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DOE/MC/11076--2991

DE91 002072

**Processing of Arroyo Grande Tar Sand
Using the Recycle Oil Pyrolysis and
Extraction (ROPE[®]) Process**

Received by OSTI
NOV 18 1991

Topical Report

S.B. King

December 1989

Work Performed Under Cooperative Agreement No.: DE-FC21-86MC11076

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Western Research Institute
Laramie, Wyoming

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SUMMARY

Western Research Institute (WRI), in cooperation with the U.S. Department of Energy (DOE), is developing the Recycle Oil Pyrolysis and Extraction (ROPE[®]) process for recovering oil from tar sand and for coprocessing heavy crude oil with tar sand. The ROPE[®] concept consists of two pyrolysis steps: (1) retorting tar sand at a lower temperature ($T < 780^{\circ}\text{F}/415^{\circ}\text{C}$) with recycle oil and (2) completing the pyrolysis of the residue at a higher temperature ($T > 780^{\circ}\text{F}/415^{\circ}\text{C}$) in the absence of recycle oil. The ROPE[®] process is relatively simple, operates at atmospheric pressure, and uses off-the-shelf equipment items. Process mechanics are gentle, yielding particulate-free liquid distillates.

The ROPE[®] process appears to be capable of producing a variety of products because of the inherent temperature control throughout the process cycle. It produces specialty products such as BTX and advanced aviation fuel feedstocks from tar sand. It also produces diluent feedstocks from tar sand and heavy crude oil that may be used for heavy crude oil and bitumen transportation.

WRI constructed and operated a 2-inch-diameter process development unit (PDU) with a throughput of 5 to 10 lb/hr and a 6-inch-diameter bench-scale unit (BSU) with a throughput of 50 to 100 lb/hr to develop the ROPE[®] process. The experimental results to date and preliminary economic evaluation suggest that the ROPE[®] process has a strong commercialization potential.

The objectives of this study are to (1) evaluate the application of the ROPE[®] process to a California tar sand using the screw pyrolysis reactor-process development unit (SPR-PDU) reactor, (2) produce kinetics data for the recycle product oil-spent sand interaction, and (3) produce oil for end-use evaluation.

INTRODUCTION AND BACKGROUND

A continued decrease in the production of light crude in the United States has expanded market potentials for economic production and upgrading of heavy crude oil and tar sand bitumen. As a result, significant interest in improved heavy crude oil and bitumen production technology is anticipated in the future, particularly as the United States reliance on imports from the world's finite light oil resources becomes greater and greater. Although a number of processes, principally steam injection, are successfully producing in situ heavy crude, tar sand remains unexploited in the United States.

The major obstacles to commercialization of tar sands include the high costs associated with bitumen production, subsequent initial upgrading of the bitumen, and then ultimate refining of upgraded bitumen to produce salable products. To encourage tar sand commercialization with much-reduced financial risks, new processing technologies that produce high-value specialty products with low capital and operating costs need to be developed.

With the addition of hydrogen, a full slate of refined products can be made from bitumen but at some expense. Western Research Institute (WRI) suggests that it is possible to make and tailor a number of products from the bitumen through a promising process that we term the Recycle Oil Pyrolysis and Extraction (ROPE[®]) process (Cha et al. 1988, 1987; Cha and Guffey 1988). In preliminary investigations, WRI has (1) produced diluents suitable for use in transporting heavy crude oils and bitumens, (2) produced BTX and advanced aviation fuel feedstocks from tar sand, (3) demetallized Boscan crude oil, (4) removed oil and produced environmentally clean sand from tank bottom sludge, and (5) coprocessed and effectively upgraded raw Canadian bitumen.

A diluent is used to reduce the pour point and viscosity of heavy crude and bitumen for in situ production and pipeline transportation. A shortage of diluents for production and transportation of heavy crude and bitumen is anticipated in both Canada and the United States by the year 2000.

A demand for premium unleaded gasoline in the United States and Europe has boosted refiners needs for aromatic streams as octane enhancers. Because of this increased demand, needs for aromatics, especially benzene, toluene, and xylene (BTX), should be continuously strong in the near future. These aromatic compounds are also used as chemical feedstocks. With the bitumen in many tar sands containing high concentrations of aromatic compounds, proper processing can produce a high yield of BTX feedstock worth two or more times the gross bitumen value in the original tar sand.

To expand the use and applicability of the ROPE[®] process to a wider range of tar sands and gather additional kinetic data, experiments were conducted on the California Arroyo Grande tar sand. The dependent variables that we attempted to optimize during these tests were oil

yield and oil quality. Results from these tests were compared with those of previous experiments using Asphalt Ridge tar sand, Sunnyside tar sand, and Athabasca oil sand to develop correlations between original material properties, the operational parameters, and the product yield and quality.

A long-term test of the ROPE[®] process was conducted in the SPR-PDU using Arroyo Grande tar sand to confirm the data produced in the shorter (24 hour) tests and conduct a test of long enough duration to obtain steady-state conditions. A SPR-PDU experiment was conducted using spent sand and product oil to simulate the chemical reactions between the two materials during the ROPE[®] processing of tar sands. This was to provide data to develop the reaction kinetics among the components for incorporation into the numerical model for the process.

