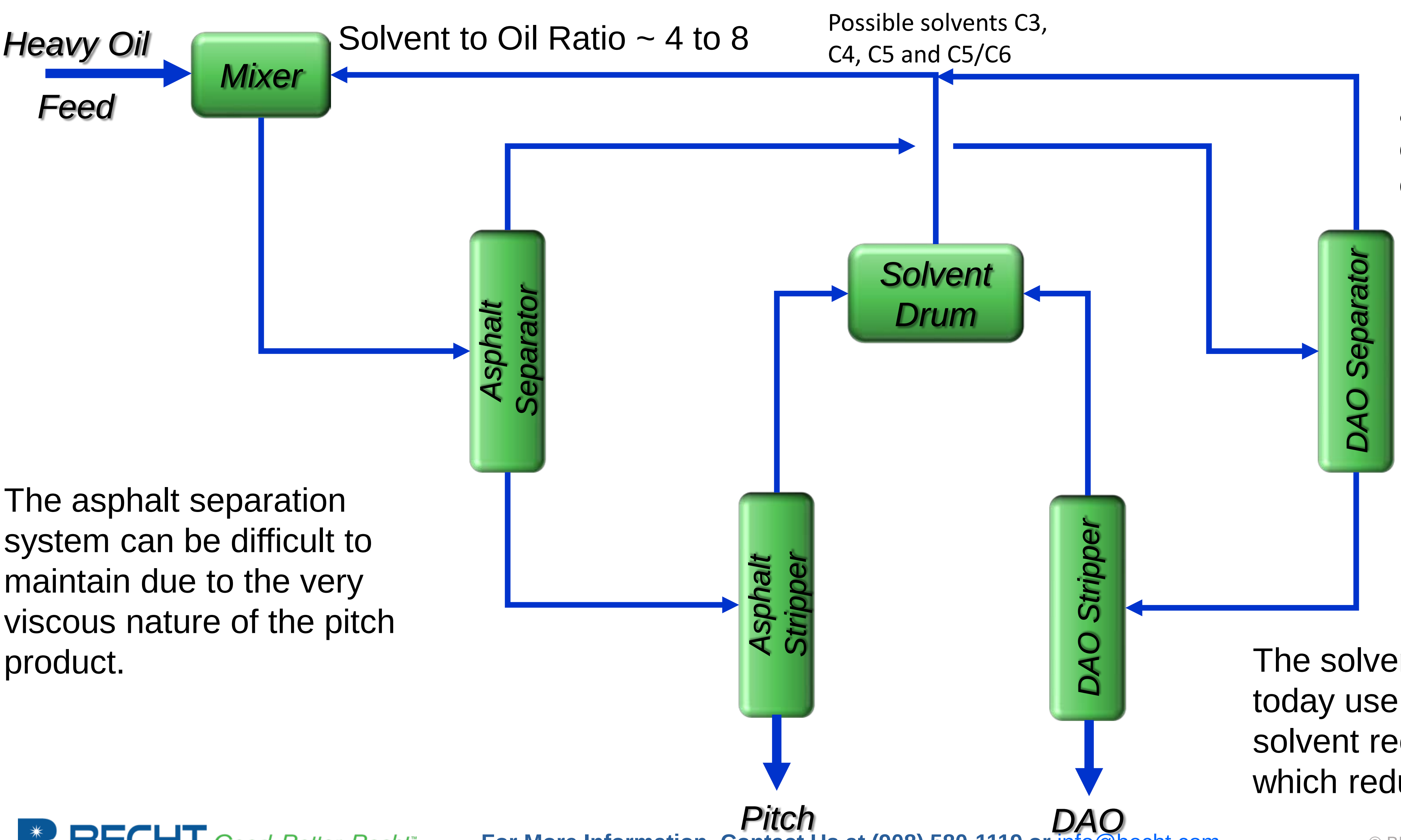
- The SDA process selectively separates by molecular type, mixing heavy hydrocarbons (i.e., vacuum bottoms residue) with a paraffinic solvent. The solvent precipitates out an asphaltene stream leaving a deasphalted oil product (DAO). The DAO product is a low-contaminant, relatively higher hydrogen oil product. The precipitated pitch product will contain the majority of the residue's contaminants (e.g., metals, asphaltenes, CCR).
- The yield of DAO is referred to as the lift, meaning how much DAO is lifted out of the feed – so a lift of 40% is a 40% yield of DAO. A DAO lift is dependent on the quality of the feed and the quantity of contaminants that can be tolerated in the DAO product. This graph shows the typical quality of the DAO for a given lift.
- The SDA process exploits the fact that most of the metals and a significant amount of nitrogen with a lesser amount of sulfur are chemically bonded to the asphaltene type molecules. Very few metals are in the more paraffinic or aliphatic type molecules.

SDA – Background History



- Solvent deasphalting technology is not a new technology with the earliest patent in 1938, which was a primitive propane deasphalting process.
- A more detailed and complex process was soon developed in the mid 1950’s and later was integrated into the crude and vacuum unit.
- For several years, the process was referred to as Propane Deasphalting as the solvent used was propane.
- Today, the SDA process can use C3, C4, and C5 or some mixture to further optimize the DAO/Pitch separation. The lighter the solvent, the cleaner the DAO but the lower the recovery.
- Additionally, the SDA process has been modified to add a third product stream or cut to allow a cleaner DAO and a slightly dirtier DAO or resin product (i.e., less paraffins and containing slightly more contaminants).
- Finally, both Kerr-McGee (now KBR) and UOP in the early 1980’s developed a supercritical solvent recovery process – KBR’s ROSE process (Residuum Oil Supercritical Extraction) and UOP’s Demex (demetallization), which allows for a more energy efficient recovery of the solvent.

