EVALUATION OF THE
TEXACO SYNTHESIS GAS GENERATION PROCESS
FOR THE PRODUCTION OF HYDROGEN
FROM SRC-II RESIDUE

by

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Date Issued: December, 1979

Report Prepared by
SCIENTIFIC DESIGN COMPANY, INC.
Two Park Avenue
New York, New York 10016, U.S.A.

Relative to

MASTER

Subcontract No. 7240
for the
Division of Fossil Fuel Processing
U.S. Department of Energy

under Subcontract with

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. DEPARTMENT OF ENERGY

Contract No. W-7405-eng-26

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy \$6.50
Microfiche \$3.00

ABSTRACT

This report presents the results of an evaluation of the Texaco Synthesis Gas Generation Process for the production of hydrogen from SRC-II vacuum bottoms residue. Based on gasification tests carried out by Texaco, the operability and efficiency of the Gasifier have been commented upon. Preliminary process designs for a Texaco gasification facility for a commercial scale coal liquefaction plant were prepared. A number of studies were performed to establish a near-optimal operating pressure and method of acid gas removal. Plant Investment and operating cost estimates are included.

The report concludes that the Texaco Gasifier is well suited for the efficient production of hydrogen from SRC-II residue and only minimal developmental work is needed prior to commercialization. Because of the short duration of the test runs, refractory and burner lives are a point of concern. Based on the current state of oxygen compression technology the gasifier should be designed to operate at about 800 psig.

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I. INTRODUCTION & SUMMARY

One of the major coal conversion projects under consideration by the U.S. Department of Energy is a demonstration plant for the Solvent Refined Coal (SRC-II) Process. The SRC-II Process being developed by the Pittsburgh & Midway Coal Mining Company (P&M), a subsidiary of Gulf Oil Corporation, is designed to produce clean, non-polluting liquid fuels from high sulfur bituminous coals. The primary products are low sulfur fuel oils suitable for power plant use in areas with stringent sulfur regulations. The physical and chemical characteristics of this coal-derived oil are such that little or no modification is required to burn the products in existing utility boilers.

The SRC-II Process, as well as almost all other coal liquefaction processes now being developed, require hydrogen to solubilize the coal. The thermal efficiency of such coal liquefaction plants is dependent upon the efficient production of hydrogen from the non-liquefied (or residue) fraction of the coal. This material, together with the inorganic ash and a small fraction of the converted coal, can be recovered after liquefaction as a residue from a vacuum distillation tower. The purpose of this report is to evaluate the Texaco Synthesis Gas Generation Process for gasification of the SRC-II vacuum bottoms to produce a syngas which can be shifted and purified to supply the hydrogen required for liquefaction.

In the late 1940's Texaco developed a non-catalytic partial oxidation process to convert natural gas to synthesis gas which was then reacted with steam to form additional hydrogen. Further developments enabled the use of light oils, residual oils and asphalts as

feedstocks. Pilot and demonstration plants have been built to prepare syngas from coals. Exploratory pilot plant runs conducted in the summer of 1975 demonstrated the feasibility of gasifying pumpable coal-derived residues containing as much as 28 percent ash.

In June of 1976 a contract was awarded to Texaco by the U.S. Energy Research and Development Administration (now the US DOE) which provided for a test program on residual materials (including SRC-II vacuum bottoms) supplied by DOE from DOE sponsored coal liquefaction projects. The main objectives of the Texaco test program were to confirm the operability of the process with the particular feedstock and to establish ranges of operating conditions and their effect on gas yield and composition.

The Texaco Synthesis Gas Generation Process is a non-catalytic partial oxidation process that is based on reactions between oxygen and hydrocarbons that take place at high temperature to produce synthesis gas composed primarily of hydrogen and carbon monoxide.

Starting in June, 1978, Scientific Design Company, Inc. reviewed the Texaco residue test program and subsequently developed preliminary process designs for a hydrogen plant to be integrated into an SRC-II commercial scale plant. The results of this evaluation further substantiates that the development of the Texaco process is well advanced and that the SRC-II residue can be gasified quite satisfactorily. The test program at Texaco's Montebello, California Research Laboratory showed that smooth trouble-free operation could be achieved at a carbon to syngas conversion level of 99%. However, because the total operating time was only 78 hours the longevity of the gasifier refractory and burner tip was not proven.

As part of SD's development of the process flowsheets, mini-studies were carried out to establish the effect of gasifier operating pressure (600, 800 and 1200 psig pressures were evaluated) and the method of acid gas removal (physical vs. chemical absorption) on plant investment and operating costs. The results of these studies indicate that:

1. The effect of pressure on plant investment and operating cost is minor in the range of 600 to 1200 psig. However, operation at 800 psig appears to be optimum.
2. Operation of the gasifier at 800 psig is further recommended because the pressure is about the maximum that can be accomodated by use of existing, commercially available, two casing oxygen compressors.
3. A physical absorption process (Selexol) is more economical than a chemical process (Benfield) for accomplishing acid gas removal at operating pressures as low as 600 psig. Higher operating pressures are even more favorable for the Selexol process.

II. COMMENTS ON THE TEXACO PILOT PLANT TESTS & DESIGN RECOMMENDATIONS

Two Pilot Plant tests to gasify SRC-II residue from Kentucky 9/14 coals have been completed by the Texaco Development Corporation at their Montebello Research Laboratory. The results of the Type II (20 barrel) and TYPE III (200 barrel) tests were published in DOE reports FE-2247-14, dated May 13, 1978 and FE-2247-20, dated February, 1979, respectively. Based on the results of these two tests and SD's observations of the Type III test, we have the following comments:

A. Texaco's Pilot Plant Tests and Design Recommendations

The Type II test consisted of only one run lasting 7.3 hours at a residue feed rate of 1048 pounds per hour. In the Type III test eight runs of 8.0-14.8 hours duration were completed with residue feed rates varying from 750 to 994 pounds per hour. Since the results of the Type II test are in line with those of the Type III test, comments on the Texaco SRC-II residue gasification tests will be limited to the more extensive Type III runs.

