GE Infrastructure
Water & Process Technologies

Technical Paper

Development and Implementation Strategies for Safe & Profitable Opportunity Crude Processing

By Neil Morgan, M. Craig Winslow, Craig Howard

Abstract

Processing opportunity crude oils has been recognized by the refining industry as a viable method for improving refinery profitability. Unfortunately, processing these opportunity crude oils has come with known risks that have often precluded refiners from capitalizing on what might have otherwise been an excellent profit opportunity. In order for refiners to take advantage of processing these opportunity crude oils they have to fully define the risks, develop risk control strategies and determine the cost of the risks and implementation of the strategies.

GE Infrastructure Water & Process Technologies has developed an innovative concept that combines three unique technology components into a single program that quantifies the opportunity value and the risk costs. Predator* allows the refiner to justify processing the opportunity crude oil, to safely capture the potential profits and to quantify the impact on the refinery operations and equipment.

Introduction

An opportunity crude oil is a crude that is priced below market value, typically because it is either new production with no previous processing history, or the risks of processing it are already known. In today's market, the most common and globally available of the opportunity crude oils are those containing an elevated level of naphthenic acids. Refiners have discovered that processing these high acid crudes impacts both operational reliability and equipment integrity. Some operational impacts experienced are exchanger fouling, reduced desalter efficiency, catalyst poisoning, poor wastewater quality and off specification finished product quality. Some principle equipment impacts have been high temperature corrosion, piping failure and loss of product containment.

These generate an increased risk of higher operating costs, environmental incidents, worker exposure, reduced unit reliability and lost production throughput. If a refiner were to process the crude and encounter these effects, the profit opportunity would be quickly reversed into a profit loss. It is easy to understand why refiners have traditionally been reluctant to take full advantage of these "opportunities."

Predator is composed of three technology platforms that allow for: **predicting** the impact a crude has on the refinery, **protecting** the refinery from those impacts and **monitoring** the results of the protection programs. By using Predator, the refiner can develop comprehensive strategies to safely and profitably process the opportunity crude to overcome risk and to take full advantage of the available profit potential.

The Predator program begins by obtaining a thorough understanding of the refiner's critical needs. Once these needs are clearly established, the Predator process flows along two parallel paths that culminate in the development of the processing strategies designed to meet these needs. One path focuses on characterizing the opportunity crude oil, the blend components and product fractions, while the other path focuses on a complete

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and detailed technical review of the refinery units, equipment components, operating practices and process conditions.

The objective of both paths is to pre-define the impacts of the crude blend on specific equipment components (desalter, heat exchangers, furnaces, towers, strippers) and on finished product quality. By clearly defining and establishing these impacts, GE engineers and scientists collaborate with the refinery personnel to systematically develop the strategies and tactics required to mitigate the impacts and meet the critical processing needs of the refiner. Once these strategies and tactics are defined, their cost can be computed so that a realistic estimate of the opportunity-to-risk value can be derived. By combining Predator with the refinery LP model yields, the full intrinsic value of the opportunity can be derived.

Characterization Phase

The Predator program begins with a detailed analysis and characterization of the opportunity crude, the other blend components and the product fractions of the proposed blend. The analytical data needed for this phase of the program resides in the Predator Knowledge Base, one of the three technology components of the Predator platform. These analyses come from three principal data sources.

Since some produced crudes are blends of several different fields, and the ratio from each field can vary from cargo to cargo, the actual crude quality can vary. For the refiner to accurately assess the impact of a varying crude, the most representative blend analysis must be available. The assay data in Predator is collated from a variety of public domain sources, assay data provided by refiners on specific crude oils of interest, or new crude oil production and assay data from special crude oil samples analyzed in GE Laboratories. By obtaining assay data from multiple sources and by frequently uploading the data, the refiner can be assured that the most current and representative data will be available.

In addition to the standard assay data, GE scientists also carry out special proprietary analytical characterizations of benchmark crude oils, opportunity crude oils and new crude oil production. These characterizations are derived from unique proprietary analytical procedures, developed by GE, and are used to provide a much more detailed analysis and understanding of the potential impact of a blend of crudes on refinery operations and equipment. Some of these characterizations included in the Predator Knowledge Base are procedures to measure and characterize the concentrations and type of naphthenic acid, determine the concentration of non-extractable chlorides and also of fouling precursors.