SDA – Process Basics



Higher MW solvents will increase DAO lift but will also increase the contaminants (metals and concarbon) in the DAO.

The asphalt separation system can be difficult to maintain due to the very viscous nature of the pitch product.

The solvent recovery systems today use a supercritical solvent recovery system, which reduces operating costs.

SDA - Molecular Management

There are many different scenarios where the SDA process might fit into a modern refinery but ultimately use of the process depends on

- Crude types being fed to the refinery – Are crude type consistently of one type (i.e., heavy sour crudes) or is there wide variety of crude types that frequently change?
- Existing bottoms upgrading capacity – The delayed coke does best with a relatively consistent feed type
  - Large differences in crude types, i.e., high paraffinic crude mixed with high asphaltic crude, do not do well in the coker and the SDA before the coker can dampen these types of coker feed variations.
- Heavy gas oil downstream capacity and disposition – The DAO flow and quality must be well thought-out
  - The downstream gas oil processing will have significant changes in feed quality and flow rates

The SDA process is an addition to molecular management – sending the right molecules to the right conversion unit can significantly change the dynamics of downstream operation such as the Delayed Coker, the FCC, and any Heavy Gas Oil Treating.

SDA - Application

- The SDA process can be a good supplemental process unit, allowing for the debottlenecking of the Vacuum Tower and/or the Delayed Coker. The SDA process does not eliminate the bottoms of the barrel; however, it can avoid expansion projects in both the Vacuum Tower or the Delayed Coker. There are very few large SDA units, and most are well under 50,000 BPD.

- In considering a revamp or installation of SDA, comparative analysis on cost, location, and infrastructure along with emissions need to be part of the review.

- Today's economics drive refiners to avoid a fuel oil product or pitch product. Additionally, the SDA pitch is generally not a good feed for road asphalt. This economic reality results in the need to further process the pitch, i.e., feed to the Delayed Coker, Fluid/Flexi Coker, H-Oil, or LC-Finer.

- Additionally, the SDA unit can "cleanup" a feed to the FCC or Resid FCC (a more typical Asian configuration). The DAO generated in the SDA is extremely friendly/beneficial to the FCC or RFCC and has some economic potential. In a high lift DAO scenario, the DAO can also go to an ebullated-bed reactor. Finally, depending upon the crude, it is possible to produce a lube oil from the DAO, which was historically a common practice.

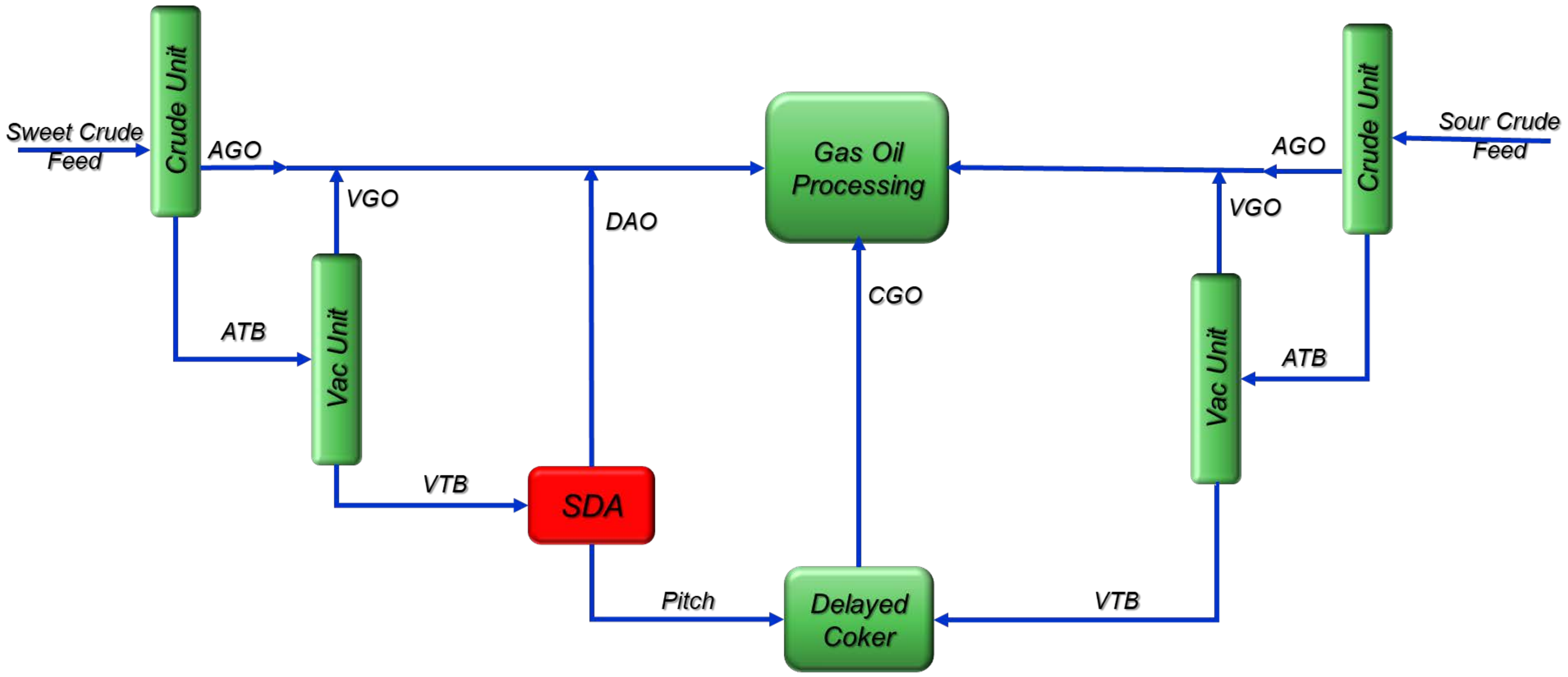
SDA - Application

Parallel vs. After a Vacuum Unit

- SDA running in parallel reduces some load to the Vacuum Unit. The resulting DAO will be a full range gas oil and the pitch will have a significant low boiling front end, albeit aromatic.
- The Vacuum Tower cannot achieve a deep cut. This option pulls the more paraffinic molecules out of the VTB and concentrates the contaminants (i.e., metals, asphaltenes, and conradson carbon) into the pitch, which a Delayed Coker can more easily process.

