

Challenges and Solutions for Shale Oil Upgrading

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Abstract

The nature of raw shale oil presents some significant challenges that must be addressed before finding a workable solution for upgrading shale oil into finished transportation fuel. Some of the key challenges involve high concentrations of heteroatomic compounds, unsaturates, and arsenic, as well as issues with particulates, and potential plugging problems due to oxygen exposure during retorting. UOP has significant experience in development and operation of shale oil upgrading technology, dating back to the operation of the Unocal plant at Parachute Creek, Colorado. Since then, UOP has continued development aimed at further improvements to product upgrading technology, resulting in an enhanced understanding of the removal of contaminants such as arsenic and particulates, and advanced hydroprocessing configurations to produce high-quality ultra-low-sulfur distillates and gasoline. This paper will provide an overview of the Parachute Creek operation, a summary of key lessons learned from that experience, and fast forward to development work conducted recently to support proposed commercial shale oil operations.

In addition, an interesting application of this technology for upgrading of raw shale oil to high-quality fuel in a future commercial plant for Viru Keemia Grupp (VKG) in Estonia will be discussed. The characteristics of this Estonian shale oil and the project's production goals provided some interesting challenges for the development of process configurations for this project. The combination of UOP's experience base and new technology development plus VKG's ninety years of experience in shale oil production has resulted in an effective and robust solution.

Introduction

In order to meet the refining requirements of the future petroleum marketplace, it will be necessary to have capabilities for producing specification fuels from a variety of feed sources. In recent years, we are seeing increasing interest in utilizing oil shale resources to fill a part of this need. The goal of producing high-quality fuel from the wide range of shale sources is certainly attainable, but there are some significant challenges associated with upgrading these materials.

The Nature of Shale Oil Presents Significant Challenges to Upgraders

Raw shale oil contains the same types of hydrocarbon and heterocyclic components found in petroleum crude oil. Raw shale oil, however, contains relatively little residuum, but many shale oils contain higher concentrations of sulfur, nitrogen, oxygen, and arsenic than most petroleum crude oils. In addition to having high contaminant levels, the sulfur and nitrogen-containing compounds tend to be distributed more evenly through the boiling range than with most conventional crude oils,

where they are often weighted more towards the heavy end of the boiling range. The olefin and diolefin concentrations in raw shale oil are also relatively high.

These properties, particularly the high sulfur, nitrogen, oxygen, olefins, and arsenic contents, make it very difficult for conventional refineries to process raw shale oil. The arsenic quickly poisons catalyst beds, and conventional refineries do not have the installed reactor volume necessary to remove the high levels of nitrogen in the lighter product cuts. In addition, diolefins polymerize when exposed to oxygen in refinery crude tanks, resulting in fouling and pressure drop problems in the refinery. Raw shale oil must first be upgraded to resolve these issues, producing either finished products, or a synthetic crude that is similar to, or even superior in quality to conventional crude oils.

The relative amounts of contaminants in shale oils vary widely between different locations and can even show significant variation within different areas of the same formation. The following chart lists the concentration ranges of some key components UOP has measured in shale oils from various locations.

<i>Composition of condensed oils vary widely with location</i>	
Sulfur	0.4 - 11.5 wt%
Nitrogen	0.3 - 4.0 wt%
Oxygen	0.7 - 7.2 wt%
Arsenic	1 - 80 wppm
Density	0.65 - 0.97

The retorting technology chosen for a shale oil project can have implications for the ability to further upgrade the raw shale oil. Some shale oil extraction

processes use combustion gases from burning of the spent shale to directly heat the fresh shale. This generates a gas product with a very low heating value. Use of this kind of extraction can also result in lower liquid yields, and oxygen contamination can cause the formation of polymers that will foul downstream equipment. Some extraction processes use a heated oxygen-free gas stream, or a heated solids stream to heat the shale resulting in higher liquid yields, limited or no oxygen contamination, and the generation of a net gas stream with a reasonable heating value.

Some raw shale oil streams, like those produced from Colorado shale, are very paraffinic in nature, so the finished products require dewaxing to meet the required cold flow properties. Other shale oil streams are fairly aromatic, so the production of high-smoke-point kerosene or high-cetane diesel is the challenge.

The properties that are characteristically unusual in shale oil, relative to other oil sources, cause some significant challenges for the upgrader. The success and optimization of the upgrading complex will depend to a large extent on the experience and database available to those preparing the performance estimates.

UOP Has a Long History of R&D and Commercial Operation Associated With Shale Oil Upgrading

During the 1970s and 1980s, Unocal did a great deal of work on shale oil process development at their research facility in Brea, California. This work included both retorting process development and shale oil upgrading process development. The pilot plant facilities

in Brea included a 3 ton per day retort plant, de-ashing and de-arsenating plants, coking, fractionation, and a full slate of hydrotreating and hydrocracking pilot plants which were shown to closely match commercial performance.

The catalyst systems developed by Unocal were uniquely suited to shale oil upgrading due to their high activity and ability to operate in a high-nitrogen, high-ammonia environment. In addition to the existing portfolio of hydrotreating and hydrocracking catalysts, some materials were developed specifically to handle the arsenic content and cold flow challenges posed by Colorado raw shale oil. As Unocal was a world leader in these capabilities at this time, many requests were received from other companies to evaluate the upgrading of their shale oils. The oils evaluated cover a wide range of properties (up to 6.7 wt% sulfur and 2.1 wt% nitrogen) and were from geographic regions around the world.

