Profiting from Western Canada Opportunity Crudes
The question of opportunity

Higher volumes of heavy conventional and bitumen-based crudes are set to emerge from the Western Canada sedimentary basin (WCSB) underlying Alberta and Saskatchewan, as oil companies invest in recovery and upgrading technology, and transport infrastructure is further developed. Unfortunately, these crudes present significant refining challenges. Aside from the difficulties associated with their extraction, WCSB heavy crudes make less than ideal refinery feedstocks, which is reflected in their often heavily discounted market prices. And therein lies the opportunity.

The important question for refiners is how much of a profit is possible when the reduced cost of WCSB heavy crudes is compared to the investment in new plants and equipment; their effect on refinery operations and product yields and quality; and the increased wear and tear on process facilities throughout the refinery.

This paper casts some light on these issues by focusing on the areas within the refinery most likely to be affected by processing WCSB heavy crudes and examines some of the measures for overcoming potential problems.

The message for refiners is that it is possible, through careful planning, and flexible and integrated diagnostic and treatment programs, to safely increase WCSB heavy crude in the feed slate without making significant capital investments or incurring a decrease in refinery performance.

Figure 1: Canadian oil sands and conventional production, 2006 to 2030. [Source: Crude Oil Forecast, Markets and Transportation, CAPP, June 2013]
The Canadian Association of Petroleum Producers (CAPP) forecasts that oil production in Canada is set to reach 6.7 MMbbl/d by 2030 (Figure 1), more than double today’s figure of 3.2 MMbbl/d (Table 1). CAPP expects the Alberta oil sands to deliver most of that growth, up from 1.8 MMbbl/d today to 5.2 MMbbl/d by 2030.

CAPP reports that extra oil is being purchased by refineries on the US Gulf Coast that are prepared to process heavy oil. Other potential regions interested in purchasing heavy oil include the US West Coast and the Midwest, and Ontario, Quebec and on the Atlantic seaboard in Canada, according to the report.

Assuming that the Enbridge Northern Gateway pipelines or the northern leg of Kinder Morgan’s Trans Mountain pipeline are approved, Alberta’s oil might find its way as far as Asia via a terminal in British Columbia.

The Alberta Energy Regulator, a Canadian government energy regulatory agency, reports there are 168 billion bbls of remaining established reserves of bitumen in Alberta; confirming there is sufficient quantity for decades to come. The breakdown of the total Canadian crude output in 2012 can be found below in Table 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Average bbl/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Canada conventional light/medium</td>
<td>658,000</td>
</tr>
<tr>
<td>Eastern Canada conventional light/medium</td>
<td>199,000</td>
</tr>
<tr>
<td>Condensate</td>
<td>139,000</td>
</tr>
<tr>
<td>Western Canada conventional heavy</td>
<td>451,000</td>
</tr>
<tr>
<td>Western Canada bitumen (from oil sands)</td>
<td>895,000</td>
</tr>
<tr>
<td>Western Canadian upgraded bitumen (synthetic crude oil)</td>
<td>892,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,234,000</strong></td>
</tr>
</tbody>
</table>

Table 1: 2012 Canadian crude output [source: Canadian Energy Research Institute]

The future of the Canadian oil industry, although dominated by heavy crude oil and bitumen production, is not totally clear. Although the environmental impact has been reduced, uncertainties surrounding the cost of production and transport of the heaviest oil; and the availability and cost of the diluent used to thin some of the bitumen for transport purposes are issues. There is also the problem that current production is close to the capacity of the existing export pipeline systems and that gaining approval for new ones, such as the proposed Keystone XL pipeline from Alberta to Texas, is uncertain. Finally, there is the arrival on the US scene of a competing opportunity crude feedstock, shale oil. Although shale oil comes with its own processing challenges, it does have the advantage of being sweet and light.
Western Canada Heavy Crudes

Canada produces a wide variety of hydrocarbons, including some barely liquid conventional light to medium crudes, and some condensate. However, the largest category (70% of production) includes conventional heavy oil, bitumen and upgraded bitumen from the WCSB.