THE ROPE[®] PROCESS--LOGIC AND DESCRIPTION

The ROPE[®] concept consists of two pyrolysis steps: (1) retorting the tar sand at a lower temperature ($T < 780^{\circ}\text{F}/415^{\circ}\text{C}$) with the recycle oil and (2) completing the pyrolysis of residue at a higher temperature ($T > 780^{\circ}\text{F}/415^{\circ}\text{C}$) in the absence of recycle oil. The process starts with an initial recycle oil that is eventually replaced by recycled product oil. Figure 1 shows an overall process flow diagram for the ROPE[®] 2-inch process development unit. Crushed and screened tar sand is fed into the feed screw reactor. Any oil and water vapors from this reactor are condensed in the demister and collected in the light oil tank, knockout #1 (KO1).

The mixture of bitumen and sand flows into the horizontal screw pyrolysis reactor (HSPR) and is mixed with the recycle oil. The material in the HSPR is heated with the hot recycle oil. The bitumen and recycle oil are pyrolyzed in the HSPR to produce lighter oil. The oil vapor flowing from the first section of the HSPR is condensed and collected in a tank, knockout #2 (KO2). The oil vapors flowing from the latter portion of the HSPR are condensed and collected in a tank, knockout #3 (KO3). A part of this distillate is returned to the feed hopper to soak the solid feed and to provide the oil seal for preventing gas leakage.

The liquid oil product (heavy oil) flows out of the bottom of the HSPR and is collected in the heavy oil tank. The heavy oil (boiling point $>700^{\circ}\text{F}/370^{\circ}\text{C}$) is pumped through the oil heater and returned to the HSPR as the recycle oil.

The retorted (pyrolyzed) solid material is separated from the heavy oil and fed into an inclined screw pyrolysis reactor (ISPR). The heavy oil absorbed solid material and the unconverted organics in the solids are recovered by heating to about 930°F (500°C) in the ISPR. The oil vapors flowing from the ISPR are condensed and collected in a tank, knockout #4 (KO4). The solids leaving the ISPR are collected in the spent sand tank.

Figure 1. ROPE® Reactor for Arroyo Grande Tar Sand

During portions of the ROPE[®] experiments using the Arroyo Grande tar sand, a small amount of product oil from a previous tar sand ROPE[®] experiment was injected into the reactor to reduce the amount of agglomeration of tar sand and assist in maintaining free flow of the solid material through the screw reactor. Typically, this injection occurred at the feed screw reactor with the raw tar sand and/or the beginning of the ISPR with the partially pyrolyzed tar sand.

For the Arroyo Grande tar sand ROPE[®] experiments, the HSPR was maintained at a 3° incline, whereas the ISPR was maintained at a 15° incline. The initial recycle oil used in the experiments was Lubriplate SAE 50W nondetergent oil that over a period of time was replaced by the oil produced from the HSPR reactor.

EXPERIMENTAL APPARATUS AND PROCEDURE

ROPE[®] Test Conditions on Arroyo Grande Tar Sand

The analysis results of the Arroyo Grande tar sand which was used as the feed in the reported experiments are listed in Table 1. Previous ROPE[®] experiments using tar sands of other origins have determined that optimum pyrolysis temperature is 400°C (752°F) and residence time in the reactor is 40 minutes. To maintain specified temperatures in the HSPR and ISPR, the electrical heaters surrounding each reactor were divided into three separate controllable zones. This allowed the temperature gradient across the reactors to be maintained at a specified value. Typically, the temperature increase across the length of the HSPR was 20 to 60°C (68 to 140°F) and the gradient across the ISPR was 150 to 300°C (302 to 572°F). The electric motors on the augers of the feed reactor, HSPR, and ISPR were set at a constant speed to provide a combined average residence time in the HSPR and ISPR of 40 minutes. The nitrogen-purge flow rates for the four entry points were maintained at a constant rate during each test. The conditions for the five ROPE[®] experiments conducted using the Arroyo Grande tar sand are listed in Table 2.

Analytical Procedure

In addition to the routine elemental analysis, the hydrocarbon-group types (e.g., alkanes, alkylbenzenes, naphthalenes) were determined in each of the produced oils using the WRI's proprietary combined gas chromatography/mass spectrometric hydrocarbon-group-type analysis. The method uses parent molecular ions for the identification of the individual hydrocarbon-group types and sums of designated fragment ions for quantitation. The raw data for analysis are recorded in the full-scan mode of data acquisition using electron impact as the method of ionization. Simulated distillation was performed on each of the distillable products and the heavy recycle oil. The analyses were performed using a Hewlett-Packard 5700 series gas chromatograph, and the boiling point distributions were determined using the method of Thomas et al. (1983).

