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Challenges of Processing Feeds Derived from Tight Oil Crudes in the Hydrocracker

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Topic: Challenges of Processing Feeds Derived from Tight Oil Crudes in the Hydrocracker

Session: Adapting to Tight Oils

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Introduction:

With the increase in supply of Domestic unconventional oils, especially tight oils; for the first time in two decades, United States oil production outweighs the country's oil imports. Current estimated reserves of approximately 50 billion barrels of shale oil in the United States, indicates Tight oil is here to stay and will play an important role in current and future refinery economics. Hence, fully understanding tight oil will be a crucial part of the current and future oil resource for refiners. Major Tight oil sources in the United States come from the Bakken, Eagle Ford and Permian Basin formations.

Refiners are processing significantly increasing amounts of crudes derived from the extraction of oil from shale deposits. While these "Tight Oils" have revolutionized crude supplies in the United States, they also are presenting refiners with new challenges. These crudes produce hydrocracker feeds with significantly fewer contaminants than oil sands derived feeds or conventionally produced gas oils, but there are reports that they may be contributing to crude blending compatibility issues, furnace and heat exchanger fouling, yield selectivity changes, and product quality issues.

Basis for study:

As part of its study, Criterion Catalysts and Technologies and Zeolyst International (Criterion) examined the performance of several hydrocrackers that are processing feed generated from Eagle Ford and Bakken crude. The Hydrocracker at Valero's Three Rivers refinery in Texas is a unit Criterion chose to highlight. The following criteria are what make this unit, one of the most significant for the study:

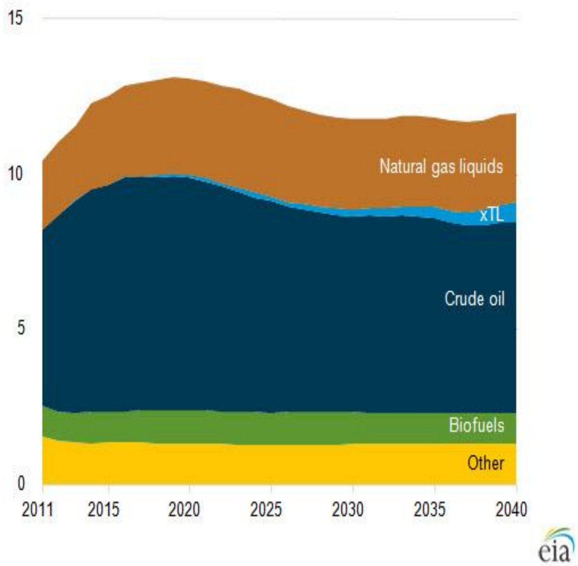
1. The majority of the refinery's crude slate is Eagle Ford tight oil.
2. The unit has successfully processed tight oils for almost two years now.
3. The amount of straight run feed processed in its hydrocracker is significant as compared to other refineries evaluated for this study.
4. The refinery's proximity to Eagle Ford tight oil production means the refinery is likely to process the tight oil from this source for an extended period.

Valero Three Rivers has taken advantage of the opportunity to run Eagle Ford and reap the associated economic benefits. At the same time, the refinery has geared up to meet the challenges from highly paraffinic feeds as found in tight oils. The refinery has been successfully running a major portion of its crude slate from tight oils for nearly two years now. With Eagle Ford crude being a significant portion of Valero Three Rivers' crude slate, understanding the effects of tight oil in the hydrocracker's performance, catalyst life cycles, yield selectivity and product quality becomes a vital part of Three Rivers' economics as well as its overall reliability.

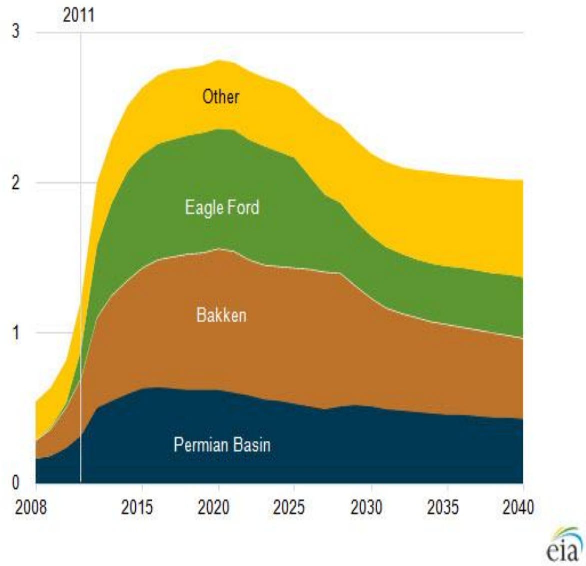
As one can see from the graphs below (Source: U.S Energy Information Administration), tight oil is expected to continue as a sizable portion of total crude oil production in the United States. Therefore, it's reasonable to expect a large number of hydrocrackers in the U.S. to prepare for the challenges from running tight oils.