Upgraded bitumen

About half of the bitumen produced from the WCSB is upgraded, mainly by three companies: Syncrude Canada Ltd., Suncor Energy and Shell Oil Company, all with plants in Alberta. Coking or hydrocracking processes are used to convert the bitumen to a light, sweet synthetic crude oil, which is relatively easy to refine because it contains virtually no bottom fraction. There are some challenges, however. Synthetic crude tends to yield high volumes of heavy vacuum gas oil and the lighter distillates are high in aromatics, which result in straight-run diesel with a very low cetane number.

Conventional heavy and bitumen-based crudes

Conventional heavy and bitumen-based crudes are often lumped together to form a single category of WCSB heavy opportunity crudes. Canada’s conventional heavy crude compares with similar crudes from other parts of the world – and is just as difficult to process. The most challenging crudes are the bitumens. If not upgraded, these crudes have to be blended to meet pipeline viscosity and gravity specifications, making it possible to move them from place to place. Dilbits are made by diluting the bitumen, normally with condensate or naphtha. Synbits and syndilbits are similarly diluted bitumens; the diluent being synthetic crude. A comparison of properties of various crudes from Western Canada, with a “traditional” heavy crude such as Arab Heavy, is shown in Table 2. These data provide some clues to the kind of challenges posed when processing these heavy crude oils.

<table>
<thead>
<tr>
<th></th>
<th>Athabasca Bitumen</th>
<th>Conventional Heavy (Wabasca Heavy)</th>
<th>Dilsynbit (Albian Heavy Syncrude)</th>
<th>Unconventional Heavy (Cold Lake)</th>
<th>Syncrude (Suncor H)</th>
<th>Arab Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.014</td>
<td>0.932</td>
<td>0.941</td>
<td>0.925</td>
<td>0.937</td>
<td>0.891</td>
</tr>
<tr>
<td>Gravity (oAPI)</td>
<td>8.0</td>
<td>20.3</td>
<td>18.8</td>
<td>21.4</td>
<td>19.3</td>
<td>27.4</td>
</tr>
<tr>
<td>Sulfur (wt%)</td>
<td>4.9</td>
<td>4.10</td>
<td>2.31</td>
<td>3.75</td>
<td>3.11</td>
<td>2.8</td>
</tr>
<tr>
<td>MCR (wt%)</td>
<td>13.6</td>
<td>8.59</td>
<td>13.50</td>
<td>10.25</td>
<td>0.84</td>
<td>7.91</td>
</tr>
<tr>
<td>TAN (mgKOH/g)</td>
<td>3</td>
<td>1.04</td>
<td>0.44</td>
<td>0.98</td>
<td>3.54</td>
<td>0.14</td>
</tr>
<tr>
<td>Nickel (mg/L)</td>
<td>92</td>
<td>53.9</td>
<td>43.0</td>
<td>65.2</td>
<td>4.8</td>
<td>16.0</td>
</tr>
<tr>
<td>Vanadium (mg/L)</td>
<td>226</td>
<td>150.9</td>
<td>76.0</td>
<td>173.3</td>
<td>11.8</td>
<td>55.0</td>
</tr>
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Table 2: The basic properties of Western Canadian heavy crudes [source: www.crudemonitor.ca and Arab heavy crude oil]
Gravity and viscosity are obvious practical problems, though a feedstock with an API value as low as 8 is a rather unrealistic proposition and explains the need to dilute and blend the bitumen output from the region. Most heavy feedstocks exported from Western Canada are of the order of 19–22 API.

One of the most serious drawbacks of the WCSB heavy crude feedstocks, certainly from the standpoint of crude unit operations, are the high levels of asphaltenes, solid contaminants and difficult-to-remove chloride salts, which are normally concentrated in the bottom fractions.

Asphaltene levels may be as high as 30% in some of the WCSB feedstocks. The concern arises when blending these oils with lighter crudes, which can lead to asphaltene deposition. It is well documented that asphaltene precipitation can lead to oil–water separation difficulties and widespread fouling.

The higher viscosity of the WCSB crudes, in combination with their required extraction/production methods, tends to pull out more solids (sands and clays) that are trapped in the formations. Sediments, corrosion scale, iron sulfide, drilling mud, etc., are also likely solid contaminants that contribute to separation and fouling issues when refining these crude oils.