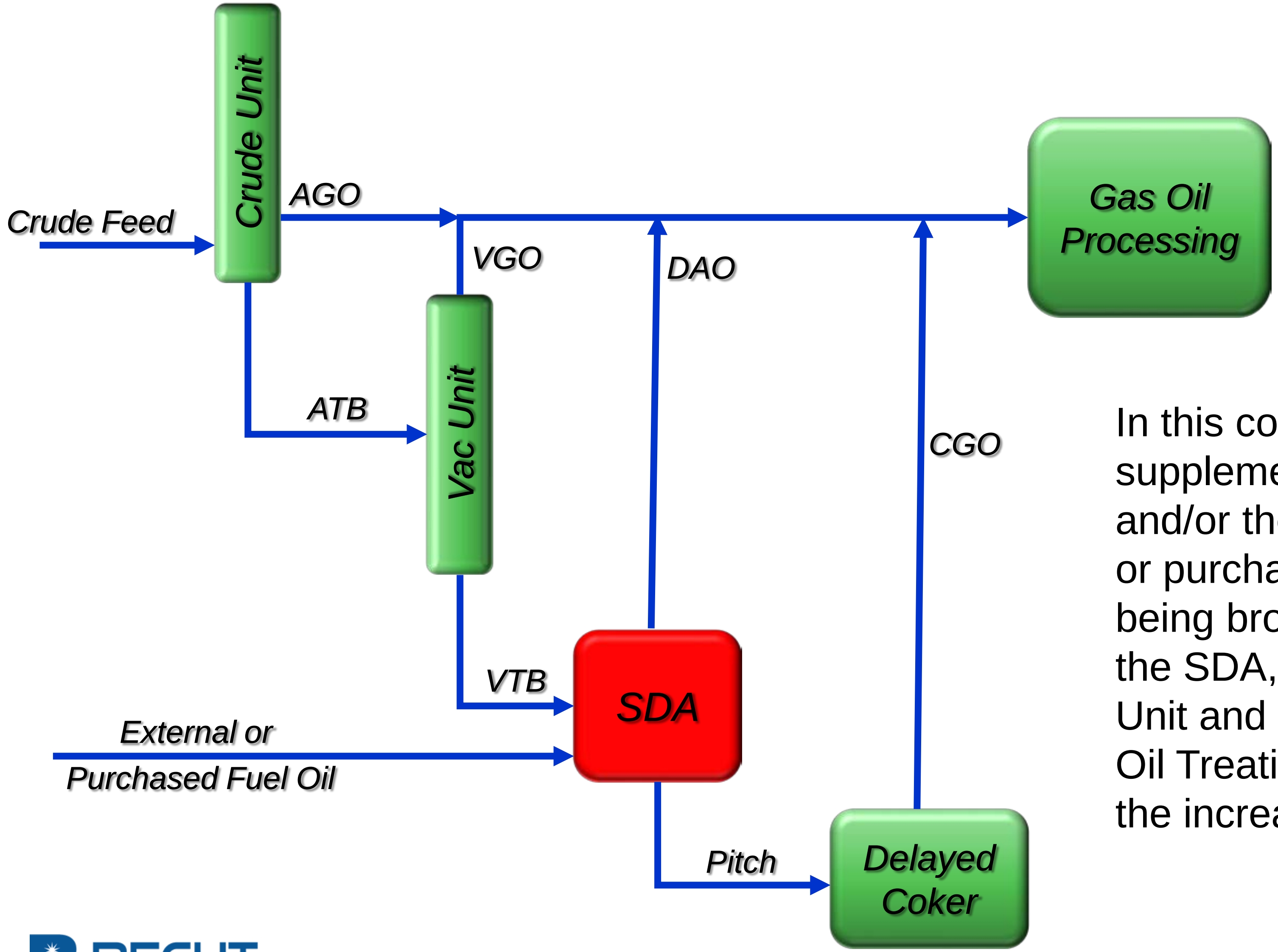
With the increase in Light Tight Oils (i.e., Bakken and Eagle Ford crudes) there is the potential for integrating a SDA process to help eliminate the potential crude compatibility problem, which can occur with blending dissimilar crudes. These compatibility problems can be partially addressed by keeping the heavy sour crudes segregated from the light sweet crudes, but problems then occur when the dissimilar VTBs are fed to the Delayed Coker. The high paraffin VTB can be made to behave in the Delayed Coker very much like the VTBs produced from a heavy sour crude, eliminating some of the reliability issues related to dissimilar streams fed to the Coker.