Table 1. Analysis of tar sand feeds for ROPE[®] Experiments using Arroyo Grande Tar Sand

	SPR-103	SPR-104	SPR-106	SPR-107 ^a	SPR-111
<u>Fischer Assay</u>					
Oil, wt %	5.58	5.63	5.83	1.14	5.97
Water, wt %	1.37	1.41	1.30	0.00	1.20
Spent Sand, wt %	91.93	91.70	91.58	97.65	91.80
Gas + Loss, wt %	1.12	1.26	1.29	1.21	1.03
Oil, gpt	14.3	14.5	15.2	2.94	15.4
Water, gpt	2.69	3.02	3.11	0.00	2.88
<u>Elemental Analysis of FA Oil, wt %</u>					
C	85.8	85.3	85.3	*	85.8
H	12.3	12.5	12.5	*	12.3
N	0.7	0.8	0.8	*	0.9
S	0.6	0.6	0.7	*	0.6
O	0.5	0.6	0.5	*	0.5
Specific Gravity (60°F)	0.9378	0.9305	0.9185	0.93 ^b	0.9287

* Insufficient sample for elemental analysis

^a SPR-107 experiment used spent sand as feed

^b Assumed value

Table 2. Run Conditions for the Arroyo Grande Tar Sand ROPE[®] Experiments

Test	Raw Tar Sand Feed Rate, g/hr	Heater Temperatures, °C						Test Duration, hr
		HSPR			ISPR			
		#1	#2	#3	#4	#5	#6	
SPR-103	2000	330	384	396	310	497	516	24.33
SPR-104	2000	337	373	373	384	536	533	24.25
SPR-106	2000	380	386	400	323	509	528	24.00
SPR-107	2000	372	388	403	314	511	535	17.00
SPR-111	2000	373	383	390	295	513	536	121.50

Note: The feed used in test SPR-107 was spent sand from a previous experiment

RESULTS AND DISCUSSION

Material Balance

During the course of each experiment the HSPR and ISPR reactors were purged with nitrogen gas to assist in carrying pyrolysis products from the reactors to the condensers. As shown in Figure 1, the nitrogen gas was injected at four different locations. After the liquids were condensed from the individual streams, the gas streams were combined into one composite stream for gas-composition analysis by the on-line gas chromatograph. The average gas analysis is reported for each experiment in Table 3.

Upon completion of each experiment, all production liquids and solids were weighed and samples were submitted for analysis. These data plus the gas analyses and known nitrogen injection rate provided the information to generate material balance calculations for each experiment. The results of these computations are reported in Table 4. As the material balance calculations demonstrate, the recovery from all five experiments were acceptable, particularly for SPR-111 which was a five-day experiment.

In conjunction with the material balance calculations, the oil yield was computed to determine the amount of oil produced during the experiment. All the experiments started with Lubriplate SAE 50W nondetergent oil as the initial recycle oil, and this tended to bias the shorter tests (SPR-103, SPR-104, SPR-106, and SPR-107, all ~24 hours) more than the long test (SPR-111, a five-day test). Therefore, only SPR-111 results are reported in Table 5. The oil yield calculation demonstrates that the ROPE[®] process provides a higher oil yield from the tar sand than the Fischer assay will predict (116.5% of Fischer assay). This corresponds to a 6.96 wt % oil for the Arroyo Grande tar sand.

Table 3. Average Gas Analyses of Produced Gases for the ROPE[©]
Experiments using Arroyo Grande Tar Sand^a, vol %

Species	HSPF					
	SPR-103	SPR-104	SPR-106	SPR-107	SPR-111	SPR-104 ^b
Helium	0.0 ^c	0.0	0.0	0.0	0.0	0.0
Hydrogen	18.9	20.5	27.5	15.4	30.3	10.5
Nitrogen	0.0	0.0	0.0	0.0	0.0	0.0
Oxygen	0.0	0.0	0.0	0.0	0.0	0.0
Argon	0.0	0.0	0.0	0.0	0.0	0.0
Carbon Monoxide	1.7	1.2	1.5	0.4	1.2	4.9
Carbon Dioxide	11.8	3.5	13.3	13.0	8.5	18.2
Methane	21.1	25.1	19.2	14.9	23.3	16.4
Ethane	9.6	11.6	8.6	9.7	7.8	7.9
Ethylene	5.4	8.4	5.3	6.0	2.4	1.5
Propane	5.8	5.4	5.0	8.4	4.6	7.8
Propylene	6.5	8.4	5.9	8.7	3.7	2.1
Butanes	12.0	8.8	7.9	14.5	8.1	11.7
Pentanes	6.0	5.0	3.7	8.6	6.6	7.9
Hexanes	1.1	1.2	0.0	0.0	0.0	2.7
Heptanes	0.0	0.0	0.0	0.0	0.0	0.0
Octanes	0.0	0.0	0.0	0.0	0.0	0.0
Nonanes	0.0	0.0	0.0	0.0	0.0	0.0
Decanes	0.0	0.0	0.0	0.0	0.0	0.0
Hydrogen Sulfide	0.0	0.9	2.1	0.3	3.5	8.4
Heating Value, Btu/scf	1535 ^d	1556	1206	1722	1258	1469

^a Reported on a nitrogen- and moisture-free basis

^b During a portion of SPR-104, additional gas analyses were taken from just the HSPR

Table 4. Material Balance Calculations for the ROPE[®] Experiments using Arroyo Grande Tar Sand