Inorganic chloride salts can pose challenges when desalting heavy Canadian crude oils. The higher viscosity of the oils makes dehydration of the crudes more difficult, resulting in higher salt content in desalted crude. Making matters worse, non-water extractable or non-desaltable chlorides are also often present in WCSB feedstocks. Potential sources are oil-wetted inorganic salts, which can result from thermal stressing during production or upgrading, and asphaltene hydrochlorides. Higher salt content can contribute to downstream fouling, but the bigger issue is an increase in the risk of corrosion in refinery overhead systems. In addition to these three issues, WCSB feeds come with higher TAN values and, consequently, pose the risk of high-temperature naphthenic acid corrosion. Higher TAN values also contribute to overhead corrosion that results from thermal degradation of the naphthenic acid to yield lower-molecular-weight organic acids. Many WCSB crudes are also high in sulfur, which produces higher hydrogen sulfide ($\text{H}_2\text{S}$) content in refinery overhead systems; another factor in overhead system corrosion.

Metal contamination, notably, iron, nickel, vanadium and arsenic, is also generally high in WCSB crudes. These metals promote fouling, cause downstream catalyst deactivation, and contaminate the final product, such as the cokes destined for the manufacture of high-quality electrodes. Sulfur and nitrogen levels are likely to be elevated and will affect catalyst performance, raise hydrotreating demands and, again, increase the probability of corrosion.

Solutions for new-to-market Canadian Crudes
A supermajor turned to Baker Hughes as their collaborative partner to provide solutions when processing a new heavy Canadian, paraffinic froth treatment (PFT) crude. The 18-month joint collaboration consisted of an R&D project to assess and validate Baker Hughes heavy Canadian crude treatment strategies on a pilot desalter, and to verify the routine handling of solids when processing heavy Canadian crudes and the newer PFT crudes. Using new methods for emulsion characterization, Baker Hughes has developed new pre-treatment chemicals and a new chemical additive, commercialized as JETTISON™ solids release agent (SRA), for the desalter to transport solids (including micro-fine solids).

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Crude oil storage

The problems with WCSB heavy crudes start before processing begins, in the tank farm. Storage tanks are prone to experience stable emulsions and sludge accumulation, and they are the first place in the refinery where asphaltenes can deposit. For example, diluted bitumens arrive with marginal asphaltenene stability (or, in some cases, already-precipitated asphaltenes), and blending these heavy crudes with lighter ones only exacerbates the situation. Consequently, operators may find it difficult to drain bottom sediment and water (BS&W) from the crude at this stage. Additionally, in line with the elevated sulfur levels it is likely that there will be higher-than-normal levels of H₂S, which can lead to tank corrosion as well as potential health and safety issues.

A key objective during crude storage is to precondition the feed, which includes: beginning the process of breaking emulsions (releasing water and solid contaminants from the oil), stabilizing asphaltenes, improving separation within the tanks, and scavenging H₂S. This is essential to in order to present the best possible feedstock to the desalter (otherwise described as the “guardian at the gate” to the crude distillation unit and beyond).

Specific solutions: Field ASIT services™ technology | XERIC™ heavy oil program | SULFIX™ additives

A US refiner was processing up to 7,000 bbl/d of WCSB heavy crude, but suffering from a range of problems including poor desalter grid stability, water carryover with the crude oil, and poor brine effluent quality. There were also issues with odors in the storage tanks, the result of an H₂S content of about 200 ppm. Baker Hughes helped the refiner to resolve the issues using a range of XERIC™ products (an oil blending aid that was added as the oil was offloaded, a primary desalter emulsifier, and a solids conditioning aid) and a SULFIX™ hydrogen sulfide scavenger. Technical support staff also recommended changes to the desalter’s operation. The program improved desalter performance across the board and enabled the refiner to increase the WCSB crude feed rate to 17,000 bbl/d – a financial benefit equating to $3–4 per barrel on throughput.
The desalter
The desalter is undoubtedly crucial to the success of processing WCSB heavy crudes. Desalting WCSB crudes is not easy. The first signs of the challenges may be tank sludge buildup or even fouling of the cold preheat train leading to the desalter. As mentioned earlier, unstable asphaltenes, suspended solid contaminants and difficult-to-remove salts combine to result in poor mixing, emulsion issues, and difficulties separating the crude oil and the brine. Getting the desalter to run in a stable fashion takes considerable skill; upsets and outages are always possible; throughput may be compromised; mud washing can become a big issue; the maintenance burden will inevitably rise; and energy consumption is likely to increase.