All of the test runs using Kentucky coal residue were completed smoothly. The residues were melted and pumped to the gasifier at an average temperature of 515°F with no pumping or handling problems. Discharge of slag from the lockhopper at the bottom of the pilot plant gasifier was also smooth. The measurement and analyses of the gasifier off-gas is straightforward and reliable. However, in SD's opinion the separation, collection and weighing of char and fine and coarse slag particles can be somewhat improved. As described in Appendix C of DOE Report FE-2247-20, separation of coarse

and fine slag was by an 8-mesh vibrating screen and was not very sharp. Elutriation of fine char particles from the collected slag particles might not be complete. Thus, the yields reported for the individual solid products could somewhat overlap. However, the total slag and the char production reported for the tests should be reasonably accurate.

All of the runs were conducted at a gasifier pressure of 350 psig. The important parameters studied in the tests were the oxygen/residue and the steam/residue ratios, which were varied from 0.70 to 0.78 and from 0.29 to 0.49, respectively. (All ratios on a lb/lb basis.) The oxygen/residue ratio controls the degree of carbon conversion of the feed while the steam/residue ratio is used to control the gasifier temperature. For the SRC-II residue tested at Montebello it was necessary to operate at a temperature of about 2600°F which is substantially above the ash fusion temperature to insure that the slag fluid is able to flow along the wall of the reaction vessel into the water bath in the gasifier quench chamber.

From the Type III test results Texaco concluded that an oxygen/residue ratio of 0.73 is required to achieve a 99 percent conversion of carbon to syngas. To maintain the Pilot Plant gasifier at the operating temperature of about 2600°F, a steam/residue ratio of 0.3 was adequate. However, Texaco recommends that a steam/residue ratio of 0.5 be used for the larger commercial gasifier because of its reduced surface to volume ratio and consequent lower external heat loss.

Texaco's recommended values for the oxygen/residue and steam/residue ratios seem reasonable to SD.

Texaco inspected the interior of the pilot gasifier after the conclusion of the eight Type III test runs, which accumulated a total on-stream time of 78 hours. They reported that no evidence of significant refractory damage or serious burner tip erosion was observed. A 78 hour running time is too short to draw definite conclusions about the life expectancy of the refractory or burner tip. However, since these items stood up quite well during the test runs, it is reasonable to assume that their life cycles will be fairly extended. In the absence of actual plant performance data the only feasible way to protect against possible loss of production due to material failure is the provision of a spare gasifier for the commercial plant.

Based on pilot plant tests at 350 psig Texaco recommended the plant design bases for a commercial gasifier operation with SRC-II residue from Kentucky 9/14 coal as follows:

Steam/Residue Ratio	0.500 Lb/Lb
Oxygen/Residue Ratio	0.728 Lb/Lb
(H ₂ + CO) Production	29.3 SCF/lb of residue
(H ₂ + CO) Concentration	89.1 mol %, dry basis
Carbon Conversion	99 wt.%

The above recommended design figures are consistent with the Pilot Plant test results.

Based on the data obtained, Texaco estimated that their largest available commercial gasifier is capable of producing 71 million standard cubic feet per day of hydrogen plus carbon monoxide when operated at 28 atmospheres pressure with SRC-II residue from Kentucky coals.

B. SD's Assessment of the Texaco Gasifier

1. Operability

Pilot plant runs at Montebello demonstrated the trouble-free operation of the Texaco gasifier when operated with SRC-II residues from Kentucky coals. Because of the simplicity of the design, start-up, operation and shutting-down of the gasifier can be easily accomplished. One contributing factor for the smooth operation is the fact that the SRC-II residue can be pumped to the gasifier as a molten slurry using a Texaco developed feeding system which consists of plunger pumps and check valve assemblies such as shown in Figure C-1 of Appendix C in DOE Report FE-2247-20. This set-up permits the pumping of the molten residue slurry without the slurry ever getting into the pump cylinders. Another factor responsible for the smooth operation is the use of the quench boot at the bottom of the gasifier which results in steadier and more reliable operation when compared to cases where other devices are used to cool the hot gas leaving the gasifier section.

2. Efficiency

The carbon conversion of 99 wt% is quite high. This is achieved through the use of the proper oxygen/residue ratio and the close control of the operating gasifier temperature. The entrained mode of operation, which permits easy access of oxygen to the molten residue particles sprayed from the burner tip is also helpful.

The cold efficiency of the tests varied between 80 and 83 percent as stated by Texaco in DOE Report FE-2247-20. However, in the calculation of cold gas efficiency, only the heating value of the fuel feed is taken as input. A better measure to evaluate gasifiers is the thermal efficiency which takes into account, besides the fuel, the energies required for providing other feed streams to the gasifier, such as oxygen and steam. It also allows a credit for the energy recoverable from the hot product gas of the gasifier.