The third data source uploaded into the Predator Knowledge Base comes from laboratory process simulations, which have been developed by GE to model potential impact of crude oils on actual plant process equipment and operations. Some of the processes that are modeled are desalter performance, heat exchanger fouling and high temperature corrosion. These same simulation techniques can also be used to define the most effective treatment program for controlling the impact. In fact, some simulations are so accurate at mirroring the actual plant performance that they have even been used as a supplemental system monitor.

The Predator Knowledge Base currently contains data records of all sources for more than 1200 individual crude oils, and more crude oils and data are being added routinely. The data from Predator is available to be combined with a detailed refinery systems review to predict the potential impacts of processing the opportunity crude.

Refinery Systems Review

The refinery review is a detailed drill down assessment of the refinery equipment, operations and operating procedures that is executed by a joint team of GE and refinery personnel. The process begins with a general mapping of the refinery units, followed by identifying those units that would be most impacted by processing an opportunity crude. The review further subdivides all the impacted units into their major individual operating equipment components (storage tanks, preheat exchangers, desalters, furnace, atmospheric distillation column, overhead condensers and vacuum distillation column) so that the mechanical and operating history of each component can be reviewed in detail. The objectives of the review are to establish the baseline of current operating conditions and performances, to identify those components that would be susceptible to any impact, and those that may have a history of operating difficulty.

Like the assay data, the refinery equipment components, operating conditions and performance data are stored in the Predator Knowledge Base. The equipment component review is a one-time process that outlines the equipment arrangement, and describes the locations and types of chemical injection and monitoring tools. The operating conditions (including items such as flows, pressures, temperatures, chemical injection rates and sample analyses), and performance data (including corrosion rates, desalter efficiencies and heat exchanger efficiencies) are uploaded by GE field service personnel routinely after each and every service event.

In order to fully assess the potential effect and risks of high temperature corrosion, a more specific and detailed analysis tool, the risk matrix analysis is also developed. The data obtained for the risk matrix analysis is a more detailed drill down data capture than the component process review. The data obtained in the risk matrix analysis includes stream analyses, velocity and phase, pipe diameters, temperatures, pressures, metallurgies and other pertinent factors needed to further define the specific impact of high temperature naphthenic acid corrosion. The pertinent operating and analytical data are entered into the risk matrix analysis and the data is used to develop the CPI (Corrosion Potential Index), to determine the relative risk and the consequence of the corrosion.

Combining the crude oil characterization with the equipment configuration, Predator uses complex mathematical algorithms to relate the actual operating and performance data from other refineries to predict the impact on the target refinery. This process clearly identifies the possible effects and risks, highlights equipment and procedures that will be impacted by processing the crude, and defines the capability of the existing process to control the impacts. With the impacts and risks identified, the team of GE engineers and refinery personnel can co-develop operating strategies and tactics. These strategies and tactics can be implemented to allow the refiner to safely process the opportunity crude, mitigate the risk and capture the opportunity profit.

Refinery Strategy Development and Implementation

Petronas Penapisan (Melaka) Sdn Bhd (PPMSB) operates a joint venture 130,000 bpsd fuels refinery in Melaka, Malaysia. Petronas was interested in the possibility of processing high acid crudes and was aware that processing them could result in operational disruptions that could pose an unacceptable risk to the refinery operation. Their prime objective was to safely capitalize on the potential of processing opportunity crude oils by minimizing associated risks. Petronas requested GE personnel to collaborate with them in forming a multifunctional cross-company team to develop a preliminary opportunity crude risk assessment and processing strategy.

The team charter was to review the operating units and equipment components as preparation for the possibility of processing indeterminate opportunity crude oils. The preliminary results of this assessment highlighted the most susceptible areas in processing opportunity crudes. The review indicated that the tank farm, the desalters, areas in the atmospheric crude tower, tower overhead, vacuum columns and some associated piping segments were the most susceptible and at risk.

