White Paper

Overcoming Shale Oil Processing Challenges

BAKER HUGHES

With the fastest-growing production rate in the United States,

shale oil has rapidly become a favorite crude feed for U.S. refiners.

The choice certainly makes sense on first glance. Shale oil is light, low-viscosity, and low in sulfur, making it desirable to process. It's abundant throughout much of the country, making it a secure source of domestic energy that enables refiners to do more accurate long-term planning. And its price differential makes it attractive to purchase.

Today, those winning characteristics have landed shale oil as a feedstock in an increasing number of U.S. refineries. But as shale oil continues to gain favor, U.S. refiners are also beginning to recognize a parallel pattern of operational issues that they haven't experienced so prevalently when processing conventional crudes.

Is it possible that these operational issues are related to shale oil? And, if so, how can refiners address them so that the economics of refining shale oil make even greater economic sense?

This paper, based on the hands-on experience of Baker Hughes technical experts who have worked with many refiners and terminals to examine issues related to shale oil, proposes that certain unique compositional factors of shale oil lie at the heart of the uptick in operational issues. The good news is that these compositional factors can be addressed at almost every step in the refining process to optimize the economics of refining shale oil.

The characteristics of shale oil impact refinery economics

While shale oil composition varies from basin to basin throughout the United States, some of its common characteristics can lead to significant disruptions across the refining supply chain – from transportation from the production site to shipment from the refinery. These disruptions cost time and energy, reduce throughput, and negatively impact overall refinery economics.

Among the culprits are the following:

- **High paraffin content.** Shale oils are highly paraffinic (with many featuring waxes melting above 200°F (93°C)) and can consequently create wax deposits that can foul transportation modes, storage tanks, and process units.
- **Light paraffinic constituents.** When the light paraffinic shale oil is blended with heavy, asphaltenic crude oil, the resulting blend can experience asphaltene instability, creating sludge/deposits that reduce tank capacity in crude tanks, stabilize emulsions in the desalter unit and foul process equipment.
- **Low sulfur content.** Refiners typically blend a mix of moderate-to-high sulfur crudes with higher TAN crudes to help reduce the risk of naphthenic acid corrosion. Replacing these moderate/high sulfur crudes with lower-sulfur shale crudes can lead to an increase in the risk of naphthenic acid corrosion.
- **Hydrogen sulfide content.** Shale oils contain hydrogen sulfide (H_2S) – a natural corrosive and a deadly gas that presents significant health and safety issues during transportation.
- **Tramp amines.** When shale oil is treated with scavengers to curb the presence of H_2S, the resulting tramp amines can affect economics throughout the refining process. When present in the crude blend, tramp amines can partition into the oil phase at the desalter. Once past the desalter, they can react with hydrogen chloride (HCl) in the atmospheric column and overhead system to deposit as corrosive salts.
- **Variations in composition.** While it's common knowledge that shale oils vary from basin to basin, it may not be so well known that even shale oil from the same formation can differ widely; for example, an analysis of three samples of Eagle Ford crude delivered to a refiner within one week revealed the following:
  - Crude density ranges from 44.6°API to 55.0°API
  - Filterable solids content ranges from 176 ptb to 295 ptb
  - Appearances ranging from light yellow, to dark brown, to opaque red
  - Bottom layers of sludge that range from 10% to 15%

A steady diet of shale oil can also impact margins on the product side. The paraffinic nature and low sulfur content of shale oil can lead to cold flow, water separation, and lubricity issues in distillate products. Some light ends products may experience corrosion problems, and heavy fuel oil stability can be negatively impacted by blending shale oil residual materials with asphaltenic stocks.

It's clear that, while shale oil remains a very attractive feedstock for U.S. refiners, its composition can impact each step in the refining process – from transportation to final product shipment. And those effects will certainly have a significant impact on refinery margins.