Graphs 1a and 1b:
1a: U.S. liquid petroleum production from different sources in million barrels per day.
1b: U.S. tight oil production from different fields in million barrels per day.

Graph 1a: U.S. production of petroleum and other liquids by source, 2011-2040 (million barrels per day)



Graph 1b: Total U.S. tight oil production by geologic formation, 2008-2040 (million barrels per day)



Conventional crude Vs crude from Eagle Ford tight oil:

The most widely available tight oils are Eagle Ford and Bakken. Eagle Ford has more than one API grade, of which Eagle Ford 45 is the most popular and used at Valero Three Rivers, which is represented in this study. It's important to note that the quality of tight oils is variable even within the same oil field. This variabilitry poses many challenges in itself.

Having a brief look at the major changes in crude properties between tight oils and some conventional oils sourced within the region, tight oils present the following qualities.
1. Higher API
2. Lower feed contaminants such as 'N', 'S'
3. More paraffinic nature
4. Lower vacuum gas oil and resid make as compared to most conventional crude mix characteristics.

Table 1 below provides a comparison of some basic properties of conventional crude oil mix with tight oils, Bakken and Eagle Ford 45.

Table 1: Typical properties of tight oils and various conventional crude oils.

	Eagle Ford 45	Bakken		LLS	Brent	Qua Iboe	Mars
API	44 -46	42 - 44		36 - 38	37 - 39	34 - 36	28 - 30
Sulfur, wt%	0.2 - 0.3	0.05 - 0.10		0.35 - 0.45	0.35 - 0.45	0.1 - 0.2	1.7 -1.9
N, wppm	200 - 400	300 - 500		900 - 1200	900 - 1100	1000 - 1200	1600 1800
TAN	0.05 - 0.1	0.01 - 0.05		0.5 - 0.6	0.05 - 0.10	0.25 - 0.35	0.5 - 0.6
Light Ends, vol%	13 - 14%	15 - 16%		9 - 11%	10 - 12%	9 - 11%	10 - 11%
K-Factor	12.3	12.1		12.1	12.1	11.8	11.9
Naphtha, vol%	22 - 24%	25 - 27%		19 - 21%	19- 21%	20- 21%	14 - 16%
Distillates, vol %	31 - 33%	31 - 32%		33 - 34%	29 - 31%	35 - 36%	23 - 25%
VGO, vol%	24 - 26%	22 - 24%		28 - 29%	28 - 30%	28 - 30%	30 - 31%
Resid, vol%	6 - 7%	3 - 5%		7 - 9%	9 - 11%	4 - 6%	19 – 21%

One of the significant challenges for hydrocrackers processing significant amount of straight run material from tight oil crudes is a lower overall gas oil make. This lower gas oil make provide less overall hydrocracker feed and has the potential to underutilize the unit capacity compared to processing conventional heavier crudes. This situation also provides the opportunity to explore several possibilities, some of which are listed below:

1. Segregate or increase crude processing capacity or process opportunity crudes at increased margins.
2. Process additional streams (i.e., imported feeds or cracked stocks) into hydrocracker feed
3. Utilize the tight oil opportunity to extend catalyst cycle life.

Gas oil from conventional crude mix vs. gas oil from Eagle Ford:

Processing gas oil derived from Eagle Ford crude in Valero Three Rivers is discussed in more detail below.

Diagram 1 shows photographs of conventional vacuum gas oil vs. gas oil from Eagle Ford. Eagle Ford derived gas oil is waxy and has a higher pour point than conventional gas oil (is solid in room temperature).

