PROGRESS IN DIRECT COAL LIQUEFACTION: THE ECONOMIC PERSPECTIVE

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ABSTRACT

The economic impact of demonstrated and projected improvements in two-stage direct coal liquefaction processes are evaluated. The computerized methodology employed estimates the quantity and quality of products from a 30,000 ton/day commercial scale plant, based on input test data. Steam, hydrogen and fuel gas balances are determined. Capital and operating costs are then estimated, and the required selling price of raw liquid products is determined by conventional discounted cash flow (DCF) analysis. Product quality is quantified by computing the cost of upgrading the raw products to motor gasoline.

Improvements in two-stage processing since the early demonstration of the Lummus Integrated Two-stage (ITSL) process in 1980 are shown to reduce the required initial selling price (RISP) of gasoline from coal liquids by about 16 percent. Further process improvements, which offer the potential for an additional 16 percent RISP reduction, are identified.

This report also compares the economics of two-stage processing with earlier studies of the H-Coal, Exxon Donor Solvent and Lummus ITSL processes. The high costs of coal liquids found in these earlier studies are explained and revised costs for these earlier plants using a common financial and technical basis are determined.

INTRODUCTION

Two-stage coal liquefaction research and development efforts have yielded significant increases in distillate quantity and quality over the last few years. The Lummus Integrated Two-stage Liquefaction (ITSL) process experience[1] showed that high yields of good quality coal liquids can be produced from bituminous coals using a combination of short contact time (SCT) thermal processing, anti-solvent deashing and LC-Fining* of deashed coal extract. Since then the concept has undergone several modifications.

At the Wilsonville Advanced Coal Liquefaction R&D Facility[2], both the thermal processing and the hydrotreating have generally been of longer duration than at Lummus. The critical solvent deashing system[3] has been more efficient at recovering coal extract and has thus rejected less soluble material than the Lummus anti-solvent process.[4] The ITSL concept itself, where the thermal first stage and catalytic second stage have been separated by the deashing step, has been modified so that the topped thermal effluent is hydrotreated before deashing. This configuration is called the Reconfigured ITSL (RITSL) mode of operation.[5] More recently the RITSL mode has been modified so that the first and second stage reactors are directly coupled together and the entire thermal effluent is

* Registered Trade Mark of Lummus-Cities Service hydrorefining process.

hydrotreated. This is the close-coupled operation (CC-ITSL). A vent separator is often used between the two-stages to let down the first stage products. In even more recent tests a portion of the ash-containing effluent from the hydrotreater is recycled to the first stage, the so called ash-recycle mode.[6] Catalytic-catalytic configurations have also been tested at Wilsonville.[6]

The overall objective of these modifications in two-stage processing is to increase the yield of high quality distillate while reducing the cost of production.

Sandia National Laboratories, which is supported by the U.S. Department of Energy under contract DE-AC04-76DP00789, has contracted MITRE to develop a method to quantify the impact of these modifications on the cost of coal liquids. In response, MITRE has developed a computerized coal liquefaction cost model that simulates the technical and economic performances of conceptual commercial scale coal liquefaction plants that incorporate the research and development improvements under study at Wilsonville.

METHODOLOGY

Introduction

The analysis methodology employed in the coal liquefaction cost model has been developed over the past several years. The objective of the methodology is to estimate the outputs and required selling price of products from a conceptual commercial scale plant. During 1986, the methodology was refined and computerized to permit rapid evaluation of the impact of variations in process performance on the required selling price of product liquids. The model is programmed in LOTUS 1-2-3 (Issue 2) and can be readily modified and expanded as refinements in the analysis methodology are developed. The paragraphs below present a brief overview of the analysis methodology. A more complete description may be found in reference (7).

Commercial Plant Output

Product outputs, product quality, and the flows to primary process units in the liquefaction plant are determined from experimental test data. The data may be directly scaled to the selected commercial size based on moisture ash free (MAF) coal throughput. (Postulated results may of course be substituted for test data in order to determine the potential economic impact of speculative process improvements.) The model is designed to make certain data adjustments if desired. In most runs, the data are adjusted to reflect operation with no net output of resid (+850°F residual material). When this adjustment is made in the model, the space velocity (hence capacity) of the hydrotreater is adjusted to the level required to achieve the desired resid conversion.

The resid adjustment provision of the program is also used when there are changes in the resid available to be converted because of assumed changes in the quantity of resid rejected with process solids (for example variations in deasher performance). The conversion factors for the resid are averages of several actual sets of data obtained during the Wilsonville operations.

Auxiliary Processes

The bottoms rejected from the liquefaction plant are gasified to produce

hydrogen. Additional coal is gasified when bottoms are not adequate to meet hydrogen requirements. Texaco gasification is assumed. Steam driven air separation equipment is used to produce oxygen for gasification. The model performs preliminary steam and fuel gas balances in order to obtain a thermally balanced plant and to determine the required capacities for auxiliary equipment. A coal fired steam plant with flue gas desulfurization is used to superheat steam produced from in-plant heat recovery, and to produce and superheat any additional steam required.

Cost Analyses

Preliminary designs of commercial plants employing two-stage liquefaction were prepared by UOP/SDC in 1981 under DOE contract[8,9]. These designs are used as the baseline for estimating capital and operating costs in the MITRE model. The UOP/SDC studies considered both Non-Integrated Two-stage Liquefaction (NTSL)[9], and Integrated Two-stage Liquefaction (ITSL)[8] configurations, and thus encompassed the major process elements of a wide variety of two-stage plant configurations.

The total erected costs (TEC) of process equipment required in the plant being analyzed are estimated by comparing the capacity required to the capacity of similar units in the baseline design. A 0.7 scale factor is used. Thus

$$\text{TEC (unit)} = \text{TEC baseline unit} \times \left(\frac{\text{unit capacity}}{\text{baseline capacity}} \right)^{0.7} \times \text{INF*}$$

Analyses of Required Selling Prices

The required selling price per barrel of raw product is computed by dividing the annual costs by the annual output in barrels. Annual costs are the sum of net operating costs and capital recovery costs. The program computes capital recovery costs by multiplying the required capital by an input capital recovery factor. The capital recovery factor for any specific set of financial assumptions is calculated by discounted cash flow (DCF) analysis in a separate program. The baseline economic assumptions used in the study are 25% equity, 15% DCF, 3% inflation, 34% tax rate, 8% interest on debt, and a 5 year construction period. These assumptions result in a capital recovery factor of 0.167.

There are substantial differences in the quality of products produced by direct liquefaction processes in terms of boiling range, hydrogen content and heteroatoms. These characteristics necessarily influence the degree to which the product must be further processed to produce specification fuels. We have accounted for differences in product quality by estimating the cost of additional processing required to produce a standard heteroatom free 40 API gravity product (e.g., "hydrotreated product") or unleaded motor gasoline.

The value of the syncrude relative to petroleum crude (equivalent crude value) is determined by computing the cost of crude that would permit gasoline to be processed and sold at the same price as the gasoline from syncrude.

RESULTS AND DISCUSSION

Table 1 summarizes the results of using the coal liquefaction cost model. The table shows economic and technical data for four conceptual commercial

* INF accounts for inflation between the year the UOP/SDC design was developed and the year 1986 (INF = 1.125).

two-stage plants processing Illinois #6 coal. The baseline plant (Lummus ITSL) can produce raw liquid product for $41.52/barrel (1986 dollars), which is equivalent to crude selling for $35.82/barrel. Wilsonville run 244-B data, which was obtained using the integrated two-stage liquefaction configuration, can produce product at an equivalent crude value of $35.36/barrel, i.e. very similar to the Lummus results. However, the close-coupled configuration run 250-D shows a significant reduction in product cost. The final column in Table 1 shows results obtained using data from Wilsonville run 250-G, which is a close-coupled run with ash-recycle. Again this shows a further decrease in product cost. Raw product cost reductions of about 16 percent have been realized in going from Lummus ITSL to the ash-recycle close-coupled Wilsonville configuration. This product cost decrease is brought about by the combination of a significant yield improvement (26 percent increase on a raw product basis) and only a slight increase in capital required to obtain that gain (about 5 percent capital increase). Therefore, it is estimated that raw coal liquids could be produced for approximately $35/barrel; this is equivalent to crude oil at about $30/barrel.

As an R&D guidance tool, the model can also be used to estimate potential savings in required selling prices that could be realized if certain potential process improvements were incorporated into the system. Potential improvements include using cleaned coal and eliminating the deashing system, increasing coal slurry concentration, and improving catalyst activity, selectivity and life. The model predicts that an additional cumulative reduction in required selling price of products of approximately 16 percent is possible by incorporating all of the above improvements into the current ash-recycle Wilsonville two-stage configuration processing Illinois #6 coal. Table 2 shows that these additional cost reductions result in production of coal liquids for about $29/barrel, which is equivalent to crude at about $25/barrel.

Table 3 summarizes earlier direct coal liquefaction economic studies undertaken by Bechtel[10], Exxon[11] and UOP/SDC[8,9] for the H-Coal, Exxon Donor Solvent and Lummus ITSL processes respectively. Direct comparisons are not meaningful, however, because of the differences in plant scale, economic factors, and other assumptions. The earlier studies were made during a period of high inflation and high capital return expectations, and the analysts assumed a continuation of high inflation through the construction period. In order to separate the impact of improved technology from the overriding impact of changes in economic conditions, the earlier technologies were re-evaluated using the our model. The required selling prices computed by the model thus reflect the same costing methodology, plant scale and economic assumptions used in the analysis of the advanced two-stage system.

The results are shown in Table 4. Required selling prices are shown for raw liquefaction products, and for products after hydrotreatment to a consistent standard of quality. The latter prices are more meaningful for comparative purposes, since they reflect the large differences in the quality of the single and two-stage products. On this basis, required selling prices have been reduced from about $49 to about $36.60 per barrel, which represents a savings of about 25%.