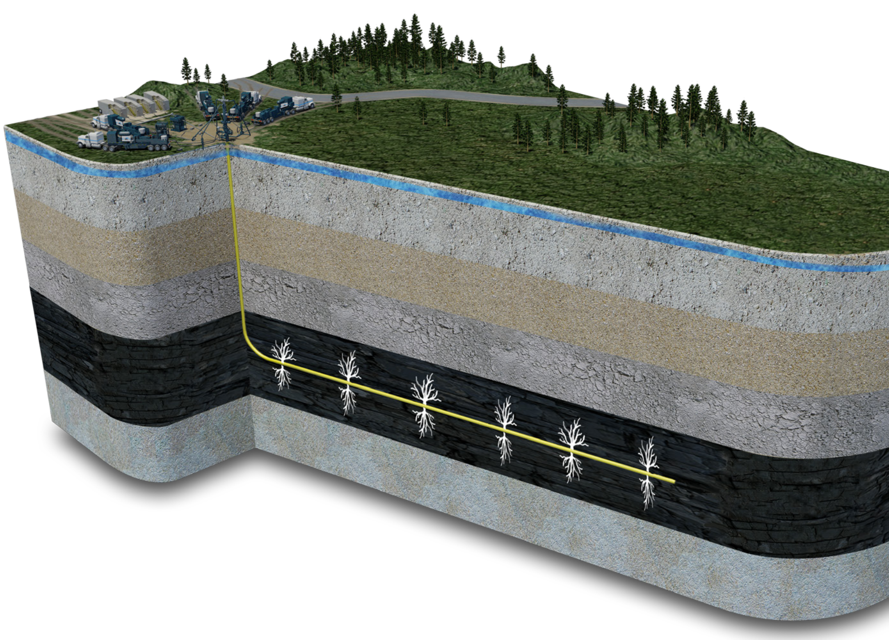
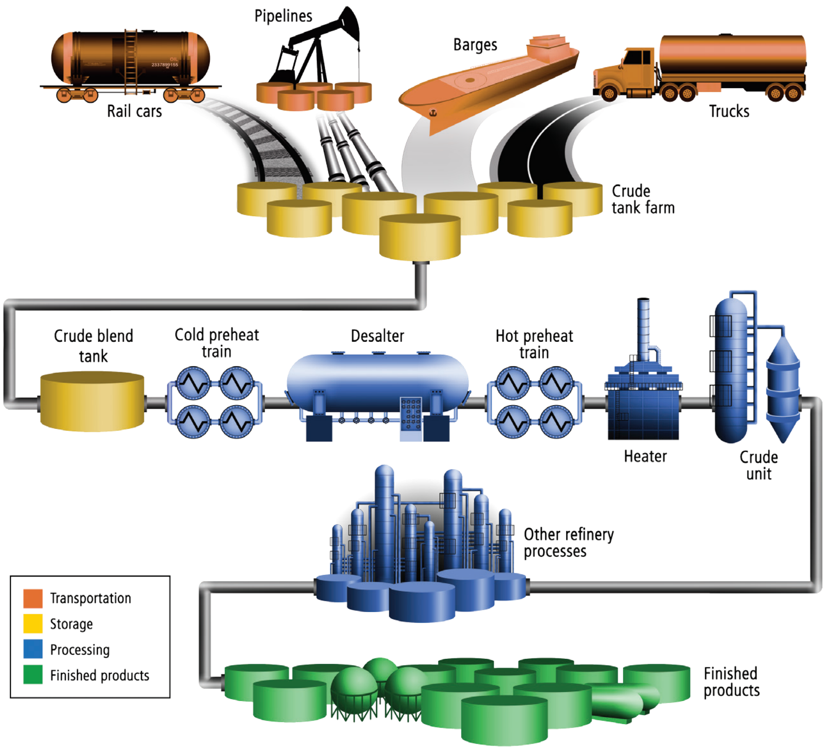


Figure 1. Shale Oil Refining Supply Chain



The impacts of shale oil in the refining process

The Impacts of Transporting Shale Oil

Whether transporting crude via pipeline, truck, barge, or rail car, shale oil composition can impact operations and constrain margins.

- **Pipelines,** the traditional and most economic method for moving conventional crudes, are impacted by slugs of wax that increase drag, reduce pipeline throughput, and require more frequent pigging operations. Some estimates are that the requirements for pigging operations to clean out the pipeline have increased from twice a year to once a month! The economic result is clear.
- **Barges and trucks**, now generally preferred over pipelines due to infrastructure challenges, are affected by wax precipitation that can cause a change in the way the crude is handled. Shale oil demands the addition of paraffin dispersants and pour point depressants to keep the crude product flowing. In addition, H_2S can cause fouling, metal corrosion, and pose serious health and safety concerns. In both barges and trucks, refiners have an opportunity to address H_2S concerns and consequently improve margins by treating the gas with scavengers. The scavengers can contain tramp amines which can lead to corrosion in downstream refinery equipment.
- **Rail cars** are rapidly becoming the most favored mode of transportation for shale oil, with 56 new or proposed rail terminals underway in the United States. Rail cars have the same exposure to fouling and corrosion as pipelines, barges, and trucks. In addition, sulfur/H_2S management is more critical since the railcars may travel through communities where the risk of exposure is at its greatest.

The Impacts of Processing Shale Oil

The fouling that can result from wax deposits, asphaltene instability or high solids content in shale oil can significantly affect refinery storage tanks and process units.