	SPR-103	SPR-104	SPR-106	SPR-107	SPR-111
<hr/>					
IN(g)					
Tar Sand	43,357	47,000	45,911	33,000	205,250
Heavy Oil	9,747	13,138	11,358	14,326	13,308
Product Oil	2,741	4,291	2,750	2,722	2,321
Nitrogen	<u>2,437</u>	<u>2,471</u>	<u>2,419</u>	<u>1,750</u>	<u>11,207</u>
Total	58,282	66,900	62,438	51,798	232,086
 OUT(g)					
Spent Sand	34,701	38,209	38,163	32,206	181,157
Heavy Oil	11,139	12,214	11,292	10,141	17,902
Product Oil	6,059	11,475	7,656	7,416	15,881
Water	607	864	1,277	0	3,181
Gas	<u>2,953</u>	<u>4,489</u>	<u>2,758</u>	<u>2,197</u>	<u>13,448</u>
Total	55,459	67,251	61,146	51,960	231,569
 % Closure					
	95.16	100.52	97.93	100.31	99.78

Table 5. Oil Yield for ROPE[®] Experiment SPR-111 using Arroyo Grande Tar Sand

<u>Sand Balance</u>			
	IN(g)	OUT(g)	
Tar Sand	205,250	181,157	
Clean Sand	178,875	174,998	Sand loading = 3,878 ^a
Benzene Extract	21,962	4,529	
Pyridine Extract	1,539	380	
Char	411	1,250	
Water	2,463	- -	
Heavy Oil	13,308	14,024	Less sand loading ^b
Product Oil	<u>2,321</u>	<u>15,881</u>	Net Product Oil = 13,560 ^c
Total Oil	15,629	29,905	Net Oil = 14,276 ^d

NOTE: The sand loading is the difference between the calculated sand IN (178,875) and the measured sand OUT (174,998). The final destination of this sand is assumed to be in the heavy oil (taking into account the sand loading of 3,878).

^a From sand balance, assumed sand loading (carry over) in heavy oil

^b Difference between heavy oil recovered and sand loading

^c 110.7% of Fischer Assay

^d 116.5% of Fischer Assay

Liquid Product Analyses

The liquids produced in KO1, the knockout receiver for the condenser coming off the feed screw, contained negligible amounts of organics and water. The organic products; which were produced in the HSPR and ISPR and condensed and collected in KO2, KO3, and KO4; were analyzed for their chemical and physical properties. These properties are listed in Tables 6-10 along with the results of the properties of the bitumen extracted from the Arroyo Grande tar sand. The important parameters to note in these tables are:

1. The significant improvement in hydrogen-to-carbon (H/C) ratio for the distillate products compared with the bitumen extracted from the tar sand
2. The substantial reduction in specific gravity of the distillates over the bitumen
3. The amount of nitrogen and sulfur in the distillates is markedly reduced compared with the bitumen extracted from the raw feed
4. The amount of material in the distillates that is classified as residuum (material distillable over 1000.4°F/537.8°C) has been dramatically reduced compared with the bitumen.

In fact, the heavy oil shows less residuum than the bitumen (Table 10, SPR-111). Examination of the results listed in Tables 6-10 suggests that all of the analyses show an improvement in the quality of the products with respect to the original bitumen.

Table 6. Chemical and Physical properties of Products Produced During the SPR-103 ROPE[®] Experiment using the Arroyo Grande Tar Sand

Properties	Bitumen	KO2	KO3	KO4
Elemental Analysis, wt %				
Carbon	81.9	85.4	85.8	85.2
Hydrogen	9.1	12.3	12.5	12.5
Nitrogen	1.2	<0.5	0.5	<0.5
Sulfur	3.1	1.4	1.4	1.1
Oxygen	3.7	0.7	0.6	0.7
H/C	1.33	1.73	1.75	1.76
Specific Gravity (15.6°C)	1.0092-1.0110	0.8869	0.8779	0.8639
Distillation Data, wt %				
IBP-600°F	8.1	52.2	41.8	65.1
600-1000°F	35.3	50.0	57.1	35.8
1000+°F	56.7	0.0	1.1	0.0

Table 7. Chemical and Physical properties of Products Produced During the SPR-104 ROPE[®] Experiment using the Arroyo Grande Tar Sand

Properties	Bitumen	KO2	KO3	KO4
Elemental Analysis, wt %				
Carbon	81.9	85.5	85.1	85.6
Hydrogen	9.1	12.2	12.5	11.4
Nitrogen	1.2	<0.5	<0.5	0.7
Sulfur	3.1	1.6	1.6	1.3
Oxygen	3.7	0.9	0.9	0.9
H/C	1.33	1.71	1.76	1.60
Specific Gravity (15.6°C)	1.0092-1.0110	0.9000	0.8701	0.8961

Table 8. Chemical and Physical properties of Products Produced During the SPR-106 ROPE[®] Experiment using the Arroyo Grande Tar Sand

Properties	Bitumen	KO2	KO3	KO4
Elemental Analysis, wt %				
Carbon	81.9	85.3	81.3	85.9
Hydrogen	9.1	12.1	11.1	11.6
Nitrogen	1.2	0.5	6.4	0.7
Sulfur	3.1	1.6	1.5	1.4
Oxygen	3.7	0.8	0.8	0.8
H/C	1.33	1.70	1.64	1.62
Specific Gravity (15.6°C)	1.0092-1.0110	0.8981	0.8751	0.8921