Based on Texaco's performance data in Table IX of DOE Report FE-2247-20, the heat inputs and outputs were calculated for the gasifier operating at 350 psig. The energy used in preparing and compressing the oxygen gas to 550 psig for delivery to the gasifier was estimated by using the high-pressure steam rates to the condensing turbine drives as shown in the attached Flowsheet 2006-X-102, adjusted for the differences in the oxygen flow rates and the compressor discharge pressure. The gasifier steam feed temperature was 1000°F and the hot product gas temperature was 2600°F. Besides the heating values of CO and H₂ in the product gas, its sensible heat at 2600°F above the base temperature of 60°F was also credited. Dividing the total heat inputs into the total heat outputs, a thermal efficiency of about 81.6% was calculated. This value was lower than the cold gas efficiency (83.3%) calculated for the same set of data. This result clearly shows that proper heat recovery from the hot product gas is extremely important. Since it is impossible in practice to accomplish the heat recovery down to the base temperature of 60°F, the actual thermal efficiency will be lower than the above calculated value.

C. Suggestions for Further Pilot Plant Tests

The pilot plant tests were limited to gasifying SRC-II residues from Kentucky 9/14 coals at 350 psig. It is recommended that additional tests be made to gasify residues from other coals and at higher pressures. A desirable modification in the test program would be the lengthening of the test runs from hours to 7 to 14 days duration as recommended by Texaco in the DOE Report FE-2247-20. From such extended tests, steady state analytical data could be obtained for the circulating water stream to establish the proper treatment of the waste purge liquor.

III. DESIGN BASIS

This section of the report outlines the Design Basis for the preliminary process design of a Texaco Synthesis Gas Generation facility to supply the hydrogen required by a grass-roots commercial SRC-II coal liquefaction plant converting approximately 33,400 tons of dry coal per stream day. Based on a paper delivered by Schmid and Jackson ("Recycle SRC Processing for Liquid and Solid Fuels", presented at the June, 1978, AIChE Meeting in Philadelphia), the SRC-II plant will use about 4.3 lb of hydrogen per 100 lb of dry coal feed and produce a mineral matter free residue equivalent to 20 wt.% of the dry coal feed, respectively. The Texaco Synthesis Gas Generation Process is used to gasify the SRC-II residue. It has been assumed that the residue production just balances that required for hydrogen generation. If there is an overage of residue, the excess can be used to prepare fuel gas for the SRC-II plant. If there is a shortage of residue, the deficiency can be made up by gasifying coal or other fuels to meet the hydrogen requirement. The material balance for this study is based on a Texaco report entitled "Type III Extended Pilot Plant Evaluation of SRC-II Vacuum Flash Drum Bottoms from Kentucky No. 9/14 Coal", DOE Report No. FE-2247-20, published in February, 1979.

The design is for a battery limits hydrogen production plant which receives vacuum bottoms from the SRC-II Plant and delivers, in return, the hydrogen required by the liquefaction plant. The utilities required by the hydrogen plant; steam, power, boiler feed and cooling water, will be supplied from the SRC-II plant. Steam generated in the hydrogen plant, preheated boiler feed water, cooling water return as well as gaseous and liquid waste effluent streams are delivered to the battery limits for further treatment.

The design bases for the plant are as follows:

Plant Location

Morgantown, W. Va.

Elevation: 1250 feet above sea level.

Coal Feed

Feed Rate = 30,000 short tons of dry coal per calendar day with an on-stream factor of 90%.

Texaco Gasifier

The evaluation utilizes the largest available commercial gasifier. Since pressure is the most important operating parameter of the Texaco Gasifier, three cases are considered, with the gasifier operating at 600, 800 and 1200 psig respectively. Other parameters such as steam/residue ratio, oxygen/residue ratio, product gas rate and composition, char and slag production, percent carbon conversion, etc. are based on DOE Report No. FE-2247-20.

Oxygen Plant

Three oxygen plants each rated at 2400 tons per stream day will be provided to supply oxygen with a purity of 99.5 mol%. The oxygen will be supplied at the cold box at 2 psig. The oxygen plant's air compressors and oxygen compressors are driven by steam turbines.

Residue Feed

The residue will be delivered from the SRC-II plant in a molten state.

Product Hydrogen Gas

Production Rate: The production rate of hydrogen gas is equivalent to 4.3 wt.% of the dry coal feed, or about 1440 short tons per stream day.

Purity: A 94 mol% pure H_2 stream will be delivered to the SRC-II Plant. (Reference Schmid and Jackson, "The SRC-II Process, Third International Conference on Coal Gasification and Liquefaction, August, 1976).

Delivery Pressure: The hydrogen product will be delivered, by compression as needed, to the suction of the Recycle Hydrogen Compressor in the SRC-II plant at 1100 psig, based on the Fort Lewis pilot plant operation.

Utilities - All utilities have been assumed to be supplied to/from OSBL.

Power: All of the major compressors and pumps will utilize steam turbine drives. Power for motor drives will be supplied from OSBL.

Steam: H.P. Superheated Steam for turbine drives will be supplied from OSBL at 1500 psig and 950°F. Condensers for the turbines will use cooling water and operate at a condensing pressure of 2½ inches HG absolute.

M.P. Steam - 600 psig saturated steam is generated in the CO shift heat recovery system and exported to OSBL. 600 psig, 800°F superheated steam for turbine drives will be imported from OSBL.

L.P. Steam - 50 psig saturated steam is generated in the CO-shift system part of which is used in hydrogen plant with the balance sent to the SRC-II plant.

Boiler Feed Water: Boiler feed water will be supplied from OSBL.

Cooling Water: Design Temperature 85°F
Max. Temperature Rise 30°F

Design Air Conditions

Design Air Temperature 85°F

Relative Humidity 60%

Design Winter Temperature 11°F

IV. PROCESS DESCRIPTION

This section of the report includes a brief description of the process, a more detailed description of flow, equipment notes and process flowsheets.