- **Storage tanks**. Solids, precipitated waxes and destabilized asphaltenes can build up in refinery storage tanks. The sludge that builds up can lead to downstream fouling of cold preheat exchangers and emulsions in the desalters.
- **Cold preheat train**. Fouling of the preheat exchangers before the desalter can occur with the presence of precipitated paraffins, waxes, asphaltenes and solids present in shale oil.
- **Desalter**. Shale oil introduces a host of challenges in the desalting process, including formation of emulsions resulting from precipitated waxes, asphaltenes, and solids. As the emulsion builds, salt removal and dehydration can be impacted, leading to downstream fouling and corrosion. Emulsions can also lead to oil in the effluent brine, creating challenges for the wastewater treatment plant.
- **Hot preheat train**. The most significant risk to the hot preheat exchangers and furnaces is fouling. Blending with asphaltenic crudes can lead to asphaltene precipitation. High solids loading will also contribute to higher rates of fouling. In addition, upstream desalting difficulties will contribute with higher levels of solids, water, and salt carryover.
- **Crude unit overhead system**. Tramp amines from H_2S scavengers can react with HCl in the crude distillation tower and overhead system to deposit corrosive amine-hydrochloride salts.

- **Crude unit high-temperature zones**. Displacing moderate to high sulfur crude oils with low sulfur shale oil can lead to an increased risk of naphthenic acid corrosion. Reduced sulfur content in the high temperature zones can lead to more aggressive naphthenic acid attack (sulfur compounds help passivate surfaces to prevent naphthenic acid corrosion).

The proper technology solutions can address all of these challenges and enable the refiner to take full advantage of economically attractive shale oils.

The Impacts of Shale Oil on Product Quality

Shale oil is refined in the crude distillation section of the refinery into the primary components of light ends (hydrocarbons ranging from C1-C4), naphtha, jet fuel/kerosene, diesel, gas oils, and residual fuel oils. Many of the refineries in operation today were designed for processing heavier crudes, so crude distillation columns and associated equipment were designed around a higher quantity of heavy fuels (gas oils and residuum) for downstream vacuum, fluid catalytic cracking unit (FCCU), and delayed coker operations. The lighter shale oils, therefore, may produce an overloading in the lighter ends processing in the crude column and associated equipment. As a result, the main crude column may operate quite differently than their original design. Among the operating issues that may be encountered are the following:

- The amine scrubbers for the C1-C4 hydrocarbons may become overburdened, resulting in off spec C3/C4 products, with copper strip corrosion failures as well as hydrogen sulfide contamination.
- An increase in the naphtha flow can overload the crude tower overhead accumulator, reducing naphtha and water separation efficiency. This can impact product quality by corroding the crude distillation column and adding to the potential for metal loading in jet fuels and distillates fractions. Microbiological contamination may also be increased due to water entrainment.
- An increase in the jet fuel or diesel water content may be noticed.

Solutions such as chemical additives for dehazing or filtration equipment can mitigate these challenges. In addition to managing the fuel quality through both dehazing or salt drying and filtration, the intermediate storage tanks and final product tanks need to have a microbiological monitoring program established.

The advantages of shale oil to the refiner

- Acquisition costs are low
- A secure domestic supply enables long-term, profitable planning
- The higher volumes of naphtha and distillates, with minimal conversion unit processing, can reduce operating costs per barrel of distillate produced
- The low-sulfur content allows refiners to purchase additional higher-sulfur, lower-cost opportunity crudes to blend with the low-sulfur content shale oils

Shale oil characteristics vary widely

- API gravity ranges from 30°API to 55°API
- High paraffin content with wax appearance temperatures greater than 200°F (93°C)
- Sulfur content as low as <0.2%
- Occasionally high hydrogen sulfide and mercaptan content
- Total acid number as low as <0.1 TAN (mg KOH/g)
- Very low asphaltene content, <0.1%
- Filterable solids content as high as 295 lbs (134 kg) per thousand barrels
- Light crude with little residual material, <10% of total yield
- Highly variable crude quality from the same reservoir

Key implications of shale oil on finished products

The right chemical additives can further enhance the profitability of processing shale oils. Some of the key implications for various fuel treatment programs include the following:

- A significant decrease in the demand for NACE or pipeline corrosion inhibitors for the shale oil derived gasoline and diesel fuels
- An increased demand for additives to meet cold flow properties due to the increased quantity of paraffin in the fuel
- A decreased demand for the copper and silver corrosion inhibitor programs when processing shale crude oils
- An increased demand for lubricity improvers, due to low sulfur crude
- An increased demand for clay filtration of the straight run jet fuels as well as increased dehazer usage for the diesel fuels due to increased water content
- Cetane numbers are dependent on the shale play and the degree of refinery processing
- A relatively low requirement for fuel stability additives
- Larger compatibility issues surrounding the blending of residual fuels

The right technology solutions can improve economics at any point in the process

The good news is that refiners can effectively mitigate the threats presented by shale oil – at any point in the process – with the right technical solutions. These solutions can include any of the following:

- Technical assessments – both in the field and in the lab – of the impacts of shale oil characteristics on crude storage compatibility, asphaltene precipitation, and desalter emulsion stabilization
- Tests to identify the crude blends likely to be affected by asphaltene precipitation
- Analytical tools to characterize feedstocks and analyze deposits
- Risk assessment models and advanced monitoring technologies to predict and eliminate the potential for fouling and corrosion
- Evaluations to determine the appropriate strategies and best treatments for processing shale oils through the refinery
- Contaminant removal and fouling control programs
- Other chemical programs – such as pipeline drag reducers to increase the throughput of the shale oil to the refinery due to the limited pipeline infrastructure; wax dispersants to reduce wax build up and pipeline pigging frequency; and hydrogen sulfide scavengers that control corrosion in crude tanks, process units, and finished product tanks.