The review indicated that the desalters were operating within design efficiency on the typical crude slate, but there were certain typical crude oils that required addition of a supplemental reverse emulsion breaker to maintain effluent brine quality and desalter efficiency. There were further indications that the desalters were mechanically challenged and achieving these normally good results required tight control of both the desalter and tank farm operations. Because of these known mechanical limitations to the desalters, the tank farm has always been operated as a crude preparation facility, and the logistics and good control of the tank farm operations has always been considered vital to achieving desalter efficiency.

In tank farm operations, the incoming crudes are always allowed a minimum of 48 hours settling time, after which water is drained to a very rigid operations protocol and specification. Only when the water content of the crude oil is below 0.1% BS&W is it allowed to be pumped to the crude unit. By adhering to this rigid specification, a consistently dry crude is charged and disruptions to the desalter operational efficiency are minimized. If an opportunity crude were to be brought into the refinery, the logistics of storing and pumping this additional crude would reduce the flexibility to store all the different crudes used for blending. It would also impact the effectiveness of tank farm dewatering of all the crudes, which would result in disruptions to desalter performance. The review further indicated that any impact on the desalter performance would cascade downstream, increase preheat exchanger and furnace fouling, and affect overhead corrosion control and refinery effluent wastewater quality. Therefore, any impact of an opportunity crude on desalter operations would also have a far-reaching effect on downstream operations. Understanding the nature and scope of the potential impacts and risks, and developing and implementing a strategy to mitigate these effects would be necessary to realize the full value if any opportunity crude oil were to be processed.

The other particularly susceptible equipment components uncovered in the review were the high temperature, HVGO and MVGO, sections of the vacuum column and associated piping. The column itself is clad with 304L stainless steel in this region, the trays in these sections are 405 stainless steel and the packing is thin gauge 405 stainless steel. All these were designed to withstand sulphidic corrosion but not naphthenic acid corrosion. As with the desalters, an operating strategy to mitigate the impact of high temperature corrosion would need to be developed and implemented to protect against the corrosion risk.

Upon completion of the reviews, no specific opportunity crude oils of interest had been identified, only general strategies had been discussed, and none had been implemented.

Subsequently, an opportunity to process Doba-2 Crude arose, and the previous general review very quickly became a laser-focused risk assessment for processing Doba-2 crude. Information from the Predator Knowledge Base on Doba-2 crude indicated that it contained a high level of organically bound calcium and a high content of naphthenic acids. The review indicated Doba-2 had a high potential to negatively impact desalter operations and a high potential for high temperature naphthenic acid corrosion. Processing the Doba-2 crude would pose a double risk, as both these high impact characteristics of the crude would directly affect the most susceptible areas of the refinery. If not controlled, the impacts could result in poor desalter performance, causing wastewater violations, increase preheat exchanger fouling and accelerate corrosion. Finalizing and implementing the control strategies would be vital for mitigating the impacts and maximizing the profit potential offered by the Doba-2.

Because desalter performance at the refinery was directly impacted by tank farm operations, the first strategy adopted was to modify the logistics of crude receiving. The process implemented dedicated only one crude tank for Doba-2, even though more could have been made available, and allowed for normal storage and handling of the other blend crudes. By configuring the tank farm in this manner additional costs were incurred, but this facilitated much tighter control on both the percentage of Doba-2 and the BS&W quality of the crude charge. By implementing this strategy, the impact of Doba-2 on the desalter operations could be more consistently controlled and any impact of the Doba-2 would be greatly diminished.

The other principal impact on desalter operations predicted by Predator, was the predisposition of Doba-2 to form a very tight and stable emulsion, which would be difficult to resolve in the desalter. The high level of organically bound calcium and the effect that Doba-2 has on increasing desalter water pH both contribute to the formation of a stable emulsion, so a strategy to mitigate the impact and control emulsion formation was needed. First, this strategy included modifications to the tank farm operations. Second, the component included a new GE product to complex the calcium and control the pH in the desalter. The remaining component was utilization of the existing demulsifier product and the previously noted reverse emulsion breaker. Because Predator predicted higher percentages of Doba-2 in the crude blend would require higher dosage of demulsifier and reverse emulsion breaker, the strategy also called for provisions to increase the injection rates of the demulsifier and the reverse emulsion breaker.