In addition to the development work in the research facility, Unocal operated an upgrading facility in Colorado with data being monitored and evaluated by R&D personnel. In 1995, UOP purchased Unocal's Process Technology and Licensing business, acquiring the rights to all of the hydroprocessing technology used at Parachute Creek. In addition to gaining access to this valuable technology, many of the key scientists and engineers that developed the technology for Parachute Creek, and designed and operated the upgrader, went to work for UOP and continue to work there today.

Due to all these factors, UOP's pilot plant and commercial database contains information from a wide range of

shale oil properties and upgrading conditions. UOP, with their acquisition of Unocal's Process Technology and Licensing group in 1995, obtained full rights to the database and intellectual property concerning the upgrading of raw shale oil into transportation fuels.

Commercial plant operation – 1984-1990

Unocal's operations at Parachute Creek included mining and retorting of 12,500 tons per day of Colorado shale and subsequent upgrading of the 10,000 barrels per day of retorted shale oil. The primary goal of this operation was to upgrade the quality of the shale oil to serve as premium synthetic crude. A pour point reduction step was added to enable the product to be pipelined.

Unocal completed construction of the Parachute Creek facility in late 1983. Shake-down operations began in 1984, but the facility was not considered to have started up until 1986 when commercial operations began. Initially, production rates were low. In 1987, the production of shale oil was only 17% of design. Production rates increased each year until 1990 when shale oil production exceeded 80% of design. The upgrader was expected to exceed four million barrels of total production by the end of 1990 when the project was shut down.

Most of the operating problems in those early years involved materials handling issues. The shale crushers and handling of spent shale from the retort itself were the major issues. During the period from December 1984 through July 1987 test runs were conducted to evaluate the upgrading operations, including operation at 100% of design capacity.

Properties of all relevant feed and product streams, required operating conditions, product yields, and product properties were all carefully monitored during these periods. In general, the de-ashing, de-arseniting, hydrotreating, and Unicracking™/Dewaxing plants operated very much as expected and the data is now available in UOP's database. The performance of the commercial unit closely matched the data from the pilot plants used to develop and estimate conditions, yields, and properties. The quality of the synthetic crude oil produced in this operation met all expectations. The product boiling range distribution of this synthetic crude is shown in Figure 1.

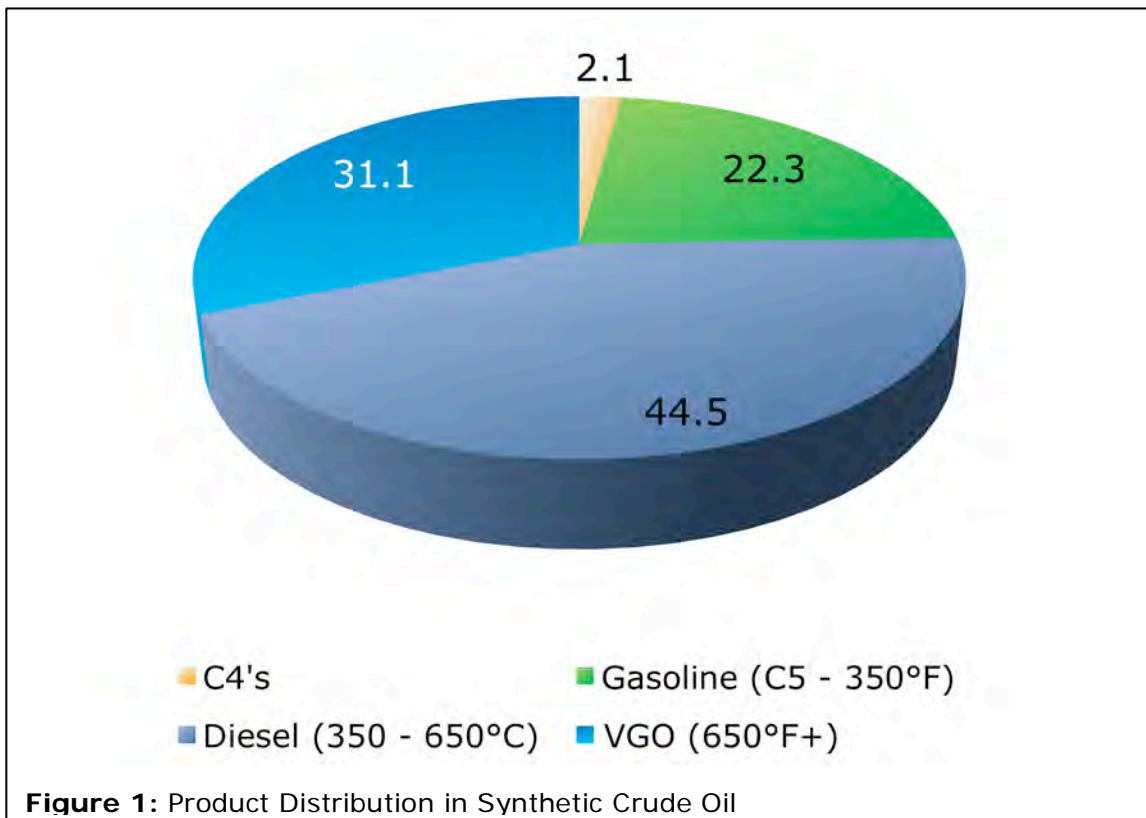
UOP has continued development aimed at further improvements to product upgrading technology, resulting in an enhanced understanding of the removal of contaminants such as arsenic and par-

ticulates, and advanced hydroprocessing configurations to produce high-quality ultra-low-sulfur distillates and gasoline.

Effective Solutions to Key Problems Have Been Found

As mentioned previously, shale oil properties have wide variability and, because of this, challenges to meeting specification product fuel properties can vary from case to case. Even so, there are some key challenges that are present for any shale oil upgrading project.