SDA Configuration Case 1



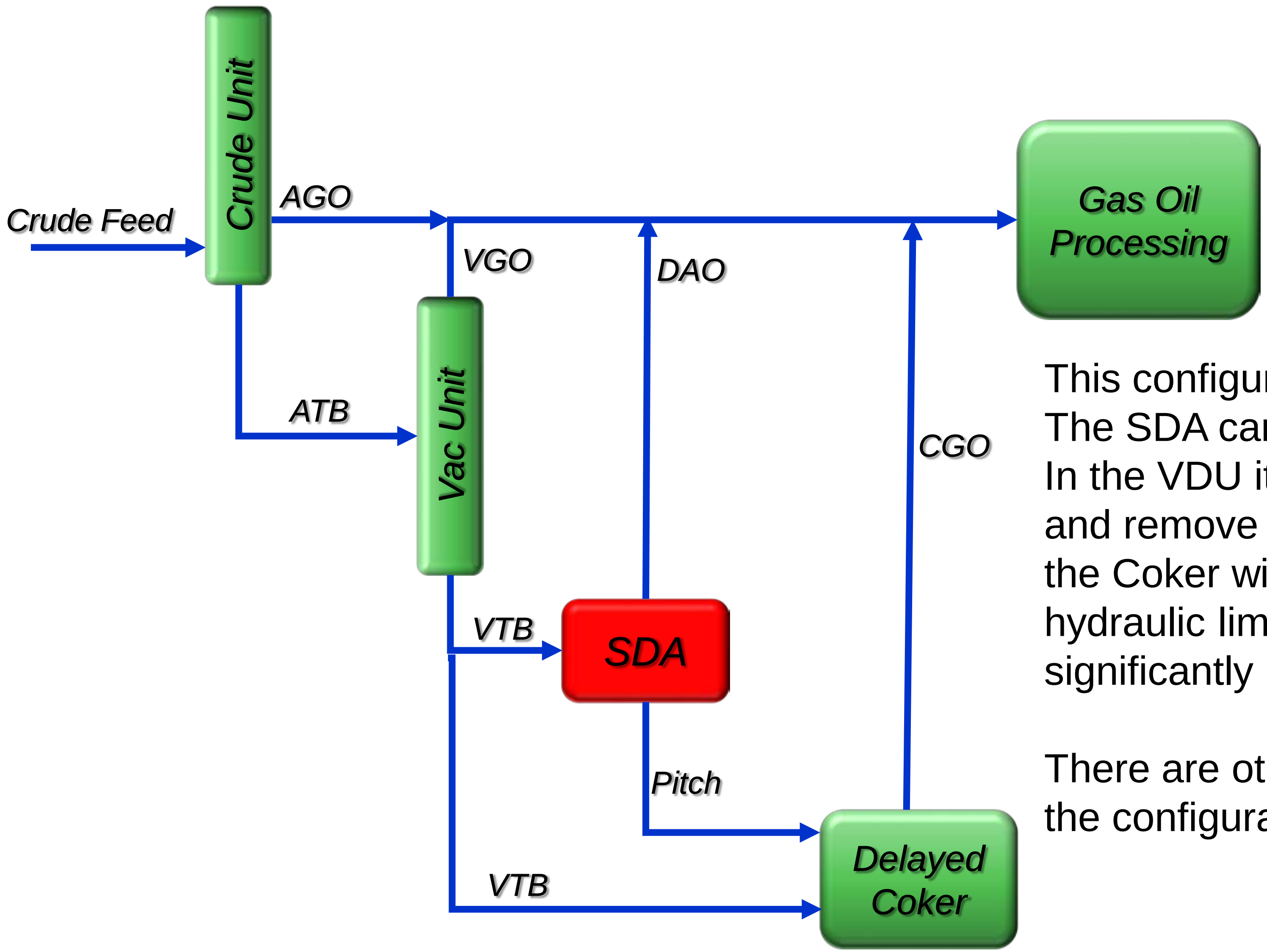
This configuration addresses crude incompatibility problems in the coker. More paraffinic material is removed from the Coker feed, allowing the Coker to process feeds that will not have solubility problems. Additionally, this configuration will unload the Delayed Coker fired heat further improving the Delayed Coker run length and reliability.

SDA Configuration Case 2



In this configuration, the SDA is being used to supplement or unload capacity in the Vacuum Unit and/or the Delayed Coker. Additionally, an External or purchased fuel oil (containing cutter and resid) is being brought into the refinery and preprocessed in the SDA, which further unloads both the Vacuum Unit and Delayed Coker. Here again, the Heavy Gas Oil Treating system must be reviewed/evaluated for the increase in capacity.

SDA Configuration Case 3



This configuration is what is most frequently seen. The SDA can support both the VDU and/or the DCU. In the VDU it can address poor cut point operations and remove some load from the Coker. Unloading the Coker will improve the fired heater capacity and hydraulic limitation. However, the SDA does not significantly reduce the amount of coke produced.

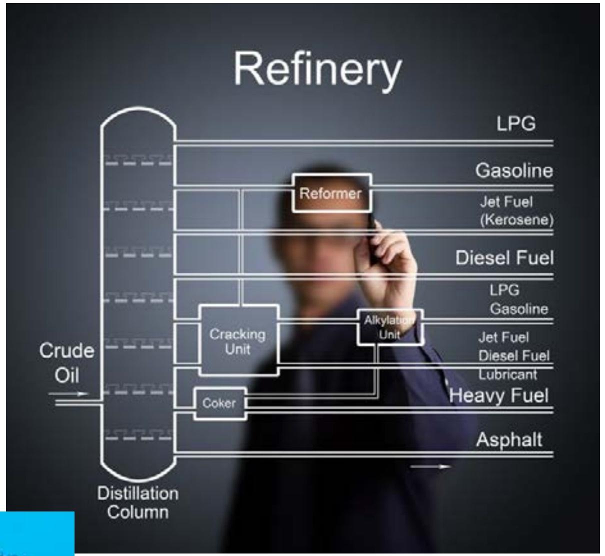
There are other configurations possible, but this is the configuration that we will expand on.