The following process flowsheets were prepared for this study and are included at the end of this section:

<u>Drawing No.</u>	<u>Description</u>
2006-X-101	Block Flow Diagram
<u>600 psig Gasifier Case</u>	
2006-X-102	Production and Compression of O ₂ & N ₂ and Refrigeration
2006-X-103	Oxygen Gasification of SRC-II Residue
2006-X-104A/B	CO Shift Conversion, Selexol & Benfield Alternates
2006-X-105A	Selexol Acid Gas Removal
2006-X-105B	Benfield Acid Gas Removal
<u>800 and 1200 psig Gasifier Cases</u>	
2006-X-202 & 302	Production and Compressor of O ₂ & N ₂ and Refrigeration
2006-X-203 & 303	Oxygen Gasification of SRC-II Residue
2006-X-204 & 304	CO Shift Conversion
2006-X-205 & 305	Selexol Acid Gas Removal

The Texaco Development Corporation has not reviewed these flow sheets for technical validity and did not check the calculations, costs, material balances or utilities presented in this report. Because of their proprietary content, the detailed flow sheets developed by SD for the gasification section have been considerably simplified for this published version. However, all internal SD calculations, costs estimates, etc. utilize the full level of detail developed during the study.

BRIEF DESCRIPTION OF PROCESS (Dwg. 2006-X-101)

Molten SRC-II residue is pumped from storage and injected into the Texaco Gasifier, where it is reacted with steam and oxygen to gasify the residue by partial oxidation in an entrained mode at around 2600°F. The hot product gas is quenched by water in a boot at the bottom of the gasifier, which drastically reduces the temperature of the raw gas and, in so doing, evaporates water into the gas stream. The in-situ generated steam is useful in the CO shift reaction further downstream in the process. The hot raw gas leaving the quench boot of the Gasifier is then scrubbed with water to remove small amounts of char and slag entrained in the gas.

The scrubbed raw gas is then catalytically shift converted to increase the H₂ content in a 3-stage reaction system. Heat removal between stages is accomplished by generating 600 psig, saturated steam.

The acid gases, CO₂ and H₂S, are removed from the hydrogen by either physical or chemical absorption. The off-gas from the acid gas regenerator is sent to the SRC-II plant for sulfur recovery and the purified hydrogen leaving the absorbers is compressed and delivered to the SRC-II plant.

DESCRIPTION OF FLOW

Production and Compression of O₂ and H₂ and Refrigeration (Dwg. No. 2006-X-102- 202 & 302)

This flowsheets shows the package air separation and refrigeration plants including major compressors and drives for each of the 3 cases (600, 800 and 1200 psig) of Gasifier operating pressure. Both the 600 and 800 psig cases utilize standard commercial two-casing designs for oxygen compression. The 1200 psig case is based upon the projected development of a third casing and is therefore not yet commercial.

Oxygen Gasification of SRC-II Residue (Dwg. No. 2006-X-103, 203 & 303)

This flowsheet includes the residue preparation and feeding system, gasification and raw gas purification.

Molten SRC-II residue from the SRC-II plant is charged into a nitrogen blanketed surge tank provided with heating coils to keep the residue molten at about 550°F. From the bottom of the surge tank, the molten residue is circulated continuously past the suction of the high pressure residue charge pump and back to the top of the surge tank. This is to insure that a positive pressure is maintained at all times at the suction of the high pressure residue charge pump. The molten residue is pumped to the gasifier under pressure at a constant rate using a positive displacement plunger pump fitted with external ball check valves. The piping between each check valve assembly and the corresponding pump cylinder is filled and purged with a clean heavy distillate fuel oil produced by the SRC-II plant. An auxiliary pump is used to maintain a small purge rate (about 1% of residue feed rate) of fresh solvent into each connecting pipe to prevent molten residue from diffusing back to the charge pumps cylinders.

Steam at the desired pressure is supplied from the SRC-II plant and fed to the burner. Oxygen gas of 99.5% purity from the air separation plant is compressed and delivered without cooling to the burner. Steam, molten residue and oxygen are fed at accurately controlled rates to a specially designed burner at the top of the gasifier. For efficient gas production and, above all, for safe gasifier operation it is very important that the mass ratios of the reactants be under close control at all times.

The gasifier is a steel vessel which is divided internally into two sections. The top section is lined with a special refractory material designed to withstand the severe operating conditions of the partial oxidation reactions which take place in an entrained mode at about 2500 to 2650°F. The lower section is a quench vessel in which a reservoir of water is maintained at all times. Syngas from the top

section of the gasifier passes through a water cooled dip tube into the water in the quench vessel. The cooled saturated syngas is removed from the gas space above the water. Water is continuously injected into the quench vessel to replace the water lost by evaporation and solids removal.

The hot, saturated syngas leaves the quench boot of the gasifier and enters a scrubber/separator where the small amount of entrained char/slag is removed. A fairly large stream of sour condensate recovered from the CO shift system is preheated and fed to the scrubber. The scrubbed gas is then sent to the CO shift system. Some of the scrubber bottoms are pumped to the gasifier.

Molten slag, which forms during the gasification of the residue, is carried into the quench section with the syngas. Upon contacting the reservoir of water in the quench section, the molten slag solidifies. Two water slurry streams exit the quench section. One stream is a char slurry from which heat is removed in two stages. In the first stage it is used to preheat the sour condensate returned from the CO shift system before it enters the scrubber. In the second stage the heat is recovered by heating the cold recycle water, after addition of make-up water, from the slag/char treatment system. The heated recycle water stream is routed to the scrubber before being pumped to the gasifier. The second slurry stream leaves the bottom of the quench section and is principally a water slurry of slag (with some char) from the bottom of the gasifier. The combined slag/char slurry leaves by way of lockhoppers, and is educted using water into an agitated slag mixing and surge tank for further treatment.