None of these components, taken either individually or collectively, can substitute for the expert guidance of people who know how to plan and execute a technical strategy.

Given the right mix of expertise and technology, however, refiners can take the actions necessary to boost refinery economics at every step in the process.

Comprehensive solutions for shale oil

Shale oil presents an excellent opportunity for refiners to positively impact their profitability. However, with new opportunities come new challenges. A working knowledge of each step of the refining supply chain process [Figure 1] allows those challenges [Figure 2] to be met and the profit improvements fully realized.

Overcome shale oil processing challenges

The introduction of shale oil into the refining industry has changed the manner in which refiners operate. There are a number of advantages to processing shale oil feedstocks, but it is not without its challenges. Baker Hughes has used its experience, proven technologies and problem-solving capabilities to develop innovative solutions that can eliminate and/or mitigate shale oil processing challenges. These solutions can be used to improve refinery feedstock selection flexibility, allow higher rates of shale oil processing, and keep finished products on specification, while maintaining reliable operations, reducing costs, and improving operating margins.

Baker Hughes has a significant amount of experience in the shale oil industry, from exploration and production through refining and the refined product quality management. As other shale oil sources come on line, Baker Hughes is committed to providing continued new solutions for shale oil transportation, storage, refining, and finished product challenges.

Figure 2. Understanding the process and designing the right programs to optimize refinery economics

	Step in the Process	Challenge	How to Solve It	The Baker Hughes Solution
Transportation	Pipelines	Presence of H_2S	H_2S scavenger treatment	SULFIX™ H_2S scavengers
		Wax build-up	Wax dispersants	Baker Hughes wax dispersants
		Throughput	Pipeline drag reducers	FLO™ pipeline drag reducers
		Transmix "sludging"	Compatibility testing	Field ASIT services™
	Barges, trucks, and rail cars	Presence of H_2S	H_2S scavengers	SULFIX™ H_2S scavengers
		Wax build-up	Disperse wax, reduce sludge	Baker Hughes wax dispersants, sludge reducers
		Blending compatibility	Monitor crude compatibility	Field ASIT services™
Storage	Crude tank farm	Wax build-up	Disperse wax, reduce sludge	Baker Hughes wax dispersants, sludge reducers
		Solids build-up	Disperse solids	XERIC™ solids conditioning aids
		H_2S	H_2S scavengers	SULFIX™ H_2S scavengers
		Blending	Monitor and increase compatibility	Field ASIT services™, XERIC™ blending aids, Baker Hughes wax dispersants
Processing	Cold preheat train	Fouling	Antifoulant treatment	LIFESPAN™ heat exchanger fouling control programs
	Hot preheat train	Fouling	Antifoulant treatment	LIFESPAN™ heat exchanger fouling control programs
	Desalter	Emulsion build-up	Destabilize emulsion	EDDA testing, Baker Hughes demulsifiers and XERIC™ wetting agents
		Presence of amines	Amine removal	EXCALIBUR™ contaminant removal program
		Presence of other contaminants	Contaminant removal	EXCALIBUR™ contaminant removal program
	Corrosion	Amine salt build-up	Remove in desalter	EXCALIBUR™ contaminant removal program
		Amine salt build-up	Corrosive environment simulations	TOPGUARD™ Ionic Model and TOPGUARD™ corrosion risk monitor
		Increased naphthenic acid corrosion potential	Determine mitigation strategy via risk assessment	SMARTGUARD™ naphthenic acid corrosion control program
Finished Products	Product quality	Pour point, cold flow	Testing, additives	TOLAD™ pour point depressants and cold flow improvers
		Water in distillates	Salt drying and coalescing, dehazers	P2R™ services and engineering solutions
		Lubricity	Lubricity additives	TOLAD™ lubricity additives
		H_2S	Hydrogen sulfide scavengers	SULFIX™ H_2S scavengers
	Product terminals	Resid blend incompatibility	Additives, compatibility tests	TOLAD™ asphaltene stabilizer, Field ASIT services
		Intermediate cold flow	Additives	TOLAD™ pour point depressants and cold flow improvers

For more information visit us at www.bakerhughes.com/shaleoilprocessing

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