SDA – Overall Consideration

- Numerous refineries have started to feed the Delayed Coker external or purchased fuel oils. This is in part due to unused capacity resulting from very low light sweet crude processing and very attractive fuel oil prices as a result of the new IMO2020 restriction on using fuel oil with high sulfur (above 0.5 wt%). These fuels can contain significant amounts of cutter, which can add to the capacity constraints in the Delayed Coker. The SDA could also be used to lift this cutter out of the purchase or external fuel oil, but problems can occur if the variability of the fuel oil cutter type and content is extreme.

- Delayed coking has been an economically proven process for processing the bottom of the barrel. The Delayed Coker can do very well with very heavy, sour, high wt% asphaltene VTB. The historical reliability concerns and possible constraints can be addressed with the addition of an SDA process, but this very much depends on the constraints of the site.

Complete Refinery Model

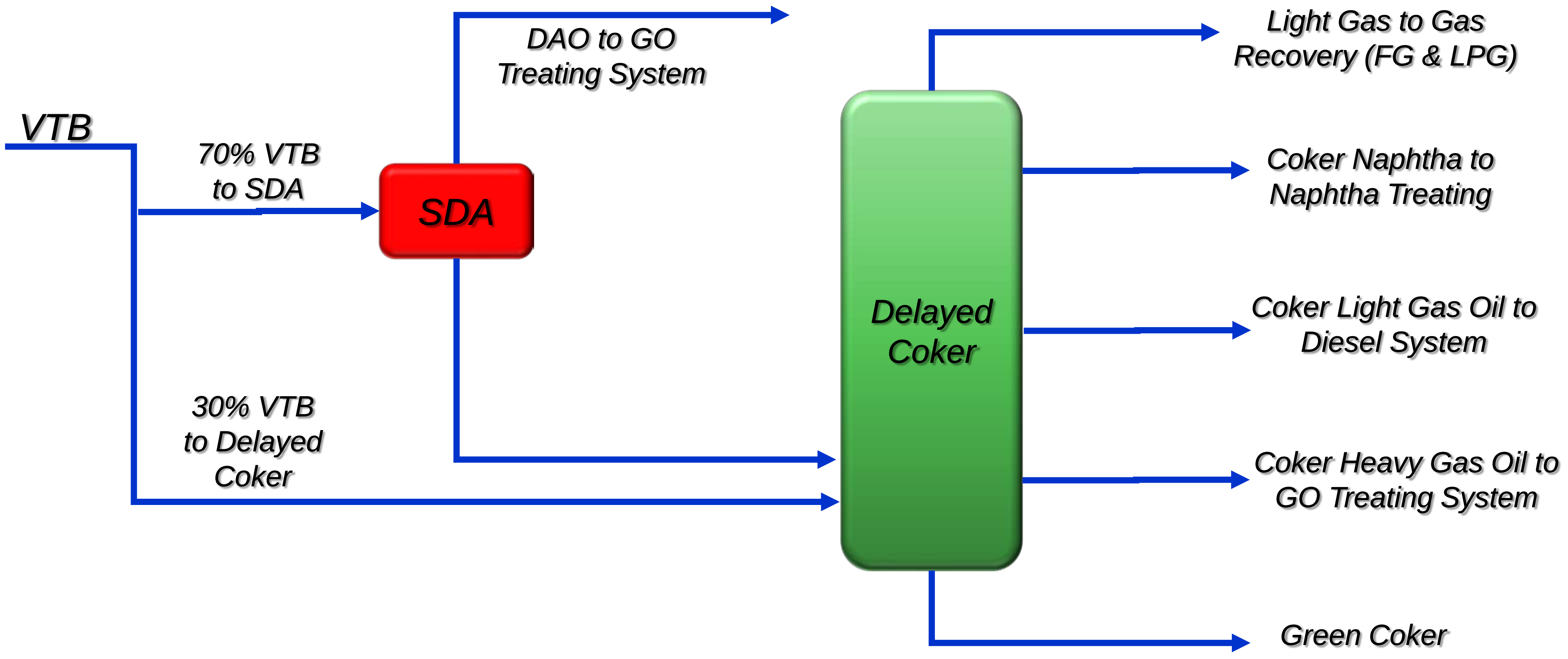


To effectively evaluate the SDA economics, it must be modeled within the whole refinery environment.

In a whole refinery simulation it is possible to quickly and easily measure the complete refinery economic impact to various configurations and unit constraints.