Equipment for the separation of the slag/char slurry has been provided. In the first step the slag is separated from the char slurry and recovered as a material suitable for landfill. The second step produces a char slurry which can be recycled to the gasifier.

CO Shift Conversion (Dwg. No. 2006-X-104A/B, 204 & 304)

Because hydrogen is the desired reagent in the SRC-II liquefaction process, the quenched and scrubbed syngas is shift converted in a 3-stage reactor system using a sulfur resistant cobalt-molybdenum catalyst. The gas is first preheated to 600°F by the hot gas leaving the first converter. It then passes through the three converters in series with the heat of reaction recovered between the converter as 600 psig, saturated steam. After the third converter, the heat in the shifted gas is recovered first in waste heat boilers and then either in a boiler feedwater preheater or in process regenerators, depending on whether a physical (Selexol) or chemical (Benfield) acid gas removal system is used. At a steam to gas ratio of 1.3 in the feed syngas the CO shift conversion system reduces the CO concentration to about 4% in the product hydrogen. The shifted syngas is then sent to the acid gas removal section.

Acid Gas Removal (Dwg. Nos. 2006-X-105A/B, 205 & 305)

The CO/H₂ ratio in the syngas from the Texaco Gasifier is quite high, about 1.4. This means that the CO₂ content of the gas after CO shift will be very high, about 39 mol% for the case under study. The partial pressure of CO₂ in the gas feed to the acid gas removal system is about 206 psi (dry basis) when the Texaco gasifier is operated at 600 psig. The CO₂ can be removed by physical absorption such as Allied Chemical's Selexol process or by chemical absorption such as Benfield's hot carbonate process.

Capital and utility requirements were obtained from flowsheets prepared for both processes (Dwg. No.s 2006-X-105A & 105B). A comparison of the two cases shows that at the high CO₂ partial pressure of 206 psi the physical absorption process is more economical and the Selexol Process has the added advantage that the H₂S can be recovered at a higher concentration and thus effect appreciable savings in the Claus plant used for sulfur recovery in the SRC-II plant. Because of the above results at the gasifier pressure of

600 psig, it was concluded that only the Selexol process will be studied at gasifier pressures of 800 and 1200 psig, since the higher total pressure will further increase the CO_2 partial pressure and makes the physical absorption process even more favorable.

Three main streams exit this flowsheet:

- A 94 mol% hydrogen product stream which is compressed to 1100 psig and sent to the SRC-II plant.
- A CO_2 rich stream containing about 8 mol% H_2S (Selexol case) which is sent to the sulfur recovery unit in the SRC-II plant.
- A CO_2 vent gas stream.

EQUIPMENT NOTES

Texaco Gasifier - Although Texaco gasifiers have been commercially used for many years for the partial oxidation of natural gas and heavy hydrocarbon residues, there is no operating pilot plant devoted exclusively to the gasification of coal liquefaction residues. However, based on the results of the extensive tests conducted at Texaco's Montebello Research Laboratory on residues from the H-coal and SRC Processes, it is reasonable to conclude that the Texaco gasifier will be suitable for use in the gasification of SRC-II residues. The present, largest available Texaco gasifier, upon which the present study is based, is rather small in size, in view of the high rates of coal or other fuels to be processed in commercial coal conversion plants. It is hoped that, by the time the commercial SRC-II plant is ready to be built, larger-sized Texaco gasifiers will be available and the number of trains required for the projected capacities can be held to a minimum.

In this study it was assumed that the char separated from the char/slag slurry from the gasifier can be recycled to extinction by feeding the char in a water slurry to the gasifier.

Oxygen Compressor - At the present time commercial oxygen compressors utilize a two-casing design with a maximum discharge pressure of about 950 psig. For the 600 psig gasifier case there will be no problem with the oxygen compressor. For the 800 psig case the maximum discharge pressure of the commercial compressor is just adequate to allow for an approximately 150 psi pressure drop between the compressor discharge and the gasifier. In the 1200 psig gasifier pressure case, an oxygen compressor discharge pressure of about 1400 psig is necessary. This pressure is beyond the reach of the existing commercial two-casing oxygen compressors. However, detailed design and pilot units of a three-casing compressor are reasonably confident that their high-pressure machines will be ready when the first SRC-II commercial size plant is built.

STREAM NO.	3001				3004			
	SRC II RESIDUE FEED				SYNGAS LEAVING SCRUBBER			
COMPONENT	M.W.	LB/HR	MOL/HR	WT%	LB/HR	MOL/HR	MOL%	
HYDROGEN	2.02	4,904		3.6	8,945	4,428.0	14.31	
CARBON MONOXIDE	28.01				170,810	6,099.4	88.41	
CARBON DIOXIDE	44.01				50,377	1,145.0	4.82	
HYDROGEN SULFIDE	34.08				7,309	67.8	0.83	
CARBONYL SULFIDE	60.08				278	34	0.07	
NITROGEN (ARGON)	28.01/39.95	1,417		1.1	18,34	66.0	0.24	
WATER	18.02				276,330	15,351	36.42	
OXYGEN	32.00	2,140		1.87				
CARBON	12.01	87,734		64.4				
SULFUR	32.06	2,310		1.7				
ASH	35.97			2.1				
CHLORIDE		109		0.08				
TOTAL		135,679		100.00	500,368	27,167	100.00