In addition to modifying the tank farm operations and the chemical injection procedures in the desalters, the strategy also included an improved monitoring plan. This monitoring plan supplemented the existing desalter monitoring program, adding some additional testing as well as increasing the frequency of testing and monitoring by the GE and PPMSB team. The purpose of the enhanced monitoring plan was to provide early warning of any process disruptions and more timely and consistent feedback for control changes. With the improved monitoring and enhanced strategies, there was reasonable assurance that the desalters could be operated without significant disruption and that the risk to desalter and downstream operations could be controlled, monitored and minimized.

The data on Doba-2 also predicted that an increased potential for preheat fouling could be expected. This potential impact could be offset by the modified desalter strategy, a pre-existing antifoulant program and the potential to bypass and clean critical heat exchangers on-line. Therefore the impact was determined to be a minor risk with low consequence. Since the risk was considered low, the only additional strategy implemented was to increase monitoring of heat exchanger pressure drop and heat duties, and to track the data so that performance changes could be quickly identified and controlled.

The data also indicated that corrosion potential in the atmospheric overhead condensers and top pump-around exchangers could be elevated. After discussion, the team determined that the increased corrosion risk in these areas could be controlled by the modified desalter strategy, so no changes to the overhead corrosion control program were implemented. However, because of the increased level of risk, it was decided that the existing monitoring program needed to be modified to include more monitoring points, new test procedures and increased frequency of monitoring. The monitoring frequency was initially increased from once per week to three times a week until sufficient data had been collected to re-evaluate the program. Since no increase in corrosion was observed, the monitoring frequency was subsequently reduced.

The analyses indicated the most significant risk of processing Doba-2 would be high temperature naphthenic acid corrosion in the vacuum tower and associated piping. Not only was the concentration of acids relatively high in these fractions, but the risk matrix assessment showed that none of the high temperature zones of the vacuum tower, the trays nor the thin gauge packing in the tower were alloyed with sufficiently robust metallurgy to handle the naphthenic acid corrosion. Depending on where the corrosion occurred, the consequences could be significant. Loss of containment could occur; product quality could be negatively impacted, as could operational reliability.

There was also a concern that the HVGO and MVGO packing would be highly susceptible to fouling and that the fouling could also impact operational reliability and product quality. Consequently, a safe and conservative operations strategy would need to be developed to handle both the impact of high temperature corrosion and packing fouling.

Chemistry for controlling naphthenic acid corrosion has been well established by the refining industry. The commercially available treatment programs that have traditionally been used are based on phosphate ester. The efficacy of these types of products has been well established and proven; however, the refining industry experience has also established and proven that the improper application of this chemistry can also result in serious phosphorous fouling and hydrotreater catalyst poisoning(1). The team was not only concerned about the corrosion issue, but was also concerned about the fouling and catalyst poisoning issues. The control strategy would have to address all three concerns.

Although recently GE developed a patented sulphur-based corrosion inhibitor(1) – proven to be very effective in controlling corrosion with no negative side effects of the phosphate ester programs – the team chose Predator 61N as the corrosion inhibitor. Predator 61N is a GE-patented product that contains a synergistic blend of phosphate ester and a multi functional organo-phosphorus adjunct. Predator 61N was chosen primarily because of its proven success in controlling high temperature corrosion. A further significant consideration was that Predator 61N had also been proven to successfully prevent fouling in refinery systems that had previously fouled when using competitively applied phosphate esters. Because of the positive operating experience using Predator 61N, the team was confident that adopting the Predator 61N program for controlling both the corrosion and fouling was the best available technology.

The strategy also allows for future progression to the new sulphur-based product. Dosage rates are approximately the same and thus no modification to the injection facilities will be required, thereby minimizing the cost of the transition. The benefits of eliminating phosphorous-related fouling and catalyst poisoning potential are obvious.