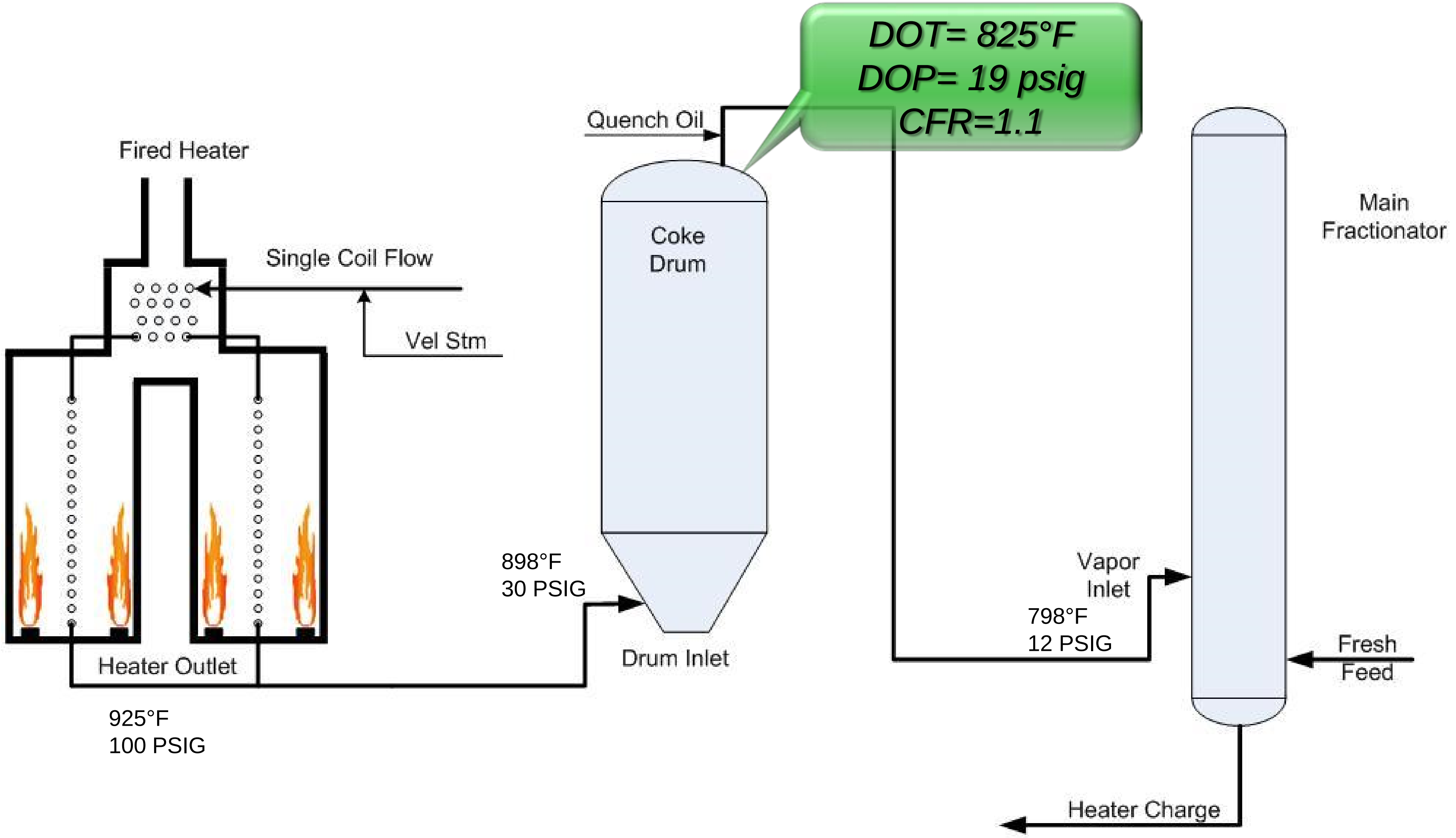
Becht can now simulate a complete refinery with all the details of the individual process units and final product blending. This allows for determining optimal configuration and operating scenarios and provides opportunities to maximize refinery margins.

Subset of the Whole Refinery Model



From the Resid Pool, the residue is sent to either the SDA or directly to the Delayed Coker. In this study, 70% is sent to the SDA and 30% to the DCU directly. The pitch or asphalt produced in the SDA is fed to the Coker. All the Coker products and the SDA DAO are then sent to downstream processing systems.

Base Case Delayed Coker Operations



The Delayed Coker's operations were kept constant and reflect a typical Delayed Coker. The Coker is a small (~25,000 BPD), 2 drum (26ft ID) Coker, operating with approximately a 16-hour fill cycle.

Summary of Results

	BPD	API	Lbs/Hr	wt%
Total VTB	24,893	6.74	371,372	100.0%
VTB to Solvent De-Asphalting (SDA)				
De-Asphalted Oil (DAO)				
SDA Pitch				
Total SDA Products				
SDA Pitch to Delayed Coker	0		0	0.0%
VTB to Delayed Coker	24,893	6.74	371,372	100.0%
Total Feed to Coker	24,893		371,372	100.0%
Delayed Coker Products				
H2S			4,797	1.3%
NH3			280	0.1%
Fuel Gas			20,802	5.6%
C3s			5,335	1.4%
C4s			4,730	1.3%
Naphtha	4,314	54.83	47,747	12.9%
Light Coker Gas Oil	7,298	34.84	90,483	24.4%
Heavy Coker Gas Oil	6,445	19.14	88,241	23.8%
Coke			108,958	29.3%
Total Coker Products			371,372	100.0%
Coke Drum Results				
C-Factor	0.31			
Fill Time (hours)	15.94			
Foam Height (ft) w/o	11.23	without Antifoam		
Foam Height (ft)	5.62	without Antifoam		
Foaming Potential	13.9%			
Heater (MM BTU/Hr)	116.10			

	BPD	API	Lbs/Hr	wt%
Total VTB	24,893	6.74	371,372	100.0%
VTB to Solvent De-Asphalting (SDA)	17,425	6.74	259,961	100.0%
Solvent De-Asphalting (SDA) Products				
De-Asphalted Oil (DAO)	3,485	25.02	45,919	17.7%
SDA Pitch	13,941	2.82	214,042	82.3%
Total SDA Products	17,426		259,961	100.0%
SDA Pitch to Delayed Coker	13,941	2.82	214,042	65.8%
VTB to Delayed Coker	7,468	6.74	111,412	34.2%
Total Feed to Coker	21,409		325,453	100.0%
Delayed Coker Products				
H2S			4,386	1.3%
NH3			269	0.1%
Fuel Gas			18,966	5.8%
C3s			4,797	1.5%
C4s			4,260	1.3%
Naphtha	3,776	54.49	41,867	12.9%
Light Coker Gas Oil	6,378	34.52	79,229	24.3%
Heavy Coker Gas Oil	4,733	19.53	64,634	19.9%
Coke			107,046	32.9%
Total Coker Products			325,453	100.0%
Coke Drum Results				
C-Factor	0.27			
Fill Time (hours)	16.16			
Foam Height (ft)	7.62	with Antifoam		
Foam Height (ft)	3.81	without Antifoam		
Foaming Potential	0.4%			
Heater (MM BTU/Hr)	99.60			

	BPD	API	Lbs/Hr	wt%
Total VTB	24,893	6.74	371,372	100.0%
VTB to Solvent De-Asphalting (SDA)	17,425	6.74	259,961	100.0%
Solvent De-Asphalting (SDA) Products				
De-Asphalted Oil (DAO)	6,970	16.82	96,913	37.3%
SDA Pitch	10,455	0.75	163,047	62.7%
Total SDA Products	17,425		259,961	100.0%
SDA Pitch to Delayed Coker	10,455	0.75	163,047	59.4%
VTB to Delayed Coker	7,468	6.74	111,412	40.6%
Total Feed to Coker	17,923		274,459	100.0%
Delayed Coker Products				
H2S			3,949	1.4%
NH3			254	0.1%
Fuel Gas			15,930	5.8%
C3s			3,735	1.4%
C4s			3,351	1.2%
Naphtha	2,922	52.04	32,832	12.0%
Light Coker Gas Oil	4,883	32.33	61,474	22.4%
Heavy Coker Gas Oil	3,782	17.63	52,297	19.1%
Coke			100,638	36.7%
Total Coker Products			274,459	100.0%
Coke Drum Results				
C-Factor	0.22			
Fill Time (hours)	17.14			
Foam Height (ft)	6.04	with Antifoam		
Foam Height (ft)	3.02	without Antifoam		
Foaming Potential	0.0%			
Heater (MM BTU/Hr)	82.50			

As the SDA lift increases, the total liquids produced from the combined SDA and DCU increase, which will significantly affect the economics of the refinery. Additionally, the Coker heater and coke drums reliability improve. However, too much lift will start to negatively affect the downstream process.

SDA Economics – 20% Lift

YIELD, ECONOMIC, AND GROSS MARGIN SUMMARY	
Δ Gross Margin, MM$/yr	$15.23
Δ Gross Margin, $/bbl Crude	$0.26

Price Basis Selector	Example		Case Selector	5	6		
			Case Type	Base	Case		
			Case Title	100% Coker, 0% SDA	30% Coker, 70% SDA, 20% Lift	Δ Case - Base	Δ Case - Base
	Pricing		Stream Rates			Stream Rates	Cash Flow
	UOM	Price	UOM				MM$/day
Feeds							
Crude 1	$/bbl	50.00	BPD	150,000	150,000	0	$0.00
Crude 2	$/bbl	45.00	BPD	0	0	0	$0.00
Normal Butane	$/bbl	35.00	BPD	62	0	-62	($0.00)
Iso Butane	$/bbl	45.00	BPD	0	0	0	$0.00
Import Ethanol	$/bbl	70.00	BPD	0	0	0	$0.00
Natural Gas	$/MMBtu	3.00	MMBtu/hr	0.0	0.0	0	$0.00
High Purity H2	$/MSCF	4.30	MSCFH	1,846	2,080	234	$0.02
Total Feeds			**MM$/Day**	$7.69	$7.71		$0.02
Total Crude			**BPD**	150,000	150,000	0	
Products							
Refinery Fuel Gas	$/MMBtu	3.00	MMBtu/hr	2799	2717	-81	($0.01)
H2 Plus Unrecovered H2S	$/MMBtu	2.00	MMBtu/hr	114	115	0	$0.00
Propane	$/bbl	30.00	BPD	1774	1767	-8	($0.00)
Iso Butane	$/bbl	45.00	BPD	722	715	-7	($0.00)
Normal Butane	$/bbl	35.00	BPD	0	12	12	$0.00
Propylene	$/bbl	50.00	BPD	3050	3240	190	$0.01
Conventional Regular	$/bbl	75.00	BPD	62112	62036	-76	($0.01)
Conventional Premium	$/bbl	85.00	BPD	0	0	0	$0.00
RBOB Regular	$/bbl	75.00	BPD	0	0	0	$0.00
RBOB Premium	$/bbl	85.00	BPD	0	0	0	$0.00
Jet	$/bbl	85.00	BPD	21127	21126	0	($0.00)
ULSD 1	$/bbl	90.00	BPD	39256	40130	874	$0.08
Low Sulfur Fuel Oil	$/bbl	55.00	BPD	2453	2209	-244	($0.01)
High Sulfur Fuel Oil	$/bbl	45.00	BPD	0	0	0	$0.00
FCC Coke	$/MMBtu	3.00	MMBtu/hr	477	486	9	$0.00
Coker Coke	$/long te	100.00	long te/day	1167	1147	-20	($0.00)
Total NH3	$/long te	0.00	long te/day	18	18	0	$0.00
Sulfur	$/long te	20.00	long te/day	364	365	0	$0.00
Total Products			**MM$/Day**	$10.69	$10.75		$0.07
Gross Margin			**MM$/Day**	$3.00	$3.04		
Gross Margin			**$/bbl Crude**	$20.00	$20.26		

The 20% lift results in an increase in refinery crude margin of about $0.26 per Crude Bbl
or
15.23 MM$/yr

The analysis was done on a fictitious refinery configuration. The cost data was also estimated and shows an overall high refinery margin. This exercise is meant to illustrate the complexity of evaluation and the impact the SDA can have on the refinery economics.