Table 9. Chemical and Physical properties of Products Produced During the SPR-107 ROPE[®] Experiment using the Arroyo Grande Tar Sand

Properties	Bitumen	KO2	KO3	KO4
Elemental Analysis, wt %				
Carbon	81.9	82.4	85.5	85.0
Hydrogen	9.1	12.0	13.1	10.9
Nitrogen	1.2	5.4	0.6	1.0
Sulfur	3.1	0.8	0.7	1.7
Oxygen	3.7	0.6	0.6	1.2
H/C	1.33	1.75	1.84	1.54
Specific Gravity (15.6°C)	1.0092-1.0110	0.8334	0.8423	0.9160

Table 10. Chemical and Physical properties of Products Produced During the SPR-111 ROPE[®] Experiment using the Arroyo Grande Tar Sand

Properties	Bitumen	KO2	KO3	KO4	PO	HO
Elemental Analysis, wt %						
Carbon	81.9	85.8	85.6	85.8	85.7	86.0
Hydrogen	9.1	12.0	12.5	12.3	12.2	12.6
Nitrogen	1.2	<0.5	<0.5	<0.5	<1.0	0.6
Sulfur	3.1	1.5	1.5	1.2	1.2	1.4
Oxygen	3.7	0.6	0.5	0.5	0.5	0.7
H/C	1.33	1.68	1.75	1.72	1.71	1.76
Specific Gravity (15.6°C)	1.0092-1.0110	0.8863	0.8625	0.8754	0.8744	
Distillation Data, wt %						
IBP-600°F	8.1	35.5	52.7	41.4	45.0	4.1
600-1000°F	35.3	64.5	47.3	55.4	55.0	58.6
1000+°F	56.7	0.0	0.0	3.2	0.0	37.3

As part of the continuing analysis of the ROPE[®] process and to more completely characterize the distillate products, representative samples recovered from the knockouts were submitted for GC/MS analysis. In addition to providing a more detailed description of the sample compositions, this analysis allows us to make preliminary evaluation of potential market value for a fuel or fuel-blending stock. This evaluation was performed by dividing the combined GC/MS data into distillate regions using a correlation that relates the boiling points of normal alkanes to the respective gas chromatographic retention times. The two distillate ranges selected for this evaluation were IBP-350°F (IBP-177°C) and 350-700°F (177-371°C). The former range was selected to represent a motor gasoline or blending stock, and the latter was selected to represent diesel fuel. The results of the GC/MS analysis are tabulated in Tables 11-20.

As the data reported in Tables 11-20 indicate, the products recovered from the ROPE[®] processing of the Arroyo Grande tar sand are suitable as feedstocks for diesel fuel and diluents for transporting heavy crude oils and bitumens. They are not suitable as feedstock for gasoline because of the combined concentration of alkanes and alkenes that upon initial processing, will all be converted to alkanes. Particular attention should be directed toward Tables 19 and 20, which report the distillate products from the five-day experiment, SPR-111. These analyses were of samples produced after ~64 hours into the experiment and are most representative of the distillate products produced by the ROPE[®] process from the Arroyo Grande tar sand. The other experiments were of a shorter duration (~24 hours), and the composition may be influenced by the fact that the initial recycle oil may not have been completely consumed when the samples were taken.

Comparison of ROPE[®] Experiments using Arroyo Grande Tar Sand with Other Sources of Tar Sand

The ROPE[®] experiments using the Arroyo Grande tar sand are part of continuing effort to demonstrate the applicability of the ROPE[®] process to various sources of tar sands and heavy crude oils. This discussion compares the results of the Arroyo Grande tar sand experiments with previous ROPE[®] experiments using Asphalt Ridge tar sand, Sunnyside tar sand, and Athabasca oil sand. Because the data collected during the five experiments using Arroyo Grande tar sand are extensive, only the results from SPR-111 will be compared with results from other tar sands. During previous tests of the ROPE[®] process on the various tar sands and heavy crude oils, the specific configuration of the reactors was modified to either improve operations or obtain samples from different locations on the reactors. To reduce any confusion that might be created by referring to a distillate product from a specific condenser/knockout, all results report the composition of product coming off the middle of the HSPR. Therefore, the source of all products are the same with respect to its origin within the HSPR itself.

Table 11. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177°C of Products from SPR-103 ROPE[®] Experiment using Arroyo Grande Tar Sand and Unleaded Gasoline, wt %

	Unleaded Gasoline	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	24.1	35.3	27.9	26.3
Monocycloalkanes	24.7	18.4	25.2	21.3
Alkenes	0.0	24.4	34.7	33.2
Dicycloalkanes	0.0	0.0	0.2	0.3
Tricycloalkanes	0.0	0.0	0.0	0.0
Total Saturates	48.8	78.1	88.0	81.1
Alkylbenzenes	41.9	21.0	11.8	18.3
Indanes/Tetralins	6.6	0.9	0.2	0.6
Naphthalenes	2.7	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	51.2	21.9	12.0	18.9
wt % of Sample	- -	5.0	39.4	35.1