STREAM NO.	4001/4051	4002/4052	4003/4053	4004/4054	4005	4006	4007/5051
SERVICE	FEED TO FIRST SHIFT REACTOR	FEED TO SECOND SHIFT REACTOR	FEED TO THIRD SHIFT REACTOR	THIRD SHIFT REACTOR EFFLUENT	GAS TO BFW HEATER	GAS TO ACID GAS REMOVAL (SELEXOL)	GAS TO ACID GAS REMOVAL (BENFIELD)
COMPONENT	M.W.	LB/HR	MOL/HR	MOL%	LB/HR	MOL/HR	MOL%
HYDROGEN	2.02	17,840	8,860	16.33	30,419	15,058	27.76
CARBON MONOXIDE	28.01	140,621	12,160	27.22	46,878	5,978	10.98
NITROGEN DIOXIDE	66.01	100,787	2,750	6.27	176,181	9,013	16.48
HYDROGEN SULFIDE	34.08	4,618	135.5	0.28	4,415	144.8	0.27
ETHANETHIOL	60.09	55	1.03	0.00	55	1.03	0.00
NITROGEN (N2)	28.01	3,109	109.1	0.24	3,109	109.1	0.24
WATER	18.02	257,460	14,440	32.67	244,981	13,714	25.23
TOTAL		470,735	24,271	100.00	470,735	24,271	100.00

NOTES
 1. TOTAL PLANT CAPACITY: 30,000 TONS DRY COAL/CALENDAR DAY.
 2. THREE 93.3% TRAINS ARE REQUIRED. THE MATERIAL BALANCE SHOWN IS FOR ONE OF THREE OPERATING TRAINS.

PFS 104A
SELEXOL ALTERNATE

PFS 104B
BENFIELD ALTERNATE

DRAWING NO. 2006-X-104A/B
 KEY
 ◊ STREAM NO.
 ◻ TEMPERATURE °F
 ○ PRESSURE PSIA
 (UNLESS OTHERWISE NOTED)

B

SCIENTIFIC DESIGN COMPANY INC.
 DESIGN • TWO PARK AVENUE • CONSTRUCTION
 NEW YORK
 HYDROGEN PLANT FOR SRC II COAL LIQUEFACTION
 CO SHIFT CONVERSION
 30,000 TONS COAL/DAY COMMERCIAL PLANT
 FUEL OIL
 DRAWN BY: E.R./J.B. DATE: 11/29/78 SCALE: 1/2"=1'-0"
 CHECKED BY: DATE: 12/1/78
 APPROVED BY: DATE: 12/1/78
 NO. 2006-X-104A/B

10

A		B				C			
STREAM NO.		3001				3004			
SERVICE		SRC II RESIDUE				SYNGAS LEAVING			
		FEED				GAS			
COMPONENT	M.W.	LB/HR	MOL/HR	WT.%	LB/HR	MOL/HR	MOL.%		
HYDROGEN	2.02	7,327		3.6	13.417	6,642.0	16.33		
CARBON MONOXIDE	28.01				25.560	912.05	23.61		
CARBON DIOXIDE	44.01				19.127	13.73	6.82		
HYDROGEN SULFIDE	34.08				34.9	1.14	0.32		
CARBONYL SULFIDE	60.08				493	4.2	0.01		
NITROGEN (ARGON)	28.02	212.0		1.1	3.78	97.6	0.14		
WATER	18.02				214.34	22.99	76.42		
OXYGEN	32.00	37.9		1.82					
CARBON	12.01	131.60		64.6					
SULFUR	32.06	2.7		1.1					
ASH	55.35			27.1					
CHLORIDE	16.02			0.05					
TOTAL		203.02		100.00	76.42	203.01	100.00		

NOTES:
1. TOTAL PLANT CAPACITY: 30,000 TONS DRY COAL/CALENDAR DAY.
2. THE MATERIAL BALANCE SHOWN IS FOR ONE OF FOUR(4) OPERATING TRAINS.

DRAWING NO. 2006-X-203	
KEY	
◇	STREAM NO.
□	TEMPERATURE ° F
○	PRESSURE PSIA (VALUES OF TEMPERATURE)

SCIENTIFIC DESIGN COMPANY INC.
1000 PARK AVENUE
NEW YORK

HYDROGEN PLANT FOR SRC II COAL LIQUEFACTION
OXYGEN GASIFICATION OF SRC II RESIDUE
30,000 TONS COAL/DAY COMMERCIAL PLANT

FUEL OIL

DRAWN BY: E.R./J.B. DATE: 1/1/10
CHECKED BY: DATE: 1/1/10
APPROVED BY: DATE: 1/1/10

REVISIONS

NO. DESCRIPTION DATE BY CHECKED DATE

1 IV-15 No. 2006 X-203

STREAM No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
SERVICE	4001	4002	4003	4004	4005	4006									
COMPONENT	W.W.	LB/HR	MOL/HR	MOL%	LB/HR	MOL/HR	MOL%	LB/HR	MOL/HR	MOL%	LB/HR	MOL/HR	MOL%	LB/HR	MOL/HR
HYDROGEN	1.02	11887	8.35E-02	16.33	30.49	15058.8	21.14	38.889	18550.7	26.10	40.500	18079.4	26.10	40.500	18079.4
CARBON MONOXIDE	1.01	580.621	12.1607	22.12	156.078	2927.2	10.78	19.485	1114.6	3.26	36.254	937.3	1.13	26.754	937.3
CARBON DIOXIDE	4.01	100.103	2.218E-02	4.22	21.185	82.12	15.25	558.663	1154.0	23.10	575.178	3.444	21.59	225.138	3.512
HYDROGEN SULFIDE	3.00	4.416	1.35E-02	2.72	4.935	14.4	0.21	9.255	16.54	0.71	13.303	16.58	0.33	14.959	16.58
CARBONYL SULFIDE	6.00	0.25	1.03	0.04	0.2	1.0	NIL	0.2	1.0	NIL	0.2	1.0	NIL	0.2	1.0
NITROGEN (AS IN)	20.00	3.709	1.2E-02	0.36	5.709	13.01	0.34	5.709	13.01	0.34	5.709	13.01	0.34	5.709	13.01
WATER	1.02	207.148	30.8182	36.52	348.916	1444.4	45.07	364.78	28.1512	21.24	365.09	13.9148	35.81	21.584	365.09
TOTAL		1020.135	54.341	100.00	1020.135	54.341	100.00	1020.135	54.341	100.00	1020.135	54.341	100.00	1020.135	54.341

NOTES
1. TOTAL PLANT CAPACITY: 30,000 TONS DRY COAL/CALENDAR DAY.
2. THREE 33.3% TRAINS ARE REQUIRED. THE MATERIAL BALANCE SHOWN IS FOR ONE OF THREE OPERATING TRAINS.

