TECHNOECONOMIC ASSESSMENT OF DEWAXING & HYDROTREATING RECYCLE DISTILLATE SOLVENT IN SUB-BITUMINOUS COAL LIQUEFACTION

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INTRODUCTION

During Wilsonville pilot plant Runs #262 and #263 with Black Thunder sub-bituminous coal, waxy deposits were found in the distillate streams of the Two Stage Liquefaction process unit(1). The quality of the distillate portion of the recycle solvent stream from these two runs was poor(2). This result indicated the potential for improving overall liquefaction performance and economics by treating the waxy distillate recycle solvent stream. This is one of the areas of liquefaction being studied under a DOE sponsored contract by a group headed by the Center for Applied Energy Research of the University of Kentucky. CONSOL Inc., Sandia National Laboratories and LDP Associates are the other organizations participating in this project. The technical approach taken to improve the solvent quality of this distillate is to first, dewax it using the commercially proven solvent dewaxing technique, followed by conventional hydrotreatment to improve the materials donor capabilities.

DESCRIPTION OF SYSTEM

A simplified block flow diagram of the dewaxing and hydrotreating processes is shown in Figure 1. Coal and a three-stream recycle process solvent are fed to the liquefaction unit. The heaviest product from the liquefaction reaction system is fed to a vacuum tower which separates a heavy distillate fraction from the ash-containing residue fraction. Part of the ashy residue is recycled while a smaller portion is fed to a ROSE unit where the net ash fed to the system is removed and a clean resid material is recovered and recycled. The 650°F+ heavy distillate stream from the vacuum tower is at least partially dewaxed and hydrotreated before being recycled back to the liquefaction system. In Wilsonville operation the analogous heavy distillate stream was recycled to liquefaction without either dewaxing or hydrotreating.

DEWAXING

Testing at CONSOL indicated that the solvent quality of the heavy distillate stream was significantly improved after solvent dewaxing(2). In the dewaxing step a solvent is used to precipitate and filter out the wax species at below atmospheric temperature. Solvent Dewaxing (SDW) is a commonly applied technique in the petroleum refining industry to remove paraffinic hydrocarbons from lube oil stocks(3). The waxy material or slack wax removed in the Dewaxing unit is highly paraffinic (Figure 2). When additional processing steps (deoiling & hydrotreatment) are used a high value, fully refined paraffin wax can be produced from the slack wax(4). Alternatively, the

highly paraffinic slack wax stream can be sent to a fluid cat cracking (FCC) unit where it is readily converted into gasoline and other refinery type byproducts.

DEWAXED OIL HYDROTREATING

Experimental work done at Sandia indicated that further improvement in solvent quality could be obtained by fixed bed hydrotreating the dewaxed oils(5). The objective of the hydrotreatment is to add about 1% hydrogen to the dewaxed distillate solvent which will subsequently be donated to the coal in the first stage liquefaction reactor. Since hydrogenation of aromatics occurs rapidly, mild operating conditions are anticipated (e.g. LHSV = 1, 1,800 psi & 750°F max.).

Data from a projected commercial scale EDS solvent hydrotreater was utilized to evaluate the cost of dewaxed oil hydrotreating(6). Estimated annualized hydrotreating costs are shown in Table 2. A 50% increase in space velocity only reduces liquefaction unit gasoline product cost by a relatively insignificant 9¢/Bbl.

TECHNOECONOMIC ASSESSMENT

A cost-benefit analysis is being used to determine an economical level of wax in the distillate recycle solvent for projected commercial operation . A good indicator of solvent quality is the concentration of alkyl beta (paraffinic) protons (ABP) in the stream. As shown in Table 1, the recycle distillate solvent stream (V-1074) in Wilsonville Run #263J contained 32.9% ABP's. Using the CONSOL experimental batch SDW data and commercial SDW information, estimated steady-state simulations of commercial SDW operations were developed as a function of the amount of the distillate solvent fed to the dewaxer. As the proportion of distillate fed to the dewaxer increases, the ABP concentration of the dewaxed oil decreases (Figure 3) and its quality as a solvent increases. Unfortunately, SDW costs also increase with increasing feedrates. Because of the rapid drop in ABP concentration versus SDWU feedrate, two SDWU feedrate cases (25% & 100%) were evaluated.