Table 12. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177-371°C of Products from SPR-103 ROPE[®] Experiment using Arroyo Grande Tar Sand and Diesel Fuel, wt %

	Diesel Fuel	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	52.7	42.9	47.5	38.2
Monocycloalkanes	7.4	0.3	1.1	1.5
Alkenes	0.0	38.3	34.2	33.2
Dicycloalkanes	0.0	0.7	0.3	1.4
Tricycloalkanes	0.0	0.4	0.5	1.2
Total Saturates	60.1	82.6	83.6	75.5
Alkylbenzenes	6.9	4.7	6.5	11.5
Indanes/Tetralins	10.5	9.3	7.0	10.6
Naphthalenes	16.0	2.8	2.1	2.3
Fluorenes	6.2	0.3	0.2	0.0
Anthracenes/Phenanthrenes	0.2	0.4	0.5	0.1
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	39.8	17.5	16.3	24.5
wt % of Sample	--	90.9	47.7	63.8

Table 13. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177°C of Products from SPR-104 ROPE[®] Experiment using Arroyo Grande Tar Sand and Unleaded Gasoline, wt %

	Unleaded Gasoline	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	24.1	14.3	21.1	11.5
Monocycloalkanes	24.7	25.1	36.7	21.1
Alkenes	0.0	2.8	22.8	9.3
Dicycloalkanes	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0
Total Saturates	48.8	42.2	80.5	41.9
Alkylbenzenes	41.9	57.8	19.2	55.6
Indanes/Tetralins	6.6	0.0	0.3	2.6
Naphthalenes	2.7	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	51.2	57.8	19.5	58.1
wt % of Sample	--	13.6	63.5	44.1

Table 14. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177-371°C of Products from SPR-104 ROPE[®] Experiment using Arroyo Grande Tar Sand and Diesel Fuel, wt %

	Diesel Fuel	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	52.7	69.8	57.9	26.9
Monocycloalkanes	7.4	0.0	3.8	1.6
Alkenes	0.0	15.6	7.1	3.9
Dicycloalkanes	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.4	1.6
Total Saturates	60.1	85.3	69.2	34.0
Alkylbenzenes	6.9	4.3	14.3	20.5
Indanes/Tetralins	10.5	5.5	14.2	31.1
Naphthalenes	16.0	3.4	2.4	8.2
Fluorenes	6.2	0.6	0.0	4.2
Anthracenes/Phenanthrenes	0.2	0.9	0.0	2.2
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	39.8	14.7	30.9	66.1
wt % of Sample	--	58.48	34.2	55.4

Table 15. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177°C of Products from SPR-106 ROPE[®] Experiment using Arroyo Grande Tar Sand and Unleaded Gasoline, wt %

	Unleaded Gasoline	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	24.1	23.1	28.4	12.5
Monocycloalkanes	24.7	25.1	29.5	24.8
Alkenes	0.0	23.9	25.9	13.2
Dicycloalkanes	0.0	0.1	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0
Total Saturates	48.8	72.2	83.7	50.5
Alkylbenzenes	41.9	26.1	15.9	47.0
Indanes/Tetralins	6.6	1.7	0.4	2.5
Naphthalenes	2.7	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	51.2	27.8	16.3	49.5
wt % of Sample	--	19.0	32.2	35.7

Table 16. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177-371°C of Products from SPR-106 ROPE[®] Experiment using Arroyo Grande Tar Sand and Diesel Fuel, wt %

	Diesel Fuel	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	52.7	45.4	48.1	20.6
Monocycloalkanes	7.4	0.9	1.8	1.8
Alkenes	0.0	31.4	29.2	5.5
Dicycloalkanes	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.8	0.1	4.5
Total Saturates	60.1	78.5	79.3	32.5
Alkylbenzenes	6.5	7.0	7.4	21.5
Indanes/Tetralins	10.5	9.1	10.3	34.8
Naphthalenes	16.0	2.9	2.7	6.5
Fluorenes	6.2	2.1	0.3	3.4
Anthracenes/Phenanthrenes	0.2	0.3	0.1	1.4
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	39.8	21.4	20.7	67.5
wt % of Sample	--	53.5	66.0	64.0

Table 17. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177°C of Products from SPR-107 ROPE[®] Experiment using Arroyo Grande Tar Sand and Unleaded Gasoline, wt %

	Unleaded Gasoline	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	24.1	27.2	33.3	10.9
Monocycloalkanes	24.7	26.6	25.8	24.5
Alkenes	0.0	24.0	25.3	8.8
Dicycloalkanes	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0
Total Saturates	48.8	77.8	84.4	44.2
Alkylbenzenes	41.9	21.2	15.0	52.1
Indanes/Tetralins	6.6	1.0	0.6	3.8
Naphthalenes	2.7	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	51.2	22.2	15.6	55.8
wt % of Sample	--	24.1	48.4	35.7

Table 18. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177-371°C of Products from SPR-107 ROPE[®] Experiment using Arroyo Grande Tar Sand and Diesel Fuel, wt %