DRAWING NO. 2006-X-204
KEY
◇ STREAM NO.
□ TEMPERATURE °F
○ PRESSURE PSIA
(UNLESS OTHERWISE NOTED)

SCIENTIFIC DESIGN COMPANY INC.
DESIGN • TWO PARK AVENUE • CONSTRUCTION
NEW YORK
HYDROGEN PLANT FOR SRC II COAL LIQUEFACTION
CO SHIFT CONVERSION
30,000 TONS COAL/DAY COMMERCIAL PLANT
FUEL OIL
DRAWN BY: S.R./R.B. DATE: 11/21/78 SCALE: NONE
CHECKED BY: G.W. DATE: 12/4/78
APPROVED FOR CONSTRUCTION BY: DATE: No. 2006-X-204

A		B				C			
STREAM NO.		1001				3004			
SERVICE		SRC II RESIDUE FEED				SYNGAS LEAVING SCRUBBER			
COMPONENT	M.W.	LB/HR	MM/HR	WT%	LB/HR	MM/HR	MOL%		
HYDROGEN	2.02	9809		3.6	17889	8856.0	16.33		
CARBON MONOXIDE	28.01				34021	12160.7	22.42		
CARBON DIOXIDE	44.01				100.35	120.0	0.22		
HYDROGEN SULFIDE	34.08				4618	135.5	0.29		
CARBONYL SULFIDE	60.08				652	10.9	0.02		
NITROGEN (BASED)	28.01	2652		1.1	3169	130.1	0.34		
WATER	18.02				22246	30658.2	56.52		
OXYGEN	32.00	4959		1.82					
CAESON	40.01	17545		64.4					
SULFUR	32.06	423		1.3					
ASH	73.04	13638		47.1					
CHLORIDE	51.5	218		0.08					
TOTAL		27179		100.00	100.735	54224.6	100.00

NOTES:
1. TOTAL PLANT CAPACITY: 30,000 TONS 28% COAL CALENDAR DAY.
2. THE MATERIAL BALANCE SHOWN IS FOR ONE OF THREE (3) OPERATING TRAINS

KEY
◇ STREAM NO.
○ TEMPERATURE °F
□ PRESSURE PSIA (UNLESS OTHERWISE NOTED)

SCIENTIFIC DESIGN COMPANY INC.
DESIGN: TWO PARK AVENUE • CONSTRUCTION: NEW YORK

HYDROGEN PLANT FOR SRC II COAL LIQUEFACTION
OXYGEN GASIFICATION OF SRC II RESIDUE
FOR 30,000 TONS COAL/DAY COMMERCIAL PLANT
FUEL OIL

DRAWN BY: E.R./J.B. DATE: 10-19-79 SCALE: AS SHOWN
CHECKED BY: DATE: APPROVED BY: DATE: 10-19-79
APPROVED FOR CONSTRUCTION BY: DATE: No. 2006-X-303

STREAM NO.	4001	4002	4003	4004	4005	4006
SERVICE	FEED TO FIRST SHIFT REACTOR	FEED TO SECOND SHIFT REACTOR	FEED TO THIRD SHIFT REACTOR	THIRD SHIFT REACTOR EFFLUENT	GAS TO BFW HEATER	GAS TO ACID GAS REMOVAL (SELEXOL)
COMPONENT	W.B.	LB/HR	MOL/HR	W.B.	LB/HR	MOL/HR
HYDROGEN	2.02	17,889	832.6	10.55	30,499	1,503.8
CARBON MONOXIDE	28.01	340,511	12,167.7	27.92	186,878	5,927.8
CARBON DIOXIDE	44.01	180,183	2,740.0	4.72	370,181	8,621.2
AMMONIA SULFIDE	34.08	1,400	13.3	0.12	4,722	144.8
CARBONYL SULFIDE	44.08	955	13.3	0.02	22	1.04
NITROGEN (ARGON)	28.02	3709	130.1	0.24	3709	130.1
WATER	18.02	657,460	30,418.1	56.52	440,310	14,444.2
TOTAL		1,020,158	34,341.4	100.00	1,020,158	34,341.4

NOTES
1. TOTAL PLANT CAPACITY: 30,000 TONS DRY COAL/CALENDAR DAY.
2. THREE 33.3% TRAINS ARE REQUIRED. THE MATERIAL BALANCE SHOWN IS FOR ONE OF THREE OPERATING TRAINS.

DRAWING NO. 2006-X-304

KEY

- ◇ STREAM NO.
- TEMPERATURE °F
- PRESSURE PSIA (UNLESS OTHERWISE NOTED)

SCIENTIFIC DESIGN COMPANY INC.