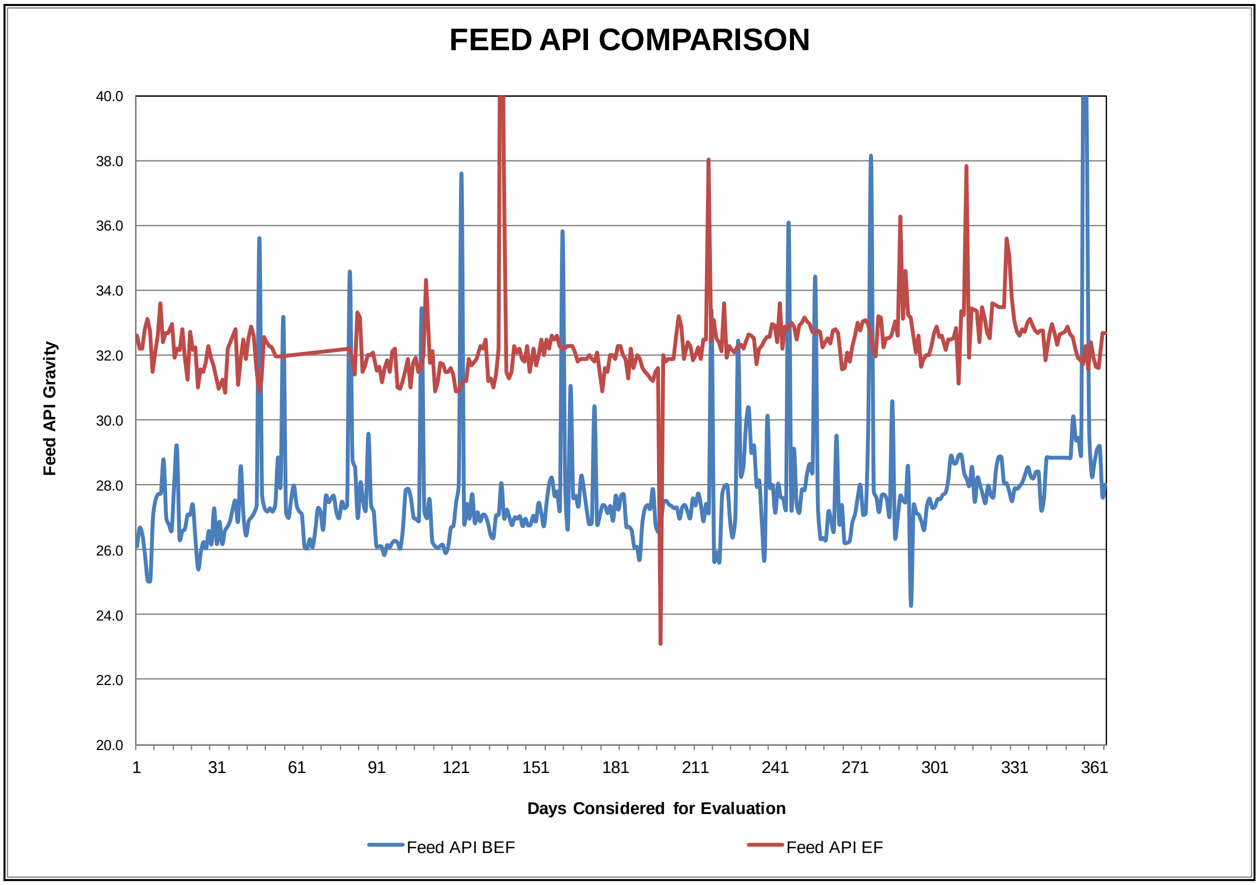
Diagram 1: Comparison of conventional vacuum gas oil and gas oil from Eagle Ford.

The higher pour point of tight oil crudes brings with it its own set of challenges. It tends to condense in places that are not heat traced including instrumentation like flow meters. These types of crudes make appropriate velocities and temperature profiles in heat exchangers critical to be maintained.

Tight oils are only a portion of the Hydrocracker Unit (HCU) feed in most refineries. However, it is a very significant portion of the HCU feed at Valero's Three Rivers refinery providing the best insights. As mentioned earlier, Valero embraced the opportunity to run Eagle Ford derived HCU feed at Three Rivers starting mid-cycle and prepared for the challenges from processing this highly paraffinic feed. Prior to Eagle Ford, a naphtha selective Criterion catalyst system had been selected on the basis of maximum volume gain given the feed and cycle length constraints. Since Eagle Ford crude has become the majority of the crude slate at Three Rivers, this opportunity has proven successful in running with the same catalyst load for nearly two years now. Since Criterion's catalyst system has been running in this unit for years before Eagle Ford was introduced and now multiple years during the Eagle Ford in the crude slate, a run period of one year before Eagle Ford (BEF) and after the introduction of Eagle Ford (EF) has been taken into consideration for making a few comparisons that made this study.