Summary data for the two Solvent Dewaxing Unit (SDWU) feed cases is shown in Table 3. Two slack wax byproduct disposition scenarios were also evaluated at each SDWU feedrate. The first scenario assumes that all of the slack wax byproduct can be sold as fully refined paraffin wax (FRPW) after the appropriate processing steps. In the second scenario it is assumed that the sale of FRPW is limited to 10% of the U.S. wax market demand. In this case, some as-is slack wax is sold to the construction industry (10% of market demand), with most of the slack wax sold as lower value FCC feedstock. The values of the FRPW, slack wax for the construction industry and slack wax as FCC feedstock are all related to crude oil price and are shown in Table 3. FCC feedstock price was determined from the expected yield structure with slack wax feed (62 vol.% gasoline), estimated product prices (e.g. gasoline @ $40/Bbl) less estimated FCC processing costs ($2/Bbl). The almost three times higher value of the specialty FRPW versus the commodity type FCC feedstock value results in huge differences in SDWU revenue between

the All-Wax and 10% Wax cases. When 100% of byproduct sales are as FRPW, the cost of SDW is exactly offset by the value of the FRPW sales for the 100% feed case. An even more favorable result occurs for the 25% feed case. FRPW sales exceed SDWU costs thereby reducing liquefaction plant gasoline product cost by 52¢/Bbl. even before taking into account the benefits of using the improved distillate solvent in liquefaction. Thus if the All-Wax byproduct disposition scenario is valid, the use of a SDWU is highly desirable.

However, in a five sub-bituminous coal liquefaction plant scenario, the amount of FRPW produced would be a significant portion of the total U.S. wax market demand. At a low wax market penetration of 10%, SDWU costs exceed byproduct revenues by $1.16/Bbl of gasoline for the 25% feed case and by $3.27/Bbl for the 100% feed case.

The above results range from a decrease in liquefaction plant gasoline product cost of 52¢/Bbl for the 25% feed-100% wax sales case to an increase of $3.27/Bbl for the 100% feed-10% wax market penetration case. These results indicate the extremely significant effect byproduct disposition and SDWU feedrate have on SDWU economics.

Hydrotreating the dewaxed oil is estimated to increase overall costs by approximately $1.16/Bbl of liquefaction plant gasoline product in all cases.

Therefore, the estimated total net cost for SDW and Hydrotreating the distillate portion of the recycle solvent ranges from a low of 65¢/Bbl for the All-Wax, 25% feed case to a high of $4.42/Bbl for the 10% Wax, 100% feed case.

FUTURE WORK

The benefit to the liquefaction system of using the better dewaxed and hydrotreated distillate solvent is being evaluated. It seems likely that the benefit of using dewaxing and hydrotreating will lie in between the respective costs of the All-Wax and 10% Wax cases at each SDWU feedrate. In addition, the use of Catalytic Dewaxing (CDW) instead of SDW will be evaluated. In CDW the waxy substances are directly cracked to lighter boiling range distillates and no waxy byproduct is produced.

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TABLE 1
DISTILLATE SOLVENT (V-1074) PROPERTIES
WILSONVILLE RUN # 263J
BLACK THUNDER COAL, HYBRID MODE OPERATION

WEIGHT RATIO TO MF COAL :	0.858
ESTIMATED SPECIFIC GRAVITY :	1.04 (4.6API)
ESTIMATED ELEMENTAL ANALYSIS , Wt.%	
- Carbon	89.28
- Hydrogen	9.49
- Oxygen	0.76
- Nitrogen	0.44
- Sulfur	0.03
BOILING RANGE, °F :	650 to 1,000
ESTIMATED WATSON "K" FACTOR :	10.5
PROTON NMR DISTRIB'N (CONSOL), %:	
- Condensed Aromatics	13.9
- Uncondensed Aromatics	4.4
- Cyclic Alpha	14.3
- Alkyl Alpha	8.2
- Cyclic Beta	14.5
- Alkyl Beta	32.9
- Gamma	11.8
SOLVENT QUALITY(CONSOL) :	70.9

(1.5/1 SOLVENT-TO-COAL, INDIANA V COAL, 750 F, 30 MINUTES)

TABLE 2
ECONOMICS OF DEWAXED OIL HYDROTREATING
ESTIMATED ANNUAL HYDROTREATER COST

BASIS :

- 83,900 BPSD Feedrate
- Wyoming Plant Location
- Mid - '92 Dollars per Barrel of Gasoline Product
- 15% Estimating Allowance on Capital Costs
- 0.15 Capital Charge Factor
- 320 Operating Days per Year
- Two Year Catalyst Life
- Costs of Makeup Hydrogen & Purge Hydrogen Excluded

	LHSV 1.0	LHSV 1.5
Annualized Capital Cost :	0.874	0.805
Catalyst Replacement @ $3/lb :	0.068	0.045
Electrical Power @ 4¢/ kw-hr :	0.085	0.085
Fuel Gas @ $2/MMBtu :	0.104	0.104
Operating Labor :	0.023	0.023
Total =	1.154	1.062

LHSV Δ = $0.092/Bbl

TABLE 3
BLACK THUNDER LIQUEFACTION STUDY
DEWAXING & HYDROTREATING
THE DISTILLATE PORTION OF PROCESS SOLVENT
ECONOMIC EVALUATION OF NET COSTS

- **BASIS**
  - Liquefaction : Five Plants @ 50,000 BPSD of Gasoline Each
  - Wax Yield : 4% of MAF Coal
  - Wax Cracking Rate : 22% of Wax Circulating
  - Crude Oil Price : $ 30/ Bbl.
  - Gasoline Price : $ 40 / Bbl.
  - Wax Value : 34.3 ¢ / lb.
  - Slack Wax Value : 18.8 ¢ / lb.
  - FCC Feed Value : 11.5 ¢ / lb.
- **TOTAL PRODUCTION DATA**

- Product Distribution	All Wax		Wax = 10% of Market	
- % of Feed to DWU	25%	100%	25%	100%
- Fully Refined Wax, T/Yr.	462,000	737,500	60,700	60,700
- Slack Wax, T/Yr.	None	None	67,200	67,200
- FCC Feed, T/Yr.	None	None	415,600	729,000
• ECONOMIC DATA PER PLANT				
- Est'd DWU Capital Cost, $ MM	236	463	180	410
- Capital Savings in Upgrading	- 24	- 39	- 30	- 64
- Net Capital Cost, $ MM	212	424	150	346
- DWU Product Revenue, $ MM/Yr.	63.4	101.2	32.5	46.9
- Decreased Gasoline Revenue	- 23.6	- 37.6	- 27.8	- 43.8
- Increase in Revenue, $ MM/Yr.	39.8	63.6	4.7	3.1
- Net Annual'd Δ in Cap. Cost*	31.8	63.6	22.5	51.9
- Net Dewaxing Cost, $ MM/Yr.	- 8.0	None	+ 17.8	+ 48.8
- Net Dewaxing Cost, $ / Bbl.	- 0.52	None	+ 1.16	+ 3.27
- Hydrotreater Cost, $ / Bbl.	+ 1.17	+ 1.15	+ 1.17	+ 1.15
- Net Δ in Gasoline Cost, $ / Bbl.**	+ 0.65	+ 1.15	+ 2.33	+ 4.42

* ASSUMING 15% CAPITAL CHARGE FACTOR
** NOT INCLUDING BENEFITS OF USING THE IMPROVED SOLVENT IN THE LIQUEFACTION UNIT

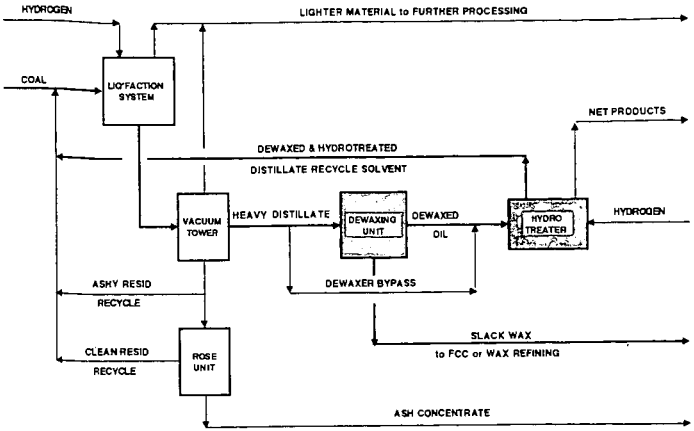

FIGURE 1
SIMPLIFIED BLOCK FLOW DIAGRAM
DEWAXING & HYDROTREATING of DISTILLATE RECYCLE SOLVENT

TEXACO DEVELOPMENT CORPORATION
TWO STAGE SOLVENT DEWAXING UNIT
WITH INCREMENTAL DILUTION

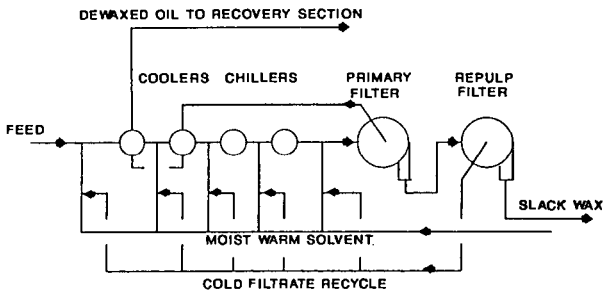

FIGURE 2
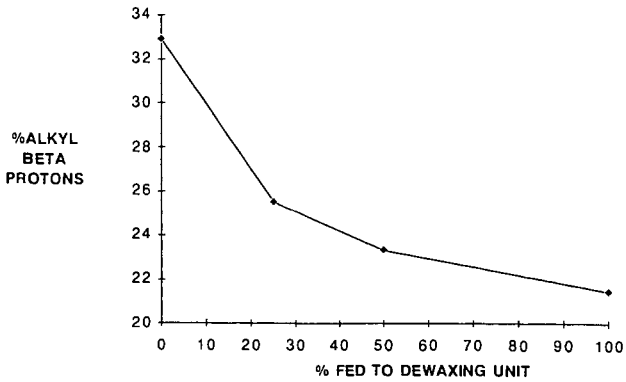
FIGURE 3
EFFECT OF DEWAXING UNIT BYPASS