But while the problems operating the desalter may be severe, it is the downstream effects beyond the desalter that are the real issues, especially those caused by carryover of BS&W into the crude distillation unit and carry-under of oil into the wastewater treatment plant. Of most concern are the effects of overhead corrosion, heat transfer loss due to fouling, and issues with wastewater quality.

Specific solutions: XERIC™ heavy oil program | EXCALIBUR™ contaminant removal technology
A US refiner made the transition to almost 100% WCSB heavy crude after technical assistance from Baker Hughes and the introduction of a XERIC™ heavy oil demulsifier program. The improved dehydration and emulsion resolution decreased operating costs even though the feed slate quality declined.

A Canadian bitumen upgrader was having difficulties controlling the quality of the brine effluent from its two-stage desalter unit. The oil and grease values were typically 7,300 ppm in the first-stage effluent and 1,200 ppm in the second-stage effluent. Switching from the upgrader’s existing demulsifier to a XERIC™ heavy oil demulsifier, but using the same wetting agents in the unit, reduced the oil and grease levels in the effluents by 65–75%. The desalter’s performance remained stable; salt removal, dehydration and solids removal were slightly improved; and there was no effect on the level of chloride in the crude unit overhead system.

Crude unit overhead corrosion
The desalter is the first line of defense against plant corrosion, which is estimated to account for 50% of maintenance costs at most refineries. One of the biggest challenges is crude unit overhead system corrosion, principally caused by hydrogen chloride (HCl). HCl is formed by hydrolysis of the chloride salts that are not removed from the feed stream at the desalter. Sulfur compounds also play a role, as do carboxylic acids from the breakdown of naphthenic acids. The situation may be complicated further by the presence of ammonia or tramp amines, when ammonium chloride and/or amine hydrochloride may form and initiate under salt-pitting corrosion. Also, higher sulfur and naphthenic acid content in these crudes leads to higher neutralizer demand and additional risk of under-salt corrosion.

Corrosion resulting from inefficient salt removal is not limited to the atmospheric tower overhead system. Salts that do not hydrolyze in the atmospheric furnace will carry downstream in the bottom’s product, impacting the vacuum overhead system and downstream heavy oil processes such as delayed coking.

An effective desalting operation is a critical element in managing refinery overhead system corrosion.

Specific solutions: TOPGUARD™ overhead corrosion control | Ionic model technology
Overhead bundle life was declining (less than eight months) for one US refiner who gradually increased the amount of heavy Canadian crudes to 100%. The corrosion severity and short bundle life led to the decision to keep a new bundle on hand at all times to minimize downtime and lost opportunity when leaks occurred. Using the TOPGUARD™ Ionic Model to determine the root cause of the corrosion—ammonium chloride salt deposition—a revised TOPGUARD overhead corrosion control strategy was put in place that doubled the bundle life.
Heat exchanger and furnace fouling

The performance of the desalting unit also influences how much fouling is likely to occur throughout the refinery. Fouling is prevalent in preheat train heat exchangers and furnaces, affecting equipment from the crude distillation unit through to the delayed and fluid cokers. Fouling may also be an issue in, for example, the diplegs of the fluid catalytic cracking unit FCCU and the regenerator vessel. There are many causes of fouling, and the underlying chemistry, both inorganic and organic, is complex. However, it is safe to say that unstable asphaltenes are prime culprits (changes in dilution, temperature, pressure and pH can all cause their deposition). Their impact is exacerbated by iron sulfide, sediments, salts and, particularly, sodium, which is known to catalyze coke formation on hot surfaces. An effective desalting operation reduces the fouling potential by removing most of the crude oil salts and solids, and by minimizing the amount of sodium in the crude.

Specific solutions: Field ASIT services technology | LIFESPAN™ exchanger fouling control program | MILESTONE™ heater fouling control program

A US refiner running primarily mid-continent and Gulf Coast crudes added 7-10% heavy Canadian crude to the blend and experienced immediate increased fouling (x3 baseline fouling rate). Baker Hughes recommended treating with LIFESPAN™ 3100 asphaltene stabilizer before blending, which reduced the fouling rate to <50% of the baseline rate. The refiner used Baker Hughes Field ASIT services™ to routinely evaluate the stability of the crude blends. As soon as the Canadian crudes were not included in the blend, the chemical treatment program was no longer required and the fouling rate returned to the baseline level.
Wastewater treatment plant

Any issues in the desalter are likely to impact the wastewater treatment plant and make it more difficult to maintain final effluent quality and achieve environmental compliance. Inefficient desalting of WCSB crudes, combined with excursions during operational upsets, lead to episodes of free oil and higher solids in the effluent brine. Brine of this nature is unsuitable for direct input to the wastewater treatment plant.