In addition to the corrosion control program using Predator 61N, the strategy included an enhanced monitoring program. The plan for corrosion monitoring called for an increase in the frequency and number of sample points for HT UT and for the placement of Electrical Resistance Probes in key risk areas of the systems. As a result a total of 11 new ER probes were added in the crude charge, LGO, HGO, atmospheric bottoms, MVGO, HVGO, XHVGO and vacuum residuum streams.

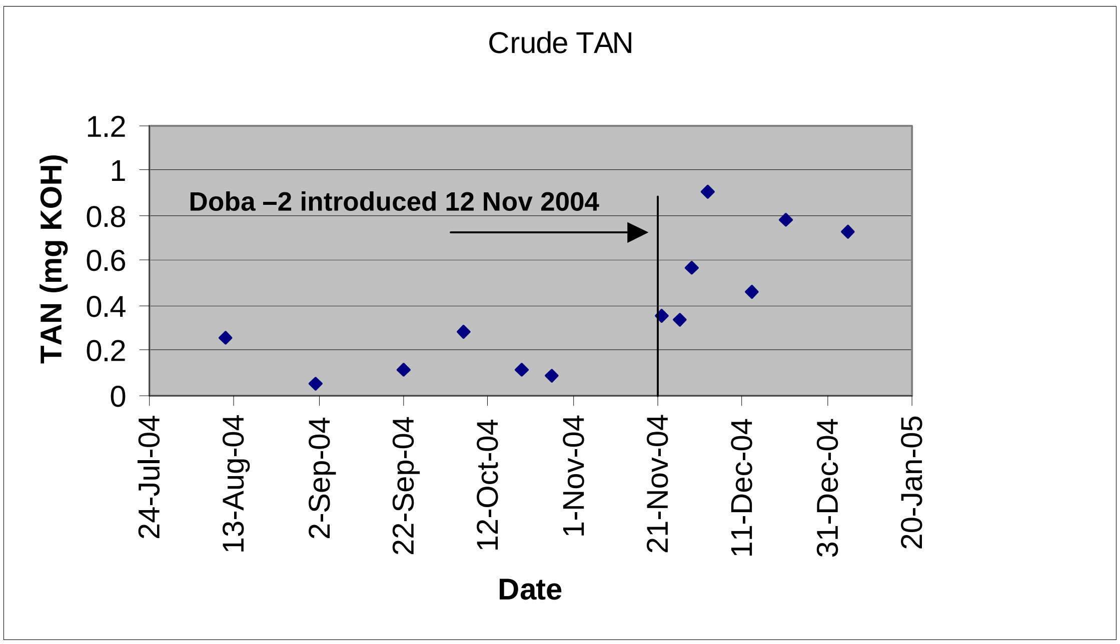
Pressure drop measurements of the packed areas were already in place in the DCS so no additional monitoring was added to monitor for any increase in fouling. However, pressure drop readings for the hot product side of the heat exchangers was implemented to monitor for potential preheat fouling.

Analytical testing of the crude blend and main product streams was also initiated. The strategy called for monitoring the metals content of these streams to provide a baseline of the process capabilities as well as monitoring for any changes in the level of metals. The principal focus of these analyses was to track iron, nickel and phosphorous content of the streams. Iron and nickel are used as a qualitative cross verification of the corrosion control program, and the phosphorous is used as a qualitative track of the fouling potential and catalyst poisoning potential.

PPMSB Operating Experience on Doba-2 Crude

Prior to the introduction of Doba-2, all the key strategies were implemented and baseline performance conditions were measured. Doba-2 was introduced initially at a target rate of 1-2% Doba-2 to crude charge. This level turned out to have no impact on refinery operations, and the percentage was increased up to the 8% range with no noticeable impact on any refining operations. Above the 8% level, the emulsion layer of the desalter was impacted, and it was necessary to implement the addition of the new adjunct calcium control chemical, the reverse emulsion breaker and to increase the dosage of the demulsifier in order to control the volume of rag. TAN levels of the crude blend are depicted in Graph 1 below.

Graph 1. TAN levels of Crude Blend



To date, the refinery has processed crude blends containing in excess of 15% Doba-2, and desalter operations have been controlled within acceptable ranges.