DESIGN TWO PARK AVENUE CONSTRUCTION

HYDROGEN PLANT FOR SRC II COAL LIQUEFACTION

CO SHIFT CONVERSION

30,000 TONS COAL/DAY COMMERCIAL PLANT

FUEL OIL

DRAWN BY E.R./J.B. DATE 11/29/78 SCALE NONE

CHECKED BY DATE APPROVED BY DATE

APPROVED FOR CONSTRUCTION BY DATE

No. 2006-X-304

A

V. PLANT INVESTMENT COST ESTIMATES

The factored estimate method was used to estimate the plant investment costs. In this method the costs of the main equipment such as compressors, pumps, drives, tanks, towers, heat exchangers, etc., for each section of the plant, were estimated from the process flowsheets and/or equipment data sheets. Where available, vendors quotations were used. The estimated equipment costs were then multiplied by appropriate factors to give installed costs, which include materials and labor for construction and construction supervision. After allowing for engineering, procurement, etc., the costs became the bare plant costs. For the first-of-kind plants under study, a contingency of 15% was added to give plant investment costs.

The costs of all sections listed in the following table were estimated by the method described above, with the exception of the oxygen plant. In this case an estimated "turnkey" cost from a vendor was used. Table V-I summarizes the plant investment costs for the 4 cases under consideration and clearly shows the following:

1. Selexol requires a somewhat smaller investment ($\sim 10\%$) at 600 psig. Since the economics of physical absorption process (Selexol) improve with higher partial pressures of CO_2 the chemical process (Benfield) was not considered at the higher pressures.
2. The effect of operating pressure is not very significant in the range of 600 to 1200 psig; however, 800 psig appears to be optimum.

TABLE V-1

TOTAL PLANT INVESTMENT COST ESTIMATES
(in Millions of Mid 1979 Dollars)

BASIS: 33,400 Tons of Dry Coal per Stream Day

On Stream Factor - 0.9

	<u>CASE 1 - 600 PSIG</u>		<u>CASE 2</u>	<u>CASE 3</u>
	<u>Case 1A</u>	<u>Case 1B</u>	<u>800 PSIG</u>	<u>1200 PSIG</u>
<u>PLANT SECTION</u>	<u>Selexol</u>	<u>Benfield</u>	<u>Selexol</u>	<u>Selexol</u>
Oxygen Production & Compression	108.1	108.1	108.7	112.1
Gasification & Ash Handling	43.5	43.5	36.5	38.3
CO Shift Conversion	56.6	56.6	64.7	74.7
Acid Gas Removal	<u>96.6</u>	<u>105.8</u>	<u>89.6</u>	<u>80.9</u>
Subtotal Plant Cost	304.8	314.0	299.5	306.0
Contingency @ 15%	45.2	47.0	44.5	46.0
TOTAL PLANT INVESTMENT	<u>350.0</u>	<u>361.0</u>	<u>344.0</u>	<u>352.0</u>

VI. OPERATING COST ESTIMATES

The operating costs are estimated on the basis of gasifying SRC-II residues from 33,400 tons of dry coal per stream day, with an on-stream factor of 0.9. The following two tables show the method used in estimating the operating costs.

Table VI-1 gives the raw material and utility consumption rates. The raw material rate is based on DOE Report FE-2247-20 prepared by Texaco for the Type III tests and the article by Schmid and Jackson "Recycle SRC Processing for Liquid and Solid Fuels" published in the June, 1978 AIChE Meeting in Philadelphia. The utility consumption/production rates are based on the Process Flowsheets prepared by SD for this study.

Table VI-2 shows estimated operating costs. The bases for these estimates are as follows:

Steam Cost/Credit:

1500 psig, superheated	\$3.00/1000 lb
600 psig, superheated	\$2.50/1000 lb
600 psig, saturated	\$2.30/1000 lb
50 psig, saturated	\$2.00/1000 lb
Condensate/Boiler Feedwater	\$0.50/1000 Gallon
Cooling Water	\$0.02/1000 Gallon
Power	\$0.02/KWH
SRC-II Residue (@ Fuel Value)	\$1.00/10 ⁶ Btu, HHV

TABLE VI-1

RAW MATERIAL & UTILITY CONSUMPTIONS

BASIS: 33,400 Tons of Dry Coal per Stream Day
On Stream Factor - 0.9

A. RAW MATERIALS

SRC-II Vacuum Bottoms Residue - 815,200 lb/hr.

B. UTILITY CONSUMPTION - PROCESS REQUIREMENTS

	<u>CASE 1 - 600 PSIG</u>		CASE 2	CASE 3
	Case 1A	Case 1B	800 PSIG	1200 PSIG
	<u>Selexol</u>	<u>Benfield</u>	<u>Selexol</u>	<u>Selexol</u>
<u>Power</u>				
Motor, BHP	3,400	4,100	3,000	3,200
Condensing Turbine, BHP	<u>236,400</u>	<u>218,500</u>	<u>223,300</u>	<u>217,800</u>
Total, BHP	239,800	222,600	226,300	221,000
<u>Steam Production (+)/Consumption (-)</u>				
1500 psig Steam				
Consumption, lb/hr	-409,200	-409,200	-409,200	-409,200
600 psig Steam				
Production, lb/hr	+407,100	+407,100	+447,300	+449,500
50 psig Steam				
Production, lb/hr	+876,000	+582,000	+996,000	+1,080,000
Consumption, lb/hr	<u>- 88,600</u>	<u>--</u>	<u>- 75,800</u>	<u>- 64,400</u>
Net Production of				
50 psig Steam, lb/hr	+787,400	+582,000	+920,200	+1,015,600
<u>Boiler Feed Water</u>				
@ 109° F, GPM	2,600	2,000	3,000	3,200
<u>Cooling Water</u> , GPM	58,400	141,100	60,900	60,800

TABLE VI-1 (Continued)

RAW MATERIAL & UTILITY CONSUMPTIONSC. UTILITY CONSUMPