MILITARY JET FUEL FROM SHALE OIL

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Military jet fuel accounts for 60% of the total fuel requirement of the Department of Defense (DOD) as shown in Table 1. Because of the need to obtain a secure domestic source for military fuel and because it is evident that the DOD must be in the position to utilize fuel produced from domestic non-petroleum sources, the Air Force has embarked on an Aviation Turbine Fuel Technology Program. As part of this Air Force Program "A Program Leading to Specification for Aviation Turbine Fuel Produced from Whole Crude Shale Oil" was initiated. Past studies have shown that oil from shale is the most promising alternate source of jet fuel. The oil shale industry is closer to commercialization than coal liquefaction and shale oil is more amenable to conversion into jet fuel than are coal liquids (Ref. 1, 2, 3). The shale oil program is investigating jet fuel qualities, yields and economics for novel processes capable of producing high yields of jet fuel. Shale derived fuel properties of special interest include boiling range, freeze point, combustion characteristics, and thermal and storage stability as affected by hydrocarbon type, and nitrogen and trace metal content. Contracts were awarded by the Air Force to three companies in January 1979 to carry out this 28 month, four phase program. Ashland Research and Development - Ashland Petroleum Co., Suntech Inc. - Sun Company, and UOP Process Division - UOP, Inc. have completed the preliminary process designs and economic evaluations constituting Phase I of this program. A brief description of the processes investigated and the preliminary results from Phase I follow.

The Ashland program is based upon a refining method called the "Extracta-cracking" process. This process is specifically designed for the conversion of nonconventional feedstocks into finished conventional products. A simple block diagram of this process is shown in Figure 1. Whole crude shale oil is converted by a combination of hydrotreating, extraction, and fluid cracking steps into a material suitable for finished fuel production. Final product treating steps are provided as necessary for the production of specification quality fuels. In general this process uses low pressure processing equipment and has relatively low hydrogen consumption for a process optimizing jet fuel.

The Suntech program is studying the technical feasibility of three different processing schemes. A base case was defined as a process in which the crude shale oil would be hydrotreated, washed with 80% sulfuric acid, and fractionated to yield straight run products. A second scheme, shown in Figure 2, involves treating with anhydrous hydrogen chloride in conjunction with hydrotreating and hydrocracking. A third scheme is similar to the HCl scheme, however, it utilizes a liquid extraction solvent. The solvent, N,N-dimethylformamide (DMF), was screened from several other candidates based on the selective removal of polyaromatics and nitrogen compounds. In general, the Suntech extraction processes offer flexibility in product slate with the capability to produce high yields of jet fuel and essentially eliminate residual fuel production.

The UOP program is studying variations of two basic flow schemes, one for JP-4 and one for JP-8. The UOP process is composed of hydrotreating and hydrocracking, utilizing a proprietary modified flow hydrocracking scheme. The UOP process for the production of JP-8 is shown in Figure 3. The only major difference between this scheme and the one to produce JP-4 is the addition of naphtha hydrotreating and platforming units for processing and gasoline fraction. Each of these two schemes was evaluated with three different product slates, one slate with the maximum jet fuel yield attainable and two slates with reduced jet fuel yields. The UOP scheme offers essentially proven operational technology to produce high yields of aviation turbine fuel from shale oil.

The shale oil crudes being studied in the Air Force program are Occidental modified in-situ retorted material and Paraho surface retorted material. These were selected primarily because of availability and because they are representative of a range of properties that could be expected in oil produced from western oil shale by various retorting methods.

The results that follow are from schemes maximizing JP-4 and JP-8 production. All information presented here was either directly extracted or derived from results presented by Ashland, Suntech, and UOP in Phase I reports submitted to the Air Force.

Yield and product information is presented in Tables 2 and 3. The product yield is based on the volume of all liquid feed material, including shale oil crude and fuel used for process heat and hydrogen production, divided into the volume of all liquid products.

It is anticipated that all product qualities will meet or exceed the current military specifications. However, the projected jet fuel qualities shown in Table 4 do show variance depending upon the processing method. It should be realized that for processes maximizing jet fuel some fuel properties will have to be pushed to the specification limit by definition. Experimental data on turbine fuel properties and on quality/yield/economic trade-offs will be generated later in these programs.

The overall economics are based on a nominal 100,000 barrel per day grass roots refinery located in the midwest adjacent to an existing refinery; some of the major economic bases are shown in Tables 5 and 6. The economic results in September 1978 dollars are shown in Tables 7 and 8 for JP-4 and JP-8 respectively. The bottom line product prices are all between 80 and 84¢/gallon at the refinery.

The economic results generated in Phase I are based on preliminary process designs. These process designs were developed without the data to be generated in bench and pilot plant scale tests which are scheduled to be accomplished in Phase II and III of the Ashlnad, Suntech and UOP programs. Data generated in Phases II and III will result in a better understanding of the yields, the properties, and the costs of jet fuel produced from whole crude shale oil. From this data, an updated overall economic evaluation will be accomplished in Phase IV of the programs.

Up to 1000 gallons of variable quality fuel samples will result from the Ashland and Suntech programs with less being generated in the UOP effort. A larger quantity of specification quality JP-4 is needed for a Fuel Mainburner/ Turbine Effects program being carried out by General Electric and Pratt & Whitney as part of the Air Force Aviation Turbine Fuel Technology program. This test fuel was procured through the Suntech program with Hydrocarbon Research Inc. (HRI) participating as a subcontractor. A total of 11,300 gallons of specification quality JP-4 was produced by HRI from Geokinetics crude shale oil in a single stage severe hydrogenation process. The JP-4 yield from this process was 33%. The properties of the JP-4 and residual material produced are shown in Table 9. Also shown in Table 9 are the average properties of the JP-4 procured by the Air Force in 1978.

REFERENCES

1. Angello, L.C., Churchill, A.V., Delaney, C.L., Lander, H.R., "Shale Oil - The Answer to the Jet Fuel Availability Question," Paper 781027 presented at SAE Aerospace Meeting in San Diego, CA, November 1978.

2. Shaw, H., Kalfadelis, E.D., "Evaluation of Methods to Produce Aviation Turbine Fuels from Synthetic Crude Oils - Phases I - II," Air Force Aero Propulsion Laboratory, AFAPL-TR-75-10, Volumes I - II, 1975, 1976, 1977.

3. Sullivan, R.F., Strangeland, B.F., Rudy, C.E., Green, D.C., Frumkin, H.A., "Refining and Upgrading of Synfuels from Coal and Oil Shale by Advanced Catalytic Processes, First Interim Report, Processing of Paraho Shale Oil," United States Department of Energy, HCP/T2315-25, 1978.

TABLE 1

DOD FUEL PROCUREMENTS FY78

220 MILLION BARRELS

FUEL	% OF TOTAL
JP-4	47%
JP-5	12%
OTHER JET FUELS	1%
DIESEL FUEL MARINE (DFM)	14%
RESIDUAL, DIESEL AND OTHER FUEL OILS	21%
GASOLINE	5%
TOTAL	100%

TABLE 2

YIELD DATA FOR PROCESSES MAXIMIZING JP-4

	ASHLAND	SUNTECH	UOP	
		HCl EXTRACTION	MAX JP-4	JP-4/DFM
PRODUCT YIELD (VOL % OF FEED)	86.8	94.1	95.5	95.3
PRODUCT SLATE (VOL % OF PRODUCTS)				
JP-4	54.3	100.0	100.0	70.4
DFM/(DF-2)	(22.9)	----	----	29.6
BURNER FUEL	5.8	----	----	----
GASOLINE	17.0	----	----	----

TABLE 3

YIELD DATA FOR PROCESSES MAXIMIZING JP-8

	ASHLAND	SUNTECH	UOP	
		HCl EXTRACTION	MAX JP-8	JP-8/DFM
PRODUCT YIELD (VOL % OF FEED)	87.4	93.1	93.3	93.8
PRODUCT SLATE (VOL % OF PRODUCTS)				
JP-8	62.3	63.1	86.9	74.2
DFM	—	—	—	15.1
BURNER FUEL	5.7	—	—	—
GASOLINE	32.0	36.9	13.1	10.7

TABLE 4

PROJECTED QUALITIES OF SHALE OIL DERIVED JP–4

	MIL SPEC	ASHLAND	SUNTECH	UOP
GRAVITY (°API)	45–57	45	50.5	52.6
AROMATICS (VOL %)	25 MAX	25	11	6
FREEZING POINT (°F)	–72 MAX	–72	–75	–72
SMOKE POINT (MM)	20 MIN	20	> 20	35
SULFUR (PPM)	(4000)	< 1	< 5	< 1
NITROGEN (PPM)	NO SPEC	1	10	< 5
HYDROGEN (WT %)	13.6 MIN	13.6	14.0	14.5
RVP (PSI)	2–3	3	2.5	1.9

TABLE 5

ECONOMIC BASIS

CAPITAL RECOVERY

COST BASE:	SEPTEMBER 78
EQUITY FINANCING:	100%
RETURN ON INVESTMENT:	15% DISCOUNTED CASH FLOW AFTER TAXES
WORKING CAPITAL:	30 DAYS CRUDE INVENTORY AT $16.00/BARREL
	30 DAYS PRODUCT INVENTORY AT $21.00/BARREL
	DEBT FINANCED AT 10% ANNUAL INTEREST RATE

TABLE 6

ECONOMIC BASIS

OPERATING COST

CRUDE SHALE OIL:	$25.00 PER BARREL AT PLANT
FUEL:	EQUAL TO SHALE OIL CRUDE COST
PRODUCT VALUES:	FUELS EQUAL ($21.00 FOR WORKING CAPITAL)
	BY-PRODUCTS - AMONIA - $120/SHORT TON
	SULFUR - $53/LONG TON

TABLE 7

ECONOMIC RESULTS FOR PROCESSES MAXIMIZING JP-4

	ASHLAND	SUNTECH	UOP	
		HCl EXTRACTION	MAX JP-4	JP-4/DFM
MANUFACTURING COSTS $/BBL PRODUCT	5.33	8.55	8.69	7.84
ADJUSTED CRUDE COST $/BBL PRODUCT	28.80	26.57	26.21	26.23
TOTAL COST				
$/BBL PRODUCT	34.13	35.12	34.90	34.07
¢/GAL PRODUCT	81	84	83	81

TABLE 8

ECONOMIC RESULTS FOR PROCESSES MAXIMIZING JP-8

	ASHLAND	SUNTECH	UOP	
		HCl EXTRACTION	MAX JP-8	JP-8/DFM
MANUFACTURING COSTS $/BBL PRODUCT)	5.20	8.55	8.39	7.56
ADJUSTED CRUDE COST $/BBL PRODUCT)	28.60	26.85	26.80	26.65
TOTAL COST				
$/BBL PRODUCT	33.80	35.40	35.19	34.21
¢/GAL PRODUCT	80	84	84	81

TABLE 9

PROPERTIES OF SUNTECH/HRI PRODUCTS

	1978 JP-4	HRI JP-4	HRI RESIDUAL
GRAVITY (°API)	53.9	50.2	37.4
AROMATICS (VOL%)	11.4	8.9	-
FREEZING POINT (°F)	-	-76	-
SULFUR (WT%)	0.04	< 0.01	< 0.01
NITROGEN (PPM)	-	< 1	4
HYDROGEN (WT%)	14.36	14.39	-
RVP (PSI)	2.6	2.5	-

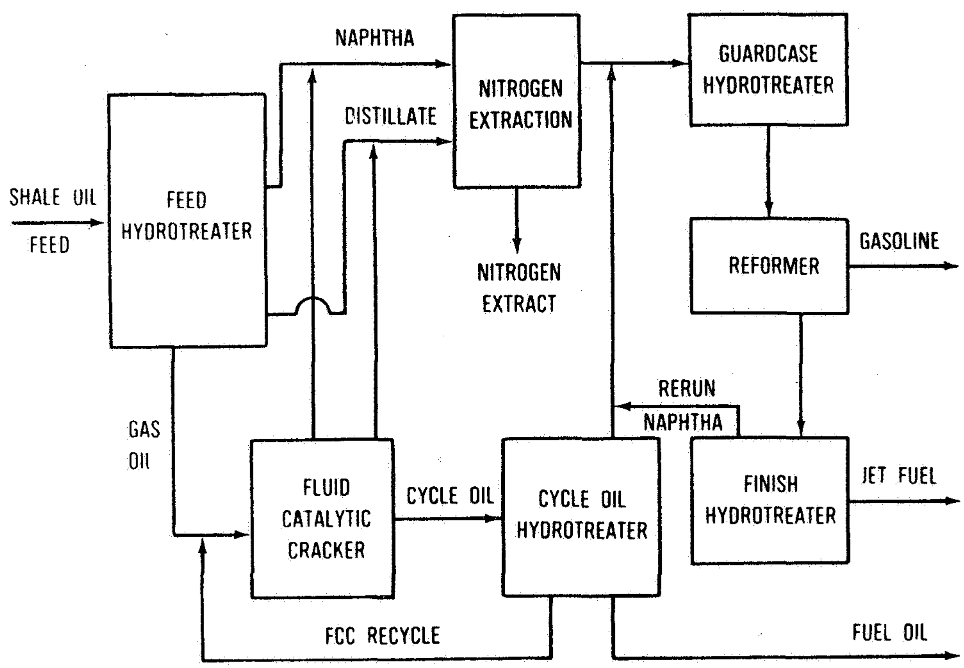

Figure 1. - Ashland Petroleum Co. - extractacracking process.