SDA Economics – 40% Lift

YIELD, ECONOMIC, AND GROSS MARGIN SUMMARY

Δ Gross Margin, MM$/yr	$28.02
Δ Gross Margin, $/bbl Crude	$0.48

Price Basis Selector	Example		Case Selector	5	7		
			Case Type	Base	Case		
			Case Title	100% Coker, 0% SDA	30% Coker, 70% SDA, 40% Lift	Δ Case - Base	Δ Case - Base
	Pricing		Stream Rates			Stream Rates	Cash Flow
	UOM	Price	UOM				MM$/day
Feeds							
Crude 1	$/bbl	50.00	BPD	150,000	150,000	0	$0.00
Crude 2	$/bbl	45.00	BPD	0	0	0	$0.00
Normal Butane	$/bbl	35.00	BPD	62	0	-62	($0.00)
Iso Butane	$/bbl	45.00	BPD	0	0	0	$0.00
Import Ethanol	$/bbl	70.00	BPD	0	0	0	$0.00
Natural Gas	$/MMBtu	3.00	MMBtu/hr	0.0	0.0	0	$0.00
High Purity H2	$/MSCF	4.30	MSCFH	1,846	2,310	464	$0.05
Total Feeds			**MM$/Day**	$7.69	$7.74	[redacted]	$0.05
Total Crude			**BPD**	150,000	150,000	0	
Products							
Refinery Fuel Gas	$/MMBtu	3.00	MMBtu/hr	2799	2649	-149	($0.01)
H2 Plus Unrecovered H2S	$/MMBtu	2.00	MMBtu/hr	114	115	0	$0.00
Propane	$/bbl	30.00	BPD	1774	1692	-83	($0.00)
Iso Butane	$/bbl	45.00	BPD	722	702	-20	($0.00)
Normal Butane	$/bbl	35.00	BPD	0	53	53	$0.00
Propylene	$/bbl	50.00	BPD	3050	3307	257	$0.01
Conventional Regular	$/bbl	75.00	BPD	62112	62032	-80	($0.01)
Conventional Premium	$/bbl	85.00	BPD	0	0	0	$0.00
RBOB Regular	$/bbl	75.00	BPD	0	0	0	$0.00
RBOB Premium	$/bbl	85.00	BPD	0	0	0	$0.00
Jet	$/bbl	85.00	BPD	21127	21125	-1	($0.00)
ULSD 1	$/bbl	90.00	BPD	39256	40863	1607	$0.14
Low Sulfur Fuel Oil	$/bbl	55.00	BPD	2453	2195	-258	($0.01)
High Sulfur Fuel Oil	$/bbl	45.00	BPD	0	0	0	$0.00
FCC Coke	$/MMBtu	3.00	MMBtu/hr	477	498	22	$0.00
Coker Coke	$/long te	100.00	long te/day	1167	1088	-79	($0.01)
Total NH3	$/long te	0.00	long te/day	18	19	1	$0.00
Sulfur	$/long te	20.00	long te/day	364	366	1	$0.00
Total Products			**MM$/Day**	$10.69	$10.81	[redacted]	$0.13
Gross Margin			**MM$/Day**	$3.00	$3.07		
Gross Margin			**$/bbl Crude**	$20.00	$20.48		

The 40% lift results in an increase in refinery crude margin of about $0.43 per Crude Bbl
Or
28.02 MM$/yr

The analysis was done on a fictitious refinery configuration. The cost data was also estimated and shows an overall high refinery margin. This exercise is meant to illustrate the complexity of evaluation and the impact the SDA can have on the refinery economics.

When Does SDA Not Make Sense?

- When the Coker has sufficient capacity
  - The cycle time is not limiting – i.e., there is a >16-hour fill cycle
  - The fired heater heat flux is low – i.e., average radiant heat flux is < 10,000 BTU/hr/ft^2
  - The Coker main fractionator and gas recovery system are not limiting
- When the Vacuum unit is achieving a deep cut, i.e., VTB cut point is > 1,030°F

This process evaluation illustrates how the SDA might fit into an existing refinery to supplement or improve refinery economics and Delayed Coker reliability. The economics cannot be done outside the context of the whole refinery, which makes this a complex and detailed analysis. Becht has the multi-disciplinary skill sets to do whole refinery simulations of process, reliability, and mechanical integrity evaluations – a holistic approach.

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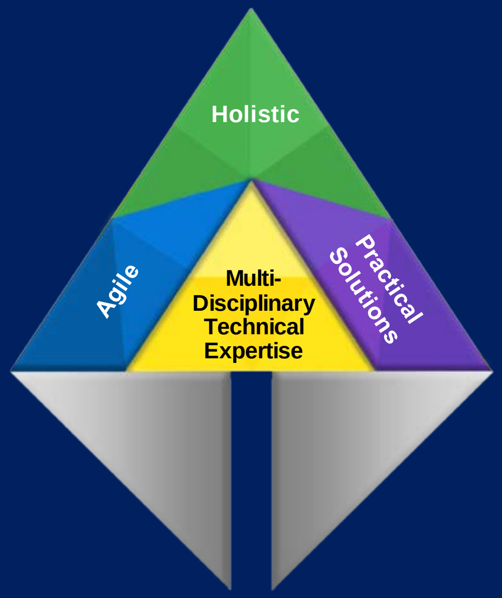

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