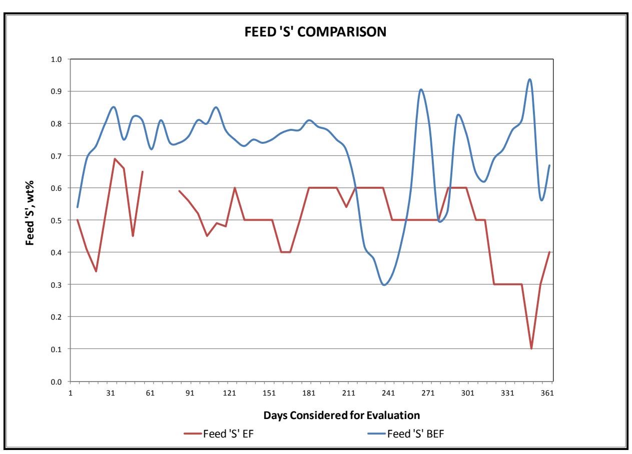
Tight oils are in general light and the feed API derived from these oils are higher than API of feeds from conventional gas oils. Graph 2 below shows API comparison of HCU feed from conventional crude mix before Eagle Ford with that of feeds derived from Eagle Ford. Average API of HCU feed in this unit has jumped from 27.6 API before Eagle Ford to 32.2 API during Eagle Ford, illustrating the lighter feed shift in operation.

Graph 2: API comparison of HCU feed from conventional crude mix before Eagle Ford (BEF) with that of feeds derived from Eagle Ford (EF).

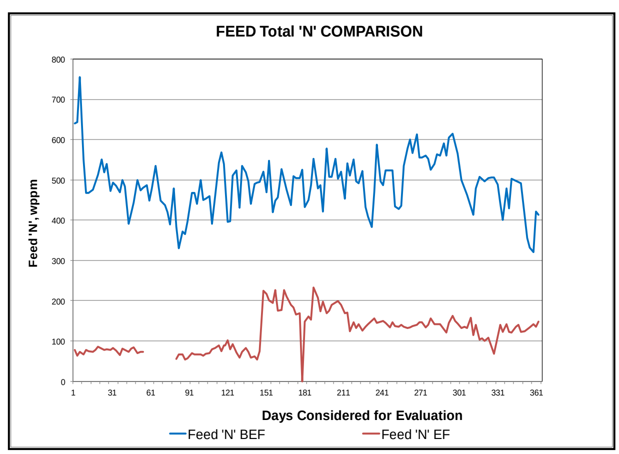


Tight oils in general have lower feed contaminants. Graphs 3 and 4 show lower sulphur and nitrogen with Eagle Ford (EF) when compared to before Eagle Ford (BEF). Sulfur is 30% lower and nitrogen is 75% lower with Eagle Ford (EF) Feed when compared with Before Eagle Ford (BEF)

Graph 3: Feed 'S' comparison.



Graph 4: Feed 'N' comparison.

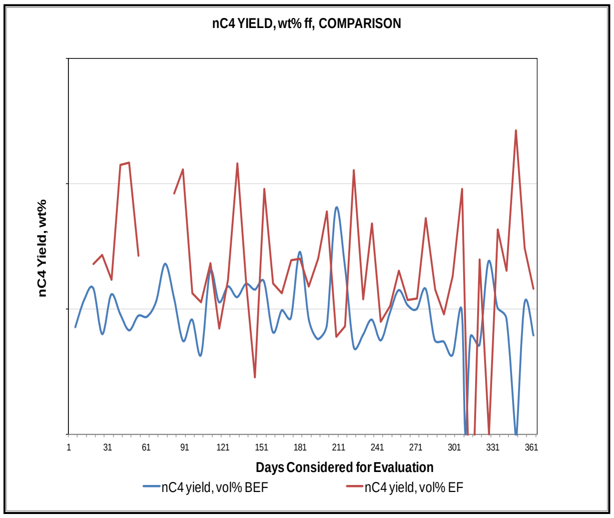


Feed CCR's were similar, however, hydrogen content in feed has increased approximately 5% during the Eagle Ford run. 'Ni+V' is 25% lower whereas 'Fe' is 25% higher during the Eagle Ford run.