	Diesel Fuel	KO2	KO3	KO4
Hydrocarbon-Group Type				
Alkanes	52.7	42.0	50.4	21.7
Monocycloalkanes	7.4	1.1	2.4	0.9
Alkenes	0.0	38.8	26.2	5.5
Dicycloalkanes	0.0	0.1	0.0	0.1
Tricycloalkanes	0.0	0.7	0.0	4.6
Total Saturates	60.1	82.7	79.0	32.7
Alkylbenzenes	6.9	6.5	9.1	16.1
Indanes/Tetralins	10.5	9.1	9.6	36.9
Naphthalenes	16.0	1.6	2.4	6.4
Fluorenes	6.2	0.1	0.0	5.2
Anthracenes/Phenanthrenes	0.2	0.0	0.0	2.7
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0
Total Aromatics	39.8	17.3	21.0	67.3
wt % of Sample	--	75.5	51.7	20.9

Table 19. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177°C of Products from SPR-111 ROPE[®] Experiment using Arroyo Grande Tar Sand and Unleaded Gasoline, wt %

	Unleaded Gasoline	KO2	KO3	KO4	PO
Hydrocarbon-Group Type					
Alkanes	24.1	22.0	21.4	23.7	22.5
Monocycloalkanes	24.7	26.8	30.5	24.2	27.6
Alkenes	0.0	15.0	32.0	32.5	20.6
Dicycloalkanes	0.0	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0	0.0
Total Saturates	48.8	63.8	83.9	80.4	70.7
Alkylbenzenes	41.9	34.4	15.2	18.5	28.4
Indanes/Tetralins	6.6	1.7	0.9	1.1	0.9
Naphthalenes	2.7	0.0	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0	0.0
Total Aromatics	51.2	36.1	16.1	19.6	29.3
wt % of Sample	--	53.7	31.8	33.3	25.5

Table 20. Hydrocarbon-Group-Type Analysis of Distillate Fraction IBP-177-371°C of Products from SPR-111 ROPE[®] Experiment using Arroyo Grande Tar Sand and Diesel Fuel, wt %

	Diesel Fuel	KO2	KO3	KO4	PO
Hydrocarbon-Group Type					
Alkanes	52.7	50.6	32.1	32.5	45.6
Monocycloalkanes	7.4	3.5	1.3	1.5	1.5
Alkenes	0.0	7.3	40.2	40.0	29.6
Dicycloalkanes	0.0	0.0	1.8	1.6	0.0
cycloalkanes	0.0	0.0	3.1	2.9	0.4
Total Saturates	60.1	61.4	78.5	78.5	77.1
Alkylbenzenes	6.9	18.3	5.4	6.0	8.1
Indanes/Tetralins	10.5	16.2	11.1	10.6	11.0
Naphthalenes	16.0	3.8	1.4	1.4	2.2
Fluorenes	6.2	0.0	2.4	2.2	1.1
Anthracenes/Phenanthrenes	0.2	0.3	1.2	1.3	0.5
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0	0.0
Total Aromatics	39.8	38.6	21.5	21.5	22.9
wt % of Sample	--	44.1	64.3	62.8	58.5

Table 21 lists the analyses of the original bitumens extracted from the raw tar sands for Arroyo Grande, Asphalt Ridge, Sunnyside, and Athabasca. All four bitumens, although not identical, are similar in nature. They show products that have a relatively low H/C, a specific gravity, and distillation range that will not be easy to transport via pipelines or are indicative of being a choice feedstock for a refinery. As has been demonstrated in previous ROPE[®] experiments, all of these characteristics can be improved when the tar sand is processed using the ROPE[®] process.

The results of the GC/MS hydrocarbon-group-type analysis for the distillate products from the HSPR for the ROPE[®] experiments for the four tar sands are listed in Tables 22 and 23. These data are compared with unleaded gasoline for the light fraction (IBP-177°C/350°F) and diesel fuel for the heavy fraction (177-371°C/350-700°F). These data show that the distillate products from the HSPR of the ROPE[®] process from the four different sources have wide ranges of concentration in the hydrocarbon-group types reported. The relative amounts of sample (wt % of sample) between the IBP-177°C (IBP-350°F) and 177-371°C (350-799°F) fractions not only varies between sources, but the aliphatic versus aromatic content also varies depending on the source.

Table 21. Analysis of Bitumens Extracted from Arroyo Grande Tar Sand, Asphalt Ridge Tar Sand, Sunnyside Tar Sand, and Athabasca Oil Sand

	Arroyo Grande	Asphalt Ridge ^a	Sunnyside ^a	Athabasca ^b
Elemental Analysis, wt %				
C	81.9	85.8	86.3	83.2
H	9.1	11.5	11.7	10.3
N	1.2	1.1	0.9	0.4
S	3.1	0.4	0.5	5.0
O	3.7	1.2	0.7	1.0
H/C	1.33	1.61	1.63	1.49
Specific Gravity (15.6°C)	1.009-1.011	0.999	0.997	1.016
Distillation Data, wt %				
IBP-600°F	8.1	9.8	6.8	7.1
600-1000°F	35.3	29.3	24.4	38.8
1000+°F	56.7	60.9	68.8	54.1