Raw shale oils, depending on mining, extraction methods, and tankage strategies, contain various quantities of inorganic solids from the crushed rock, organic solids (or semi-solid organic matter), and ash formed during the retorting process. The organic solids could be tars or gums, formed because



of exposure to oxygen during the re-torting process. These materials will likely cause serious plugging issues in the fixed-bed catalysts required to hydrotreat the raw shale oil to produce finished transportation fuel.

The inorganic solids commonly have very wide particulate size ranges, including a significant amount of sub-micron particles. The breadth of the size range, combined with the presence of some organic material presents some significant challenges for effective removal. In the Parachute Creek upgrading operation, these issues required a significant amount of R&D and demonstration effort to achieve a sustained operation. For any given project, effective particulates handling may require a somewhat different solution but, in UOP's experience, an optimized combination of mechanical filtration, ash removal, and graded bed technology has proven effective for a variety of shale oils.

One of the causal factors contributing to the formation of organic plugging material in shale oil feedstocks is the potential exposure to oxygen for significant residence times, at high temperatures, during extraction. The olefins and diolefins generated during the re-tort process will react with any oxygen available in the system, causing polymerization reactions that will form gums. These gums have the potential to foul downstream heat exchangers and plug reactor catalyst beds. Even very low levels of oxygen have been shown to cause gum formation.

Unocal's early experience in the operation of Unocal's Retort A at Parachute Creek and subsequent pilot plant work with the products from that operation showed that the oxygen exposure in

this direct heating by combustion of retorted shale resulted in the formation of polymerized materials, which caused serious plugging issues in downstream upgrading reactors.

Arsenic is a powerful poison that rapidly deactivates hydroprocessing catalysts. Even the parts-per-billion concentrations found in some crude oils can be damaging and must be removed in specifically designed graded beds. The high arsenic content found in shale oils would overwhelm a typical graded bed configuration and requires a different solution.

To solve this problem for the Parachute Creek upgrading plant, the catalyst group within Unocal R&D invented a catalytic material called SOAR-100 (Shale Oil Arsenic Removal) which was designed to have a large capacity and high activity for arsenic removal, while maintaining its integrity within the operating environment. These pre-treat catalyst beds were demonstrated to work very well for the Colorado shale oil, which contained arsenic levels as high as 50-60 wppm. Arsenic content from the dearseniting reactor section was consistently below 0.5 ppm during the commercial plant operation. The total expected arsenic retention in the pre-treat beds was expected to reach 40-50 percent of the fresh SOAR-100 weight by the end of the cycle. This technology is an important component of UOP's current upgrading configurations.

Some shale oils, such as the Colorado oil, have a paraffinic character in the heavier boiling ranges. When these materials are hydrotreated, the paraffins are likely to give the product a high pour point, causing problems in transporting the full-range product via pipe-

line.

In support of the Parachute Creek upgrading plant, a catalyst was developed to selectively convert these normal paraffinic compounds and reduce the pour point of the product to -10°F , while also improving the product viscosity. In addition to improving the transportability of the synthetic crude oil, this pour point reduction expanded the boiling range and yield of specification diesel fuel.

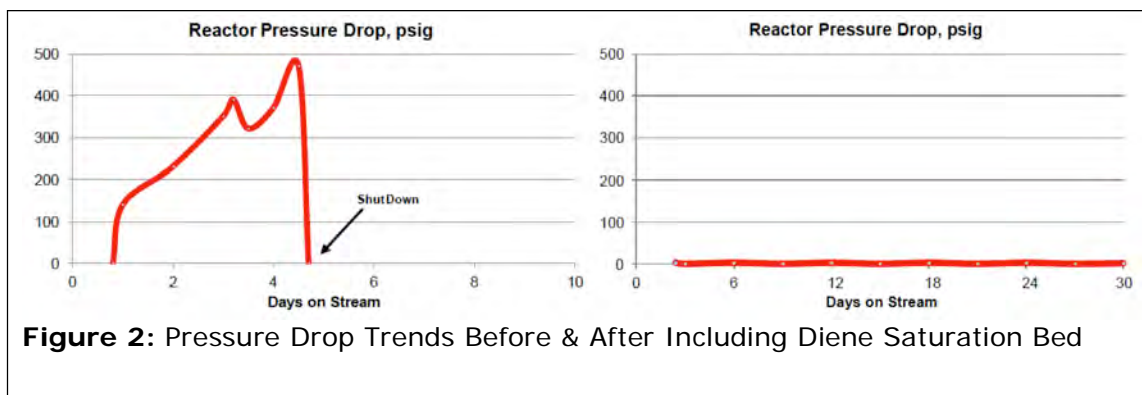
We now have paraffin cracking catalysts of varying activities which operate effectively in the high-ammonia and hydrogen sulfide atmosphere of the on- through hydroprocessing reactor system. Additional dewaxing capabilities for products are also available through an alliance between UOP and ExxonMobil Research and Engineering Company. These deliver a comprehensive suite of lube and advanced fuels hydroprocessing options for dewaxing to be used in conjunction with UOP hydroprocessing solutions.

Product fuel specifications can be challenging to meet when upgrading many shale oils. The high concentration of heteroatomic compounds in many of these oils can create problems in meeting fuel sulfur and stability specifications. Most refineries do not have hy-

droprocessing units with high enough pressure and catalyst volume to remove the high levels of nitrogen that can be present in raw shale oil fractions. Unocal testing at Parachute Creek indicated that the jet and diesel fuel product nitrogen contents had to be kept below a certain level to ensure that the products would be thermally stable.