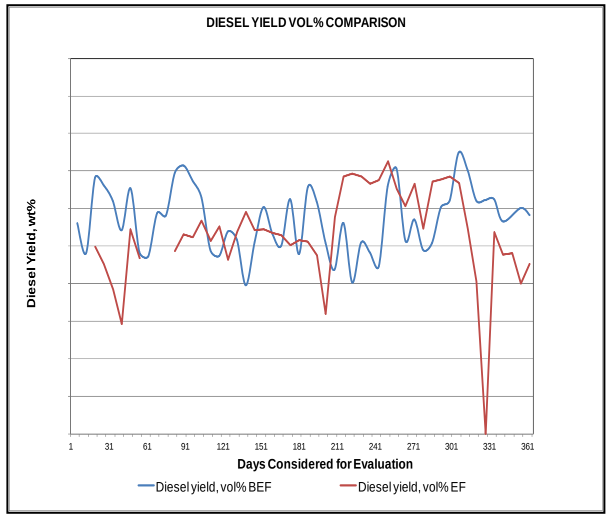
Product yields from conventional crude mix vs. product yields from Eagle Ford:

Distillation swell is observed on both lighter and heavier ends. However, the swell is greater towards lighter ends showing increased lighter ends in feed derived from Eagle Ford crude as compared to feeds before Eagle Ford (BEF). The increased lighter ends have increased the Naphtha yield in products. Proportional decrease in mid distillates yield is also observed. Gas make is higher during Eagle Ford due to the lighter ends and lower contaminants pushing the conversion more towards cracking catalyst. nC4 and diesel yield comparisons could be observed from Graphs 5 and 6 below. nC4 is higher and diesel yield is 10% lower with feeds derived predominantly from Eagle Ford crude as compared to the run Before Eagle Ford.

Graph 5: nC4 yield comparison.



Graph 6: Diesel yield comparison.



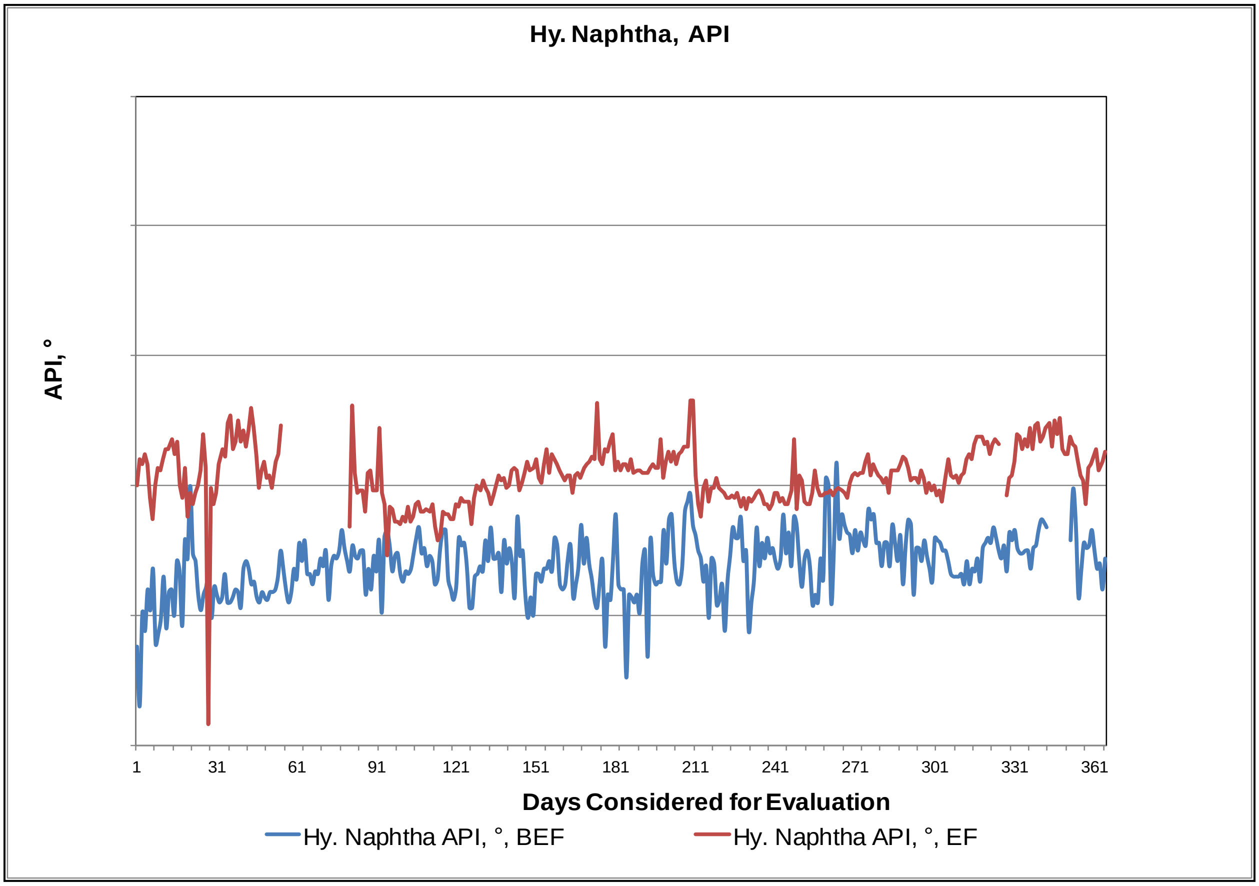
Overall catalyst deactivation and required WABT is much lower in the Eagle Ford Run compared to before Eagle Ford. Hence, there may be an opportunity to add more severe feeds into the HCU feed slate and also a consideration to increase the recycle rate in order to improve yield selectivity. Valero together with Criterion is exploring the option to increase recycle rate or process additional feed streams in-order to obtain higher diesel yields. For future cycles, a more distillate selective hydrocracking catalyst will also be considered. Valero and Criterion are interested to optimize and explore additional and future opportunities in this Hydrocracker unit.