CONCLUSIONS

Over the past decade continued research in the production of liquid fuels from coal has substantially increased both the quantity and the quality of distillate from a ton of coal. This increase of distillate, which amounts to approximately 35 percent, has resulted in a significant real decrease in the cost of liquid products

from coal of about 25%. Continued research is expected to further reduce the cost of coal liquids.

ACKNOWLEDGEMENT

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TABLE 1
CONCEPTUAL COMMERCIAL PLANT SUMMARY DATA
FOR ILLINOIS #6 COAL FEEDSTOCK

	LUMMUS ITSL	244-B ITSL	250-D CC-RITSL	250-G-RAR
Economic Data (Million $)				
Plant Capital Cost	4,418	4,859	4,670	4,658
Coal Cost	271	290	314	330
Other Operating Cost	337	389	380	374
Byproduct Credit	79	69	126	150
Hydrotreating Cost	227	330	190	209
Total Operating Cost	756	939	758	762
Plant Coal Requirements TPD (AR)				
Coal to Liquefaction	33,232	33,232	33,232	33,232
Coal to Steam Plant	2,564	1,980	2,433	2,626
Coal to Gasification Plant	371	3,441	6,276	8,162
Total Coal to Plant	36,166	38,652	41,941	44,019
Plant Product Outputs (BPD)				
Raw Product	92,400	106,900	112,200	116,900
Hydrotreated Product	103,800	122,800	124,400	127,700
Gasoline	111,100	131,400	133,100	136,600
Required Selling Price ($/Bbl)				
Raw Product	41.52	40.27	36.40	34.52
Hydrotreated Product	43.61	43.21	37.46	36.56
Gasoline	45.75	45.26	40.07	39.30
Equivalent Crude Value ($/Bbl)	35.82	35.36	30.40	29.66

TABLE 2
CUMULATIVE POTENTIAL IMPROVEMENTS SUMMARY FOR CONCEPTUAL
COMMERCIAL PLANTS PROCESSING ILLINOIS #6 COAL

	BASE CASE 250 G	CATALYST ACTIVITY DOUBLED	CATALYST SELECTIVITY IMPROVED	CATALYST LIFE DOUBLED	CLEAN COAL NO DEASHER	SLURRY COAL 36 PERCENT
Economic Data (Million $)						
Plant Capital Cost	4,659	4,528	4,510	4,501	4,619	4,457
Coal Cost	330	330	330	330	376	376
Other Operating Cost	374	369	368	348	395	395
Byproduct Credit	151	151	57	57	88	88
Hydrotreating Cost	209	209	149	149	174	174
Total Operating Cost	762	757	790	770	857	857
Plant Coal Requirements TPD (AR)						
Coal to Liquefaction	33,232	33,232	33,232	33,232	33,596	35,596
Coal to Steam Plant	2,630	2,630	2,630	2,630	3,075	3,075
Coal to Gasification Plant	8,162	8,162	8,162	8,162	11,574	11,576
Total Coal to Plant	44,023	44,023	44,023	44,023	50,245	50,245
Plant Product Outputs (BPD)						
Raw Product	116,851	116,851	128,672	128,672	147,663	147,663
Hydrotreated Product	127,663	127,663	135,270	135,270	155,500	155,500
Gasoline	136,599	136,599	144,739	144,739	166,385	166,385
Required Selling Price ($/Bbl						
Raw Product	34.52	33.81	32.83	32.34	29.85	29.14
Hydrotreated Product	36.56	35.91	34.57	34.10	31.73	31.07
Gasoline	39.30	38.69	37.64	37.20	34.98	34.36
Equivalent Crude Value ($/Bbl)	29.66	29.08	28.07	27.66	25.53	24.94

TABLE 3
REQUIRED SELLING PRICES FROM PUBLISHED STUDY DESIGNS

PROCESS DATA SOURCE DEBT/EQUITY RATIO	H-COAL BECHTEL 0/100	H-COAL BECHTEL 52/48	EDS EXXON 0/100	ITSL UOP/SDC 75/25
Required Selling Price ($/Barrel)				
1981 Dollars	$ 57	$ 36	$ 53	$ 43
Start-Up Year Dollars	$ 90	$ 57	$121	$ 69
(Year)	(1988)	(1988)	(1993)	(1986)
Financial Assumptions				
Return on equity	15.0%	15.0%	15.0%	26.0%
Interest Rate	NA	10.8%	NA	17.0%
Inflation Rates				
Construction costs	8.5%	8.5%	7.5%	10.0%
Operating Costs	6.0%	6.0%	7.0%	10.0%
Product Value	6.7%	6.7%	9.0%	10.0%

TABLE 4
REQUIRED SELLING PRICE OF PRODUCTS $/BARREL ($1986)
(ILLINOIS #6 COAL)

	SINGLE-STAGE PROCESSES		TWO-STAGE PROCESSES	
	EDS	H-COAL	ITSL	CURRENT
Raw Product	$43.58	$42.35	$41.52	$34.52
Hydrotreated Product	$49.18	$48.80	$43.61	$36.56