The relatively high concentration of olefins and diolefins found in raw shale oils is another aspect that must be considered in an upgrading solution. Diolefins will polymerize on exposure to oxygen in refinery crude tanks, which would in turn cause fouling and pressure drop problems in the refinery. In addition, the diolefins will rapidly react at typical hydroprocessing conditions and cause almost immediate plugging of the catalyst beds.

In a recent pilot plant test upgrading a shale oil from a Middle East source, the need for a diolefin saturation capability was investigated. The initial catalyst configuration contained pretreating materials but no diolefin saturation beds. As can be seen in Figure 2, after only 278 hours into the start-up protocol, almost immediately after starting the shale oil feed, the pressure drop across the first reactor increased dramatically and forced a shutdown of the



pilot plant. The next step in this investigation included the addition of a diolefin saturation capability. After re-start with the diolefin saturation bed there was no noticeable pressure drop build up in the reactor circuit during the remainder of the 30 day study. As a final test, the diolefin bed was removed from the configuration near the end of the study and the pressure drop began to increase after a short period of time. This was a rather vivid demonstration of the necessity of this protective measure.

Configuration Options for Robust Upgrading of Raw Shale Oils

The general configuration of a shale oil upgrading facility, depending on the desired product slate, can be rather simple. There are usually fewer process units required than even the most simple conventional refinery. Even so, just as there is wide variation in the properties of raw shale oils, there is no one upgrading configuration that is optimal for all situations. The appropriate configuration for a given case depends on many factors like fuel oil – diesel price differential, feedstock boiling range, heteroatomic compound concentrations, olefin content, contaminant levels, and product quality requirements.

Three potential upgrading configurations will be discussed in the following sections. Each of these options has been used successfully to achieve product quality goals for different situations. All three options include processing the full-range raw shale oil through a De-arseniting/ Pretreating unit to filter out solids, remove arsenic and other contaminant metals, convert some organic oxygen species, and saturate the olefins and diolefins present in the feed.

High Pressure Hydrotreating of Full-Range Raw Shale Oil

One option when upgrading raw shale oil is to produce a full-range premium synthetic crude oil. Since many shale oils contain levels of nitrogen higher than most conventional crudes, and this nitrogen is more evenly distributed throughout the entire boiling range than any conventional crude, it can make sense to treat the full-range shale oil rather than fractionating the oil into different cuts before processing.

If the shale oil has a paraffinic character, it will have poor cold flow properties and must be dewaxed before it can be shipped to downstream refiners in a pipeline. The nitrogen in the shale oil needs to be reduced prior to processing over the dewaxing catalyst. High-severity hydrotreating to remove the nitrogen followed by a dewaxing step can produce a synthetic crude with very low nitrogen levels and a pour point suitable for shipment in crude pipelines.

This configuration can also be used to hydrotreat the shale oil at a severity necessary to upgrade the jet and diesel fractions to finished fuel specification levels. A high-severity once-through hydrotreating of full-range shale oil has the advantage of simplicity, but is likely to result in over-treating of the vsccum gasoil (VGO) fraction in order to treat the fuel fractions to specification levels. This overtreatment of the VGO will result in unnecessary use of hydrogen. A simplified flow diagram of this type of configuration may be seen in Figure 3.

In Unocal's Parachute Creek commercial operation this configuration was used to produce a high quality synthetic crude oil. The properties of the full-range product and the naphtha, kerosene, diesel, and VGO cuts from this

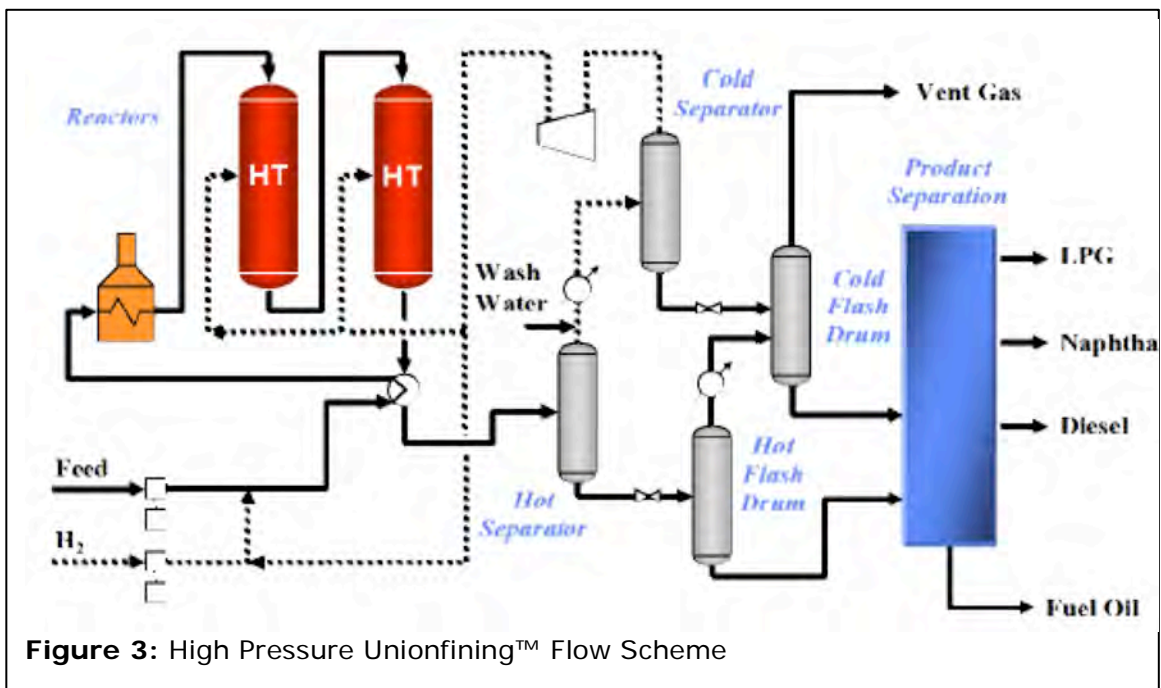


Figure 3: High Pressure Unionfining™ Flow Scheme

synthetic crude are shown in Tables 1 and 2.