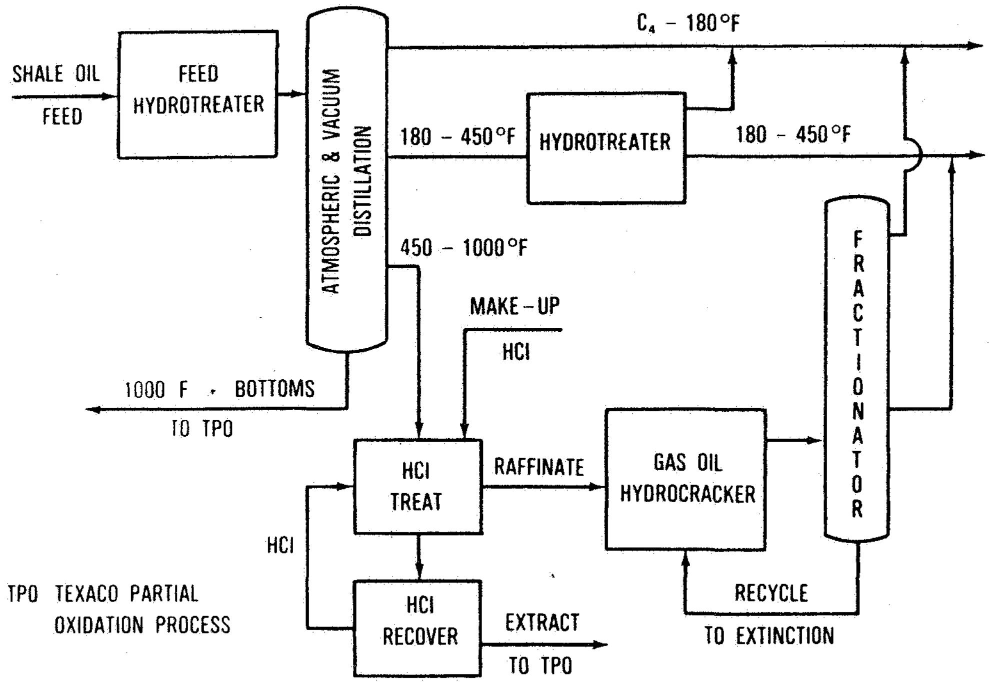

Figure 2. - Sun Technology - HCl extraction/max JP-4.

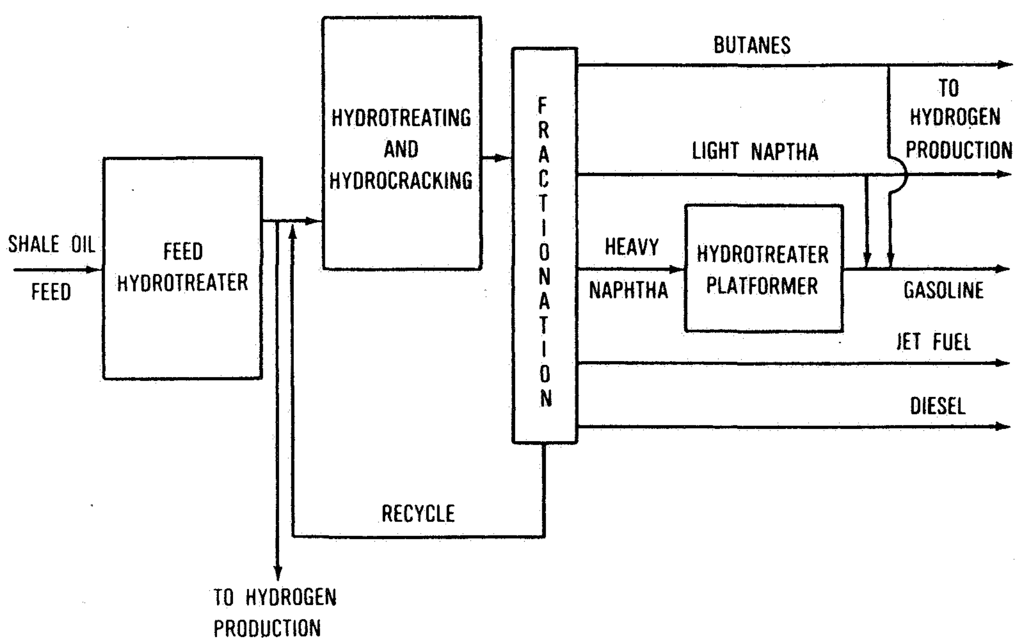

Figure 3. - UOP Process Division - modified flow hydrocracking JP-8.