To mitigate this issue, the first step is to optimize desalting operations and performance. As limitations are reached at the desalter, it may be necessary to introduce a brine pretreatment process. This could include using a heated cone bottom tank to initially separate the oil, emulsion and solids; followed by gas flotation technology to treat the emulsion, and centrifuging to clean up the solids. Importantly, although effluent brine may be relatively oil-free, WCSB crudes are high in solids, which can challenge the wastewater plant. Refiners that process WCSB on a consistent basis have, in many cases, upgraded their wastewater handling facilities to manage the challenges of salts and oil undercarry.

Specific solutions: XERIC heavy oil program

Soon after introducing WCSB heavy crude onto its feed slate, a North American refiner began to experience issues with its desalter unit; oil carryover to the wastewater treatment plant was causing particular concern. The existing demulsifier could not cope with the increased demands; therefore, the charge rate to the desalter had to be reduced. A Baker Hughes technical support team worked with refinery personnel to develop a Crude Oil Management™ program that involved electrostatic dehydration demulsification apparatus (EDDA) testing to establish the best possible desalting program, and jar testing to aid in selection of a proper brine treatment strategy. The use of XERIC heavy oil demulsifiers (continuous feed and slug treatment) in the desalter, crude oil pretreatment in the tank farm, and the addition of coagulants to the brine leaving the desalter, completely eliminated desalter upsets and dramatically reduced the oil carryunder in the effluent brine. The desalter’s performance was no longer a factor in determining the crude throughput rate. Any solids in the brine were oil free, thereby reducing the impact on the wastewater treatment plant.

Slop oil processing facilities

Effluent brine produced while processing WCSB crudes can contain substantial oil, solids and other contaminants, as well as stable emulsions of oil and water. Prior to discharging the effluent water to the wastewater plant, separation facilities, such as an API separator, are used to remove the oily phase, which can encounter substantial solids and oil-water emulsions. This oily mess ends up in the refinery slop system. The accumulated slops are often rerun at the crude unit, which compounds the problem; and the difficult-to-separate oils in the effluent brine are no longer prone to separate after a second trip through the desalter. Mitigating this endless cycle begins with improved desalting and brine pretreatment. Less oil to be separated from the brine, and reduced emulsion and contamination in the oil recovered from the wastewater plant will reduce demands on the refinery slop system and on the desalters when the oil is re-run. For systems where challenging slops are still produced, or systems with limitations in brine handling facilities, a sound slop oil management process backed up by a coherent treatment program to reduce emulsion formation and remove filterable solids will pay dividends throughout the cycle.

Specific solutions: XERIC heavy oil program

A US refiner has reduced its overall demulsifier usage by 15% and seen crude oil dehydration improve by 35% through initiating a crude oil storage pretreatment program designed by Baker Hughes. The refiner’s desalting system has also become more robust and capable of processing increased volumes of high-solids slop oil.
High-temperature corrosion
Most of the challenges associated with processing WCSB crudes are linked to the desalting process. An important exception is high-temperature corrosion, which can be either sulfidic in nature or caused by naphthenic acids. Such corrosion is widely encountered toward the bottom of the crude unit atmospheric tower, throughout the vacuum tower, and within ancillary equipment. The rate is driven by the acid content (TAN number) of the crude, the temperature (in the range 400–750°F), the flow rate (and areas of high shear) and the materials used in the construction of the unit.

Specific solutions:
SMARTGUARD™ naphthenic acid corrosion control
A refiner processing crudes from WCSB was alerted to a high risk of naphthenic acid corrosion by the Baker Hughes SMARTGUARD™ risk assessment model. An enhanced monitoring program was implemented, including the SMARTGUARD hydrogen permeation monitoring, which was applied at locations specified by the risk assessment model. An increase in hydrogen flux was noted shortly after the start of WCSB crude processing, equating to corrosion rates in excess of 30 mpy. Application of the SMARTGUARD inhibitor program reduced the rate of corrosion by 5X, which allowed continuous processing of the price-advantaged crude oil.

Crude Oil Management
Refiners are faced with a myriad of chemical additives, diagnostic tools and monitoring systems to help process heavy crudes such as those coming from the WCSB. Baker Hughes leads the field in being able to offer products and services carefully designed to address the specific challenges inherent in these crudes. Some of the key solutions are listed and described briefly in Table 3 on the back. Not highlighted in this paper, however, is the range of expert technical support that Baker Hughes provides with these programs: crude oil characterization, wetting and solids control, emulsion control, phase behavior modeling, metallurgy, analytical characterization, additive technology, diagnostic technology and application expertise.

Equally, it must be stressed that the ability to process WCSB crudes is not simply provided by smart chemistry; further, there is no single solution, nor, for that matter, a single set of solutions, that will enable a refiner to substitute WCSB heavy crude on its crude slate without consequences.

Success depends on more than smart chemistry. The power to process WCSB crudes at high levels in the feed slate comes through the application of a sound knowledge of refinery process chemistry and plant design, combined with real experience of the impact that opportunity crudes like these can have on apparently robust facilities. With the knowledge and experience Baker Hughes possesses comes the confidence to define best practice in the operation of key units, such as the desalter, and the judgment necessary to make informed decisions about serious concerns to the success of the entire refinery.

Part of that judgment includes a constant appreciation that the cause and effect of a particular problem are often found in very different places, and that treating the effect without dealing with the cause rarely leads to the best overall solution.

Experience indicates that when processing WCSB heavy crudes, the tank storage within a refinery, the desalter, the wastewater treatment plant and the slop oil processing facilities are heavily related and need to be handled as an integrated system. Only by taking this approach is it possible to exploit operating synergies within the system and to raise the overall performance to the levels required to deal effectively with the most challenging feedstocks. By optimizing the performance of these systems as a whole, the refiner creates a platform from which to feed challenging crudes into the distillation section and, further downstream in a controlled way with minimum disruption.
The ability to think holistically about the effects of WCSB heavy crude on refinery operations and to come up with a genuinely integrated solution to its processing is the cornerstone of Baker Hughes Crude Oil Management program. The keys to successfully processing WCSB heavy crudes are built around a strategic approach rather than a tactical one, and a programmed approach rather than an additive only. Chemistry has a critical role, although the initial focus should be on the management of the issue and its solution and not necessarily on the individual chemicals.

**Conclusion**

Processing WCSB heavy crudes presents the refiner with a wide range of difficulties that cannot be viewed in isolation. Together they present the refiner with a complex operational challenge that affects the entire refinery.

Simply understanding the variety of solutions available is not enough. Given the economic demands associated with oil refining today, which are partly responsible for the drive to process more opportunity crudes, it is tempting to focus on apparent simple solutions and to be drawn by the lowest-cost chemical treatments.

A different approach is required. This paper has argued that, by taking a more holistic and managed approach to processing WCSB heavy crudes, it is possible to increase the levels of opportunity crudes in refinery feedstocks and to raise profitability without incurring any long-term negative effects on the running and integrity of the facilities. (Some case studies are provided to illustrate this point.)

Crudes from Western Canada clearly present a profit opportunity; however, the degree of profit will depend on the quality of the crude being processed at any one time and the proactive plans taken to limit plant disruptions.
### Field ASIT services™ technology
Feedstock analysis in the field that determines the asphaltene stability of crude blends. Results are important in determining feedstock segregation and blending strategies. They also help drive the appropriate chemical mitigation strategy.

### XERIC™ heavy oil program
A specific heavy oil management program that includes system-wide analysis and effective demulsifier technology, and additives to improve separation in crude tanks, the desalter, and the wastewater treatment plant and during slop oil processing.

### JETTISON™ solids release agent technology
An advanced chemical technology designed for use in the desalter to draw solids out of the crude with the effluent brine. The JETTISON technology should be incorporated into a tailored Crude Oil Management approach involving crude oil pretreatment, demulsifier choice, desalting best practices, and careful design and control of mud-washing operations.

### SULFIX™ additives
A comprehensive hydrogen sulfide treatment program with scavengers that is used for a wide range of applications. It can be used to treat crude oil feedstocks during storage. A key advantage is that, unlike most scavengers, SULFIX additives are not amine-based and therefore do not contribute to under-salt corrosion in the crude unit overhead systems.

### EXCALIBUR™ contaminant removal technology
A chemistry-based program that uses a range of novel acidifiers. It is designed primarily to adjust the pH within the desalter (to reduce emulsion formation and aid separation) in a highly controlled process to avoid corrosion and scaling. The technology also removes iron, calcium, heavy metal and amine contaminants.

### LIFESPAN™ exchanger fouling control program
Heat exchanger fouling control for crude units, hydrotreaters and fluidized catalytic crackers. These programs bring a systematic approach to dealing with refinery fouling. Thorough unit surveys are followed by process and mechanical data analysis to gain a clear picture of fouling mechanisms. Mitigation strategies are developed that include, but are not limited to, the selection of the most effective fouling control additives, such as asphaltene stabilizers and dispersants. Ongoing monitoring is also a feature.

### MILESTONE™ heater fouling control program
Similar to the LIFESPAN program, but focused on high-severity applications such as heater fouling in coking plants and visbreakers. The program includes detailed studies of fouling mechanisms and development of mitigation strategies, backed by a range of high-temperature-resistant fouling-control additives.

### SMARTGUARD™ naphthenic acid corrosion control program
This is a naphthenic acid corrosion control program that combines a predictive modeling capability to identify the areas most at risk in order to develop a tailored mitigation strategy; corrosion inhibitor assessment to select the most appropriate candidate from a range of proven products; and real-time, non-intrusive corrosion monitoring in high-risk areas.

### TOPGUARD™ overhead corrosion control program
This is an engineering-based corrosion control program designed specifically for overhead corrosion. The program uses thorough plant and process survey and feed characterization; detailed root-cause analysis to define the scale of the challenge; Baker Hughes’ Ionic Model to provide critical insight into the phase behavior that leads to corrosion; a range of purpose-designed neutralizers and corrosion inhibitors; and ongoing field monitoring using the TOPGUARD corrosion risk monitor.

### Table 3: Proven solutions to the successful, safe processing of Western Canada sedimentary basin heavy crudes

<table>
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<tr>
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<tr>
<td>EXCALIBUR™ contaminant removal technology</td>
<td>A chemistry-based program that uses a range of novel acidifiers. It is designed primarily to adjust the pH within the desalter (to reduce emulsion formation and aid separation) in a highly controlled process to avoid corrosion and scaling. The technology also removes iron, calcium, heavy metal and amine contaminants.</td>
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<tr>
<td>LIFESPAN™ exchanger fouling control program</td>
<td>Heat exchanger fouling control for crude units, hydrotreaters and fluidized catalytic crackers. These programs bring a systematic approach to dealing with refinery fouling. Thorough unit surveys are followed by process and mechanical data analysis to gain a clear picture of fouling mechanisms. Mitigation strategies are developed that include, but are not limited to, the selection of the most effective fouling control additives, such as asphaltene stabilizers and dispersants. Ongoing monitoring is also a feature.</td>
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<tr>
<td>MILESTONE™ heater fouling control program</td>
<td>Similar to the LIFESPAN program, but focused on high-severity applications such as heater fouling in coking plants and visbreakers. The program includes detailed studies of fouling mechanisms and development of mitigation strategies, backed by a range of high-temperature-resistant fouling-control additives.</td>
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<tr>
<td>SMARTGUARD™ naphthenic acid corrosion control program</td>
<td>This is a naphthenic acid corrosion control program that combines a predictive modeling capability to identify the areas most at risk in order to develop a tailored mitigation strategy; corrosion inhibitor assessment to select the most appropriate candidate from a range of proven products; and real-time, non-intrusive corrosion monitoring in high-risk areas.</td>
</tr>
<tr>
<td>TOPGUARD™ overhead corrosion control program</td>
<td>This is an engineering-based corrosion control program designed specifically for overhead corrosion. The program uses thorough plant and process survey and feed characterization; detailed root-cause analysis to define the scale of the challenge; Baker Hughes’ Ionic Model to provide critical insight into the phase behavior that leads to corrosion; a range of purpose-designed neutralizers and corrosion inhibitors; and ongoing field monitoring using the TOPGUARD corrosion risk monitor.</td>
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