Parallel Hydrotreating of Raw Shale Oil Fractions

In situations where the nature of the jet and diesel fractions of the raw shale oil require severe hydrotreating to meet finished fuel specifications, there would be a significant hydrogen consumption and capital cost penalty to treating the

full range material at such high severity. The VGO boiling range would be upgraded to a much greater extent than necessary.

For these situations, it is attractive to separate the pretreated shale oil into diesel-minus and diesel-plus fractions, and then treat the fractions independently at conditions that are optimized for those boiling ranges. The full-range de-arsenated shale oil is di-

Table 1 - Comparison of Synthetic Crude to Arab Light Crude

	Synthetic Crude from Shale Oil	Arab Light
Gravity, °API	40	34
Sulfur, wppm	7	17,000
Nitrogen, wppm	75	800
Pour Point, °F	-6 to +25°F	
Carbon Residue, wt%	0.05	3.6
Metals, wppm (Ni + V + Fe)	--	20
Distillation, lvs% IBP – 1000°F	100	85
1000°F+	--	15

Table 2 - Detailed MQD Unionfining Unit Product Properties

	SOR	EOR
<i>C5-C6 Light Naphtha</i>		
Specific Gravity	0.6680	0.6682
Gravity, API	80.34	80.25
Sulfur, wppm	<5	<5
Nitrogen, wppm	<2	<2
<i>C7-290°F Heavy Naphtha</i>		
Specific Gravity	0.7281	0.7300
Gravity, API	62.85	62.34
Sulfur, wppm	<5	<5
Nitrogen, wppm	<2	<2
RON / MON	56/56	57/56
P/N/A, wt%	57/37/6	57/35/8
<i>290-350°F Kerosene</i>		
Specific Gravity	0.7624	0.7644
Gravity, API	54.11	53.62
Sulfur, wppm	<5	<5
Nitrogen, wppm	<10	<10
Aromatics, vol%	6	8
TCC Flash Point, °F	87	87
Smoke Point, mm	35	32
Freeze Point, °F	<-80	<-80
Naphthalenes, wt%	<3	<3
<i>350 - 650°F Diesel</i>		
Specific Gravity	0.8274	0.8290
Gravity, API	39.51	39.18
Sulfur, wppm	<8	<8
Nitrogen, wppm	<10	<10
Cetane Index (D-976)	55.3	54.7
Cetane Number	56	55
Aromatics, vol%	5	7
Poly-Aromatics, wt%	<2	<4
PM Flash Point, °F	160	160
Pour Point, °F	-30	-30
Cloud Point, °F	-3	-3

vided in a splitter column added to the back end of the De-arseniting/ Pretreating unit.

This column separates the fuel oil-range

material from the diesel and lighter product fractions. The fuel oil range material is then sent to a VGO Unionfining reactor, while the diesel and lighter range products are sent to a Distillate

Unionfining reactor. These two reactor trains would be integrated into a single process unit, and share much of the equipment in a common high-pressure circuit.

Some complexity is added in this type of configuration, but the ability to set appropriate conditions for processing the different boiling ranges can be beneficial. A flow diagram of this parallel configuration is shown in Figure 4.

Hydrocracking for Maximum Diesel Fuel Yield

Should the project economics indicate an advantage to producing maximum yields of finished products, a second reactor train could be added to the high-pressure Unionfining Unit, converting it into a two-stage Unicracking unit. Coupled with a full fractionation section, the Unicracking unit would produce light and heavy naphtha streams, finished kerosene, finished ultra-low-

sulfur diesel, and a small volume of unconverted VGO-range material. A flow diagram of this maximum fuels configuration is shown in Figure 5.

For a recent evaluation we compared the three configuration options discussed above as part of an optimization study. Operating conditions and yield for the three cases are shown in Table 3. Some of the trade-offs between the options are apparent from this data.

Current Application of Technology Demonstrates Ability to Deal with a Unique Shale Oil

A recent study in UOP's pilot plant facility provides a good example of optimizing an upgrading configuration and processing conditions to provide a robust solution meeting a refiner's goals. Viru Keemia Grupp (VKG) wanted to process a challenging full-range feed through the Shale Oil Upgrading Unit to maximize the production of Euro V diesel and