Product properties from conventional crude mix Vs product properties from Eagle Ford:

As could be expected from paraffinic crudes, densities of products from naphtha to diesel have all reduced (Higher API) in Eagle Ford run. Graph 7 below shows a comparison of heavy naphtha density before Eagle Ford (BEF) run and during Eagle Ford (EF) run.

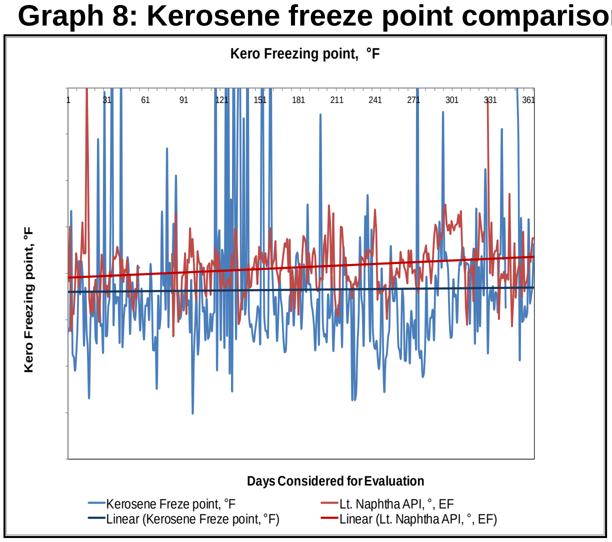
Graph 7: API comparison of Heavy Naphtha feed from conventional crude mix before Eagle Ford (BEF) with that of feeds derived from Eagle Ford (EF).

There is an API increase up to 3.5 in the Eagle Ford run.

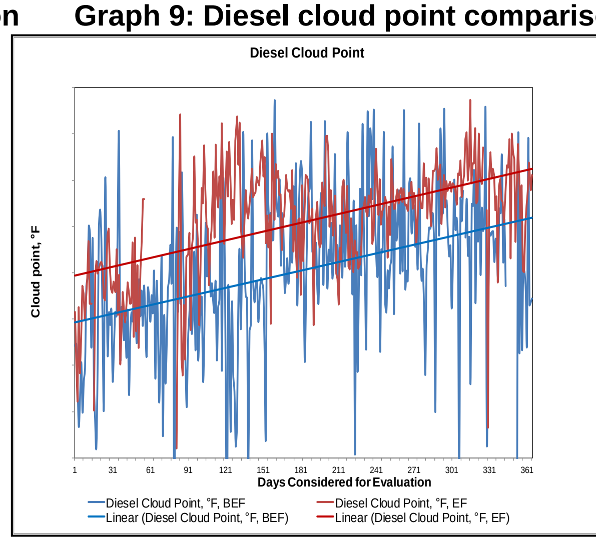


Similarly, kerosene freezing point and diesel cloud point have increased in Eagle Ford run. Graphs 8 and 9 below show comparison of kerosene freezing point and diesel cloud point Before Eagle Ford (BEF) run and during Eagle Ford (EF) run respectively.