^a Western Research Institute 1987

^b Wallace et al. 1988

Table 22. Comparison of Hydrocarbon-Group Types Identified in Unleaded Gasoline with the IBP-177°C Distillate Fraction from the ROPE® Products using Arroyo Grande Tar Sand, Asphalt Ridge Tar Sand, Sunnyside Tar Sand, and Athabasca Oil Sand, wt %

Hydrocarbon-Group Type	Unleaded Gasoline	Arroyo Grande	Asphalt Ridge	Sunnyside	Athabasca
Alkanes	24.1	22.0	0.0	72.8	13.7
Monocycloalkanes	24.7	26.8	11.9	6.0	3.6
Alkenes	0.0	15.0	0.0	1.2	0.0
Dicycloalkanes	0.0	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0	0.0
Total Saturates	48.8	63.8	11.9	80.0	17.3
Alkylbenzenes	41.9	34.4	88.1	20.0	82.7
Indanes/Tetralins	6.6	1.7	0.0	0.0	0.0
Naphthalenes	2.7	0.0	0.0	0.0	0.0
Fluorenes	0.0	0.0	0.0	0.0	0.0
Anthracenes/Phenanthrenes	0.0	0.0	0.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0	0.0
Total Aromatics	51.2	36.1	88.1	20.0	82.7
wt % of sample	--	53.7	11.6	60.0	19.3

Table 23. Comparison of Hydrocarbon-Group Types Identified in Diesel Fuel with the 177-371°C Distillate Fraction from the ROPE® Products using Arroyo Grande Tar Sand, Asphalt Ridge Tar Sand, Sunnyside Tar Sand, and Athabasca Oil Sand, wt %

Hydrocarbon-Group Type	Diesel Fuel	Arroyo Grande	Asphalt Ridge	Sunnyside	Athabasca
Alkanes	52.7	50.6	4.4	69.5	20.5
Monocycloalkanes	7.4	3.5	0.0	3.7	5.6
Alkenes	0.0	7.3	0.0	1.1	0.0
Dicycloalkanes	0.0	0.0	0.0	0.0	0.0
Tricycloalkanes	0.0	0.0	0.0	0.0	0.0
Total Saturates	60.1	61.4	4.4	74.3	26.1
Alkylbenzenes	6.9	18.3	7.0	25.7	19.9
Indanes/Tetralins	10.5	16.2	34.4	0.0	37.8
Naphthalenes	16.0	3.8	36.8	0.0	15.1
Fluorenes	6.2	0.0	12.5	0.0	0.3
Anthracenes/Phenanthrenes	0.2	0.3	5.0	0.0	0.0
Pyrenes/Fluoranthenes	0.0	0.0	0.0	0.0	0.0
Total Aromatics	39.8	38.6	95.7	25.7	73.1
wt % of sample	--	44.1	88.4	38.5	80.7

CONCLUSIONS

The following conclusions may be drawn from the 2-inch PDU tests performed on the Arroyo Grande tar sand:

- Arroyo Grande tar sand can be processed without any major operational difficulty in the ROPE[®] process.
- Oil yield greater than Fischer assay was obtained for the Arroyo Grande tar sand.
- Product oil from the ROPE[®] processing of Arroyo Grande tar sand has lower nitrogen and sulfur contents than the bitumen extracted from the raw feed sand.
- Arroyo Grande tar sand ROPE[®] distillate products appear to be excellent feedstocks for either diesel fuel or diluents for transporting heavy crude oils and bitumens.

ACKNOWLEDGEMENTS

The author expresses his appreciation to the U.S. Department of Energy for funding this work under cooperative agreement DE-FC21-86MC11076. The author also thanks Frank Guffey and John Fahy for their assistance in sample analysis and operation of the experiments.

DISCLAIMER

Mention of specific brand names or models is for information only and does not imply endorsement.

REFERENCES

- Cha, C.Y., L.J. Fahy, and F.D. Guffey, 1988, Asphalt Ridge Tar Sand Recovery using the ROPE[®] Process. Western Research Institute, Laramie, WY, Report to DOE, DOE/MC/11076-2659.
- Cha, C.Y., and F.D. Guffey, 1988, Recycle Oil Pyrolysis and Extraction of Tar Sand. Western Research Institute, Laramie, WY, Fourth UNITAR/UNDP Conference on Heavy Crude and Tar Sands, Paper No. 106.
- Cha, C.Y., F.D. Guffey, and L.J. Romanowski, 1987, Tar Sand Pyrolysis with Product Oil Recycling--Progress Report. Western Research Institute, Laramie, WY, Report to DOE, DOE/MC/11076-2642.
- Thomas, K.P., R.V. Barbour, J.F. Branthaver, and S.M. Dorrence, 1983, Chemical and Physical Properties of Tar Sand Bitumens and Thermally Recovered Oils, in Synthetic Fuels from Oil Shale and Tar Sand, Institute of Gas Technology: Chicago, IL, 191-211.
- Wallace, D., J. Starr, K.P. Thomas, and S.M. Dorrence, 1988, Characterization of Oil Sand Resources. ISBN 0-55006-101-1.
- Western Research Institute, 1987, Annual Technical Progress Report for the period October 1986 - Sept 1987. Laramie, WY, Report to DOE, DOE/MC/11076-2455.

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