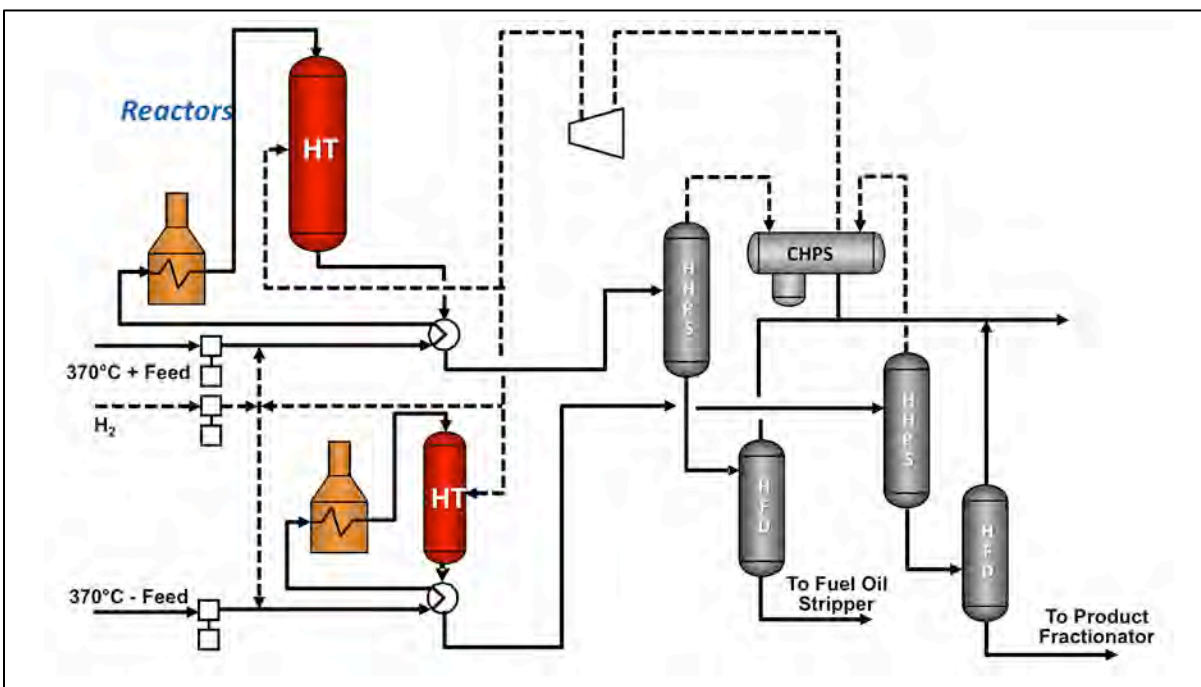


Figure 4: Parallel Unionfining Flow Scheme

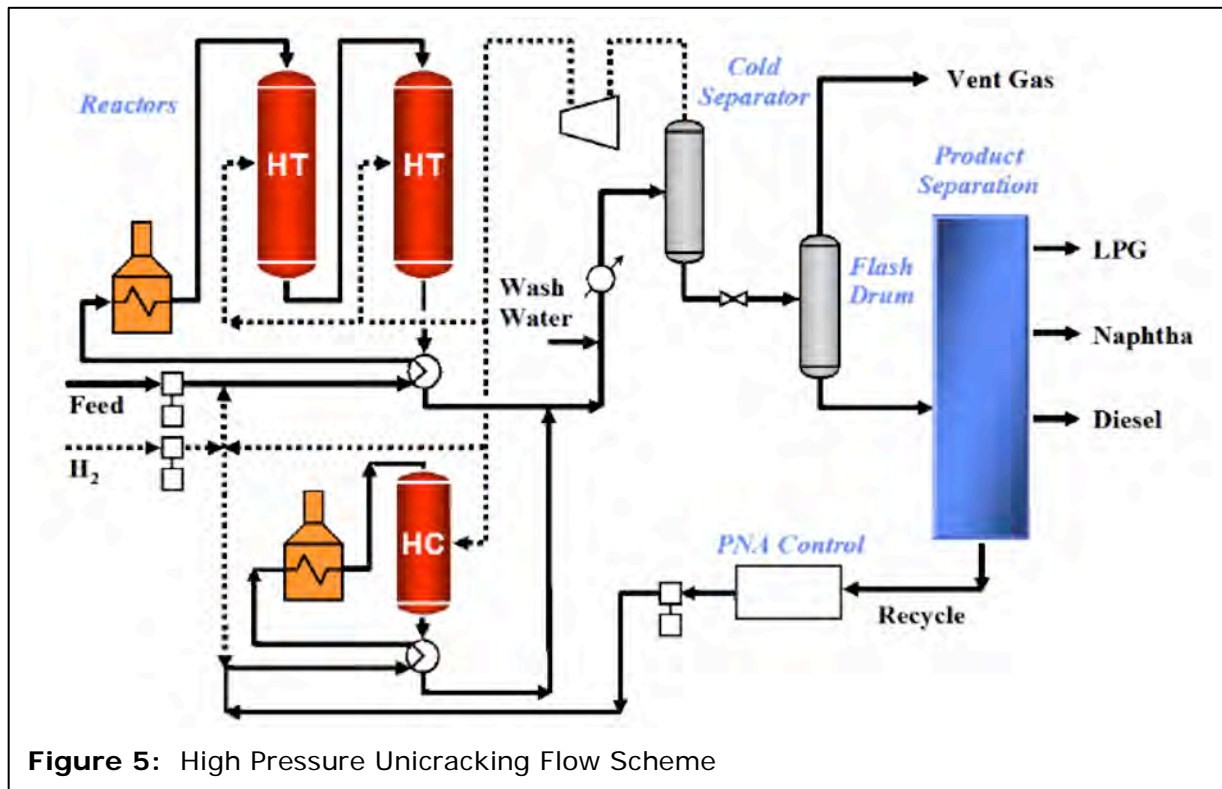


Figure 5: High Pressure Unicracking Flow Scheme

Low-Sulfur Fuel Oil to meet the proposed MARPOL regulations. Naphtha production was to be minimized.