Stream analyses conducted during the processing of the Doba-2 crude provided verification that the high TAN/NAN streams predicted were indeed experienced in practice. The NAN values observed during the run are outlined in Table 1 below. As predicted, the streams with the highest NAN values were the HGO, Atmospheric resid, MVGO and HVGO streams.

Table 1: Stream NAN Readings (2-15% Doba-2)

Stream	Min NAN	Max NAN	Average NAN
MPA	0.02	0.05	0.05
LGO	0.02	0.32	0.15
HGO	0.13	0.88	0.48
Atmospheric Residual	0.12	0.71	0.45
MVGO	0.18	0.90	0.65
HVGO	0.18	1.25	0.72
XHVGO	0.11	0.68	0.41
Vacuum Resid	0.07	0.64	0.25

Corrosion rates in the overhead and crude preheat fouling have not shown any increase since the Doba-2 charge began. High temperature corrosion as measured by UT and ER probes has been controlled within the desired range. These rates have not shown any increase above those measured during the baseline data collection phase. Average corrosion rates measured in the main areas of concern to date are shown below in Table 2.

Table 2: Average Corrosion Readings

Stream	Average Corrosion Rate (mm/yr / mpy)
HGO	0.16 / 6.3
HVGO	0.25 / 9.8
XHVGO	0.23 / 9.0

As further corroboration of the HT-UT and ER probe data, a series of 18 Computed Radiography measurements were taken by a third party inspection company on areas of concern. These areas included the Atmospheric Resid system, Vacuum Furnace pass flow controllers and transfer line, XHVGO system and Vacuum Resid system. No anomalies were detected by the inspection.

The summary page from the third party inspection report is included as Attachment 1.

Furthermore there has not been any measurable increase in the vacuum column top pressure or the packed bed pressure drop instruments, which indicates column fouling is not occurring. There has also been no measurable increase in the pressure drop in the crude preheat exchanger train.

To date, there has been no discernable impact of the Doba-2 in the predicted areas, on the operation or downstream units. The refinery has completed a 4 month long initial phase of processing Doba-2 and is currently reviewing and modifying the strategies to facilitate further processing of Doba-2 crude in the near future. The majority of the modifications under review involve improvements to monitoring techniques so that a more, rapid, precise and accurate assessment of conditions can be obtained. This improved monitoring will translate to enhanced impact control and minimization of the potential for unforeseen issues.

Summary

PPMSB has safely and profitably processed in excess of 15% Doba-2 in their crude blend with no observed acute or chronic impact in the refinery.

With data from the Predator Knowledge Base, the GE and PPMSB team worked side by side to predict the risks and to create a complete and comprehensive set of strategies designed to assure the minimization of these risks and the maximization of the profits associated with processing of Doba-2 crude. By determining the risks, their costs, the control strategies and their costs, the real value of the Doba-2 opportunity has been determined. The comprehensive program that was implemented has provided effective control of the program of processing Doba-2 while providing accurate data upon which to base decisions to further advance the program.

Predator provided PPMSB the assurance that the refinery could safely handle the double risk of Doba-2 and profit from it. PPMSB is continuing with the strategy of processing Doba-2 and is implementing improvements designed to further increase the value of this profitable opportunity.

References:

(1) Terry Jackson, M. Craig Winslow, Mark Wilson, “Prolonged Experience Processing High Acid Crude - Cross Oil & Refining Company,” Paper presented at ERTC 9th Annual Meeting, Prague, Czech Republic, November 2004.

Attachment 1

REPORT NO.: WCR/01/05(01)

4. Summary of Item Inspected

DATE: 04 ~ 06 January' 2005

Below is the summary of 18 locations inspected on the Line Works. One CR image is taken per location.

FINDINGS / SYSTEM	No sign of anomaly	Sign of anomaly	Total No. of locations
Atmospheric Resid	4	Nil	4
Vacuum Furnace	4	Nil	4
Vacuum Furnace Transfer Line	4	Nil	4
XHVGO	3	Nil	3
Vacuum Resid	3	Nil	3
TOTAL	18	0	18

Computed Radiography (CR) by LOTT INSPECTION SDN. BHD.