Graph 8: Kerosene freeze point comparison



Graph 9: Diesel cloud point comparison



As Criterion and Valero expected from the bulk properties of this paraffinic feed slate, average jet/kerosene smoke point and diesel cetane are better with the Eagle Ford (EF) run when compared to the run Before Eagle Ford (BEF). This is an improvement for the product pool. However, the diesel pour point in addition to other cold flow properties are higher during the Eagle Ford (EF) run when compared to the run before Eagle Ford (BEF) which is less desirable. Similarly, the naphtha pool octane number is lower with the Eagle Ford (EF) Run when compared to the run before Eagle Ford (BEF).

In order to address the above issues, few of the recommendations are listed here:

- Select a more mid distillate selective catalyst.
- Optimize product cut points.
- Evaluate catalysts with better cold flow improvement properties where applicable
- Plan/utilize the lower deactivation by blending in more cracked feed streams into the hydrocracker feed and
- Vary the recycle rates according to requirement.

In responding to the more paraffinic component in hydrocracker feed diet, Criterion and Zeolyst has developed and commercialized several hydrocracking catalysts for handling highly paraffinic feeds in the hydrocracker feed stream. The benefits of the new type of hydrocracking catalyst not only enhance catalyst activity and selectivity (lower C4- gas and higher distillate yields) but also improve diesel cold flow properties. This class of hydrocracking catalyst will become viable option when refiners start processing significant amount of tight oils.

Table 2 below provides a comparison of yields between conventional catalysts vs. catalyst developed for paraffinic crudes.

Table 2: Typical delta between yields from conventional catalyst system vs. yields from catalysts developed for paraffinic feeds.

Values	CONVENTIONAL CATALYST	CORRESPONDING NEW CATALYST
Shape	TL	ATX
Catalyst CBD	0.76	0.63
WABT/°F	Base	Base -2
C_1-C_4/%w	Base	Base -0.5
C_5-180°F/%w	Base	Base -2.5
82-300°F/%w	Base	Base -4.0
300-480°F/%w	Base	Base +1.0
480-700°F/%w	Base	Base +6.0

Summary:

As a general overview,
The advantages of processing feeds derived from tight oil crudes in hydrocrackers are:
1. Higher bulk properties of products (cetane, smoke)
2. Lower weighted average bed temperatures and lower deactivation rates (more so if these were existing limitations) leading to longer cycle length or opportunity to co-process more difficult feed streams
3. Lower vacuum gas oil make (could explore processing more cracked feeds into hydrocrackers) or explore possibilities of processing higher crude rates or opportunity crudes in distillation units.

The challenges of processing feeds derived from tight oil crudes in hydrocrackers are:
1. More lighter end product yields at same conversion levels.
2. Less favourable cold flow product properties of mid distillates
3. Lower octane number of naphtha platformer feed stocks etc.

As refiners contend with these very paraffinic feeds, opportunities now exist to use more diesel selective hydrocracking catalyst systems with cold flow improvement capabilities. These catalysts are designed to handle highly paraffinic feeds in Hydrocracker feed streams. Criterion is working to address Valero's specific needs in yield selectivity as well as cold flow properties improvements. Valero engineers are reviewing Criterion's pilot plant studies and advanced modelling capabilities to evaluate further improvements and optimizations to meet future needs. Valero has successfully processed the Eagle Ford tight oil for almost two years now. We believe that as a result of these studies there will be added economic benefits to be gained from the use of tight oil. In order to further increase profitability, extensive studies related to product selectivity; product cut point changes and processing additional streams in the hydrocracker are underway.

Upon completion of this study, Criterion will continue to explore the adaptability of tight oil feeds to various hydrocrackers based on individual unit's needs. With Criterion's strong R&D program and modelling capabilities Criterion will continue to support other Valero refineries in preparing to process tight oils where desired.