The shale oil feedstock had somewhat unusual characteristics, which included

a heavy tail-end boiling fraction, moderate concentrations of sulfur and nitrogen, and high olefin (including significant content of dienes) and oxygen concentrations. The challenge was to find the best configuration to achieve

Table 3 - Comparison of Three Configuration Options

Parameter	Case 1	Case 2	Case 3
Process Conditions	VGO Unionfining Unit	Integrated Distillate/VGO Unionfining Unit	Unicracking Unit
Separator Pressure, barg	Base	Base x 0.82	Base x 1.25
Overall LHSV (1/hr)	0.31	Base x 2.7	Base x 1.2
Catalyst Cycle Length, years	2	2	2
Number of HP Reactors	2	2	3
Yields, wt.-% FF			
C5-150°C Naphtha	15.40	14.20	21.98
150-360 °C Diesel	53.40	46.10	71.20
Low Sulphur Fuel Oil	26.10	33.20	1.15
Chemical H ₂ Consumption	Base	Base x 0.56	Base x 1.12

high diesel yields and specification quality fuel oil within reasonable cost constraints and hydrogen usage. The typical properties of the full range raw shale oil feed are shown in Table 4.

Selection of Configuration

Several processing configurations were considered for this project and compared on the basis of product yields, hydrogen usage, product qualities, catalyst requirements, and capital costs. In the first step of the selected processing scheme, the full-range shale oil is pretreated to remove particulates, saturate the olefins and dienes, and remove arsenic and other metals. During this pretreatment, a significant amount of desulfurization also takes place. Following pretreatment, the full-range dearsenitized shale oil is divided in a splitter column into fuel oil range material and diesel and lighter product fractions. The diesel and lighter range products are sent to a Distillate Unionfining reactor where they can be hydrotreated at conditions that are optimal for this purpose. The fuel oil fraction produced from the De-arseniting/Pretreating unit is significantly upgraded and has a low sulfur content. This is a striking example of optimization by separating the oil into fractions. Properties of the two fractions from the splitter can be seen in Table 5.

Hydrotreating of the Diesel-and-Lighter Fraction

The hydrotreating of the 370°C-Minus fraction of the pretreated shale oil was demonstrated in a UOP pilot plant. This was largely a study of the impact of key operating conditions on the critical diesel properties. The temperature, pressure, and space velocity were varied in the pilot plant to provide data for opti-

Table 4: Feedstock Properties

Specific Gravity @ 15.6°C	0.9874
API	11.8
Hydrogen, wt%	9.73
Nitrogen, wppm	1796
Sulfur, wppm	7216
Oxygen, wt%	7.2
Chloride, wppm	57
Arsenic, wppm	4
Ni, wppm	0.5
Bromine Number	70
SimDist (°C)	
IBP	60.8
5	121.0
10	172.0
30	291.4
50	372.0
70	446.4
90	561.8
95	619.4
EP	727.8

mization. For this shale oil, achieving the specification cetane number in the diesel fuel fraction was the most challenging goal.

The plots in Figures 6 and 7 show the response of the cetane number to adjustments in temperature, pressure, and space velocity. For this shale oil in the condition ranges studied in the pilot plant, temperature and pressure adjustments increased the diesel cetane number, but with a relatively low response slope. Space velocity, however, was an important variable for achieving the target cetane. As can be seen from the plot, the cetane number response to LHSV changes was very significant. The pilot plant data allowed us to choose an optimum set of conditions to meet all of the refiner's product quality targets.

Table 5 – Properties of Pretreated Product Fractions

	370°C-Minus	370°C-Plus
Specific Gravity @15.6°C	0.8945	1.005
API	26.7	9.31
Hydrogen, wt%	11.80	10.11
Nitrogen, wppm	1132	2118
Sulfur, wppm	272	747
Oxygen, wt%	2.37	3.53
1 Ring Aromatics, wt%	25.7	----
2 Ring Aromatics, wt%	7.3	----
Poly Aromatics, wt%	11.1	----
Bromine Number, g/100g	44.0	----
Derived Cetane Number	33.83	----
Arsenic-Naphtha, wppb	5	10

A summary of the product properties at the optimized conditions can be found in Table 6.

Conclusions from the Pilot Plant Study

The De-arsenating/Pretreating unit is very effective at removing contaminant metals from the feed. All feed metals

were reduced to very low levels and only 5 wppb Arsenic remained in the product. Chlorides in the feed were reduced from more than 60 wppm to less than 7 wppm in the product. Sulfur and oxygen removal in the pretreating unit was very significant; 93 percent desulfurization, 57 percent oxygen removal and 15 percent denitrogenation.

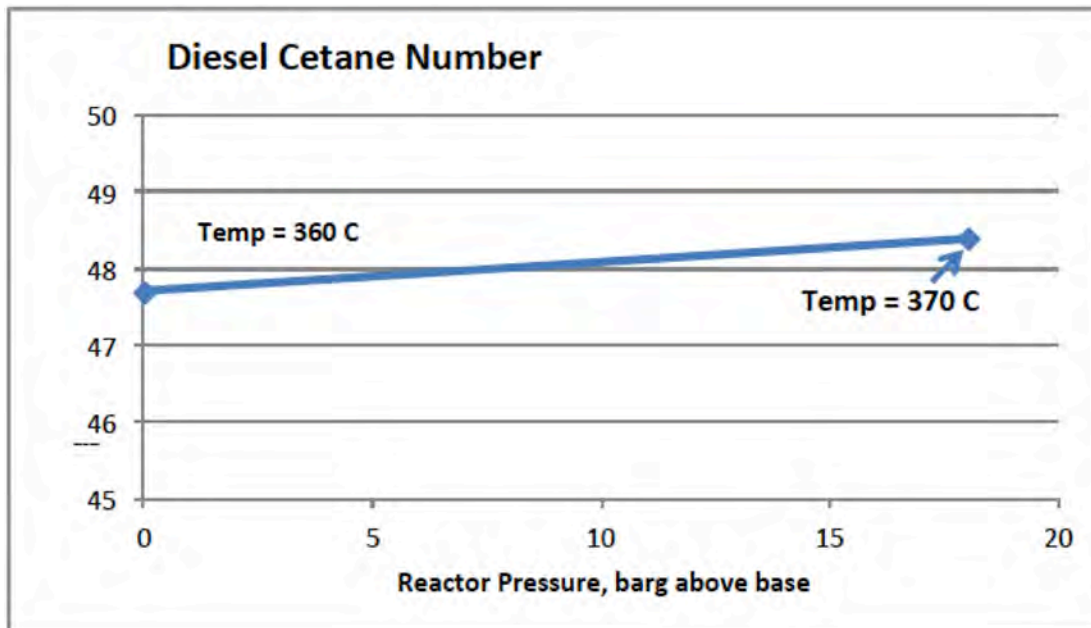


Figure 6: Impact of Temperature and Pressure on Cetane Number

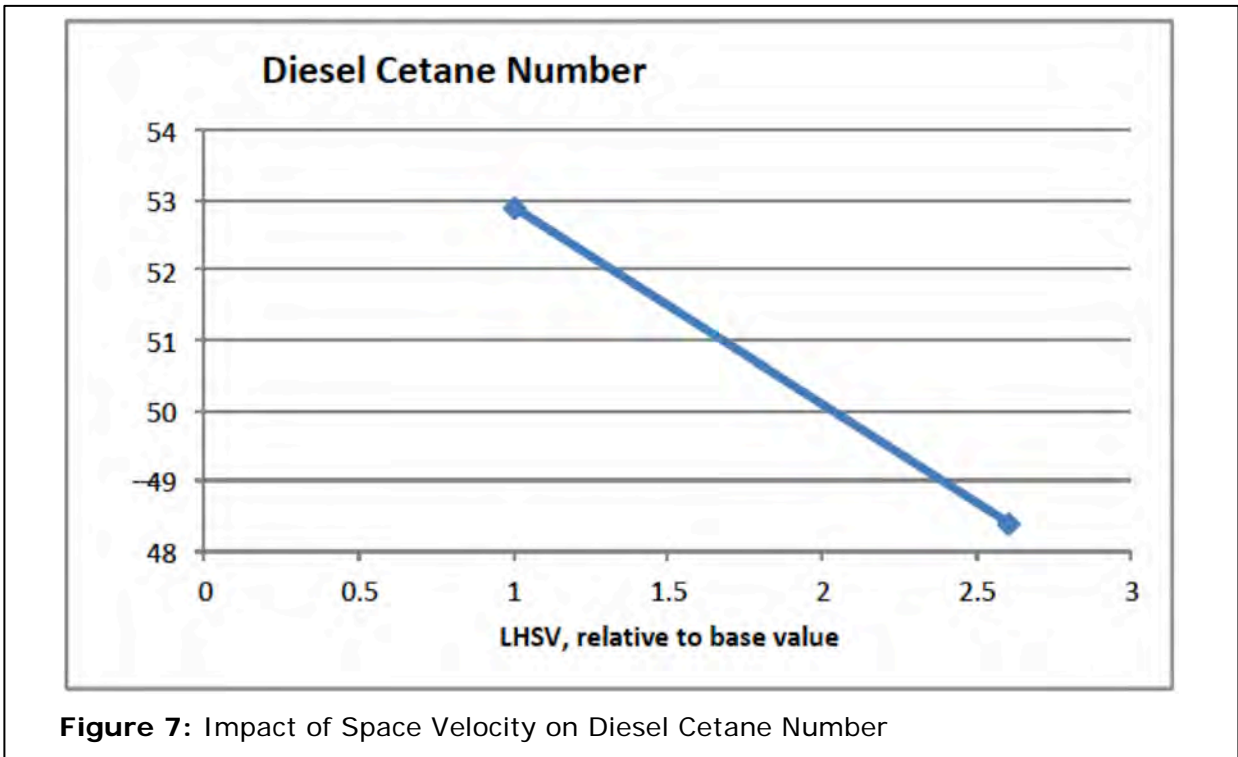


Figure 7: Impact of Space Velocity on Diesel Cetane Number

The capability and conditions to produce Euro V diesel in the Distillate Unionfining unit have been confirmed. Diesel aromatics are reduced to low levels and the cold flow properties of the diesel product meet Estonian win-

ter-time Arctic Class specifications.

The VGO-range material (370°C+) produced from the selected configuration meets specifications for being sent to fuel oil sales.

Table 6: Product Properties

		Heavy Naphtha Cut (IBP - 150°C)	Diesel Cut (150°C+)
Weight Percent	wt%	7.05	92.95
API		53.1	37.0
Density, SG		0.7666	0.8397
Sulfur by XRF	wppm	<1	<1
Nitrogen Chem	wppm	0.3	0.3
Centane Number D613			52.9
Cloud Point	oC		-30
Pour Point	oC		-42
CFPP	oC		-32
1 ring aromatics	wt%		8.5
2 Ring Aromatics	wt%		0.4
Poly Aromatics	wt%		<0.1

Removing most of the contaminants in the De-arseniting/Pretreating unit reduces the capital cost of the project, and protects the operation of the Distillate Unionfining unit. The selected configuration also minimizes hydrogen consumption, and therefore the overall operating cost of the complex.

VKG has confirmed this option was the most economic solution for their process objectives. Basic design of the complex is underway, and VKG intends to start up the complex in 2016, producing clean Euro V diesel from Estonian shale, to meet Estonia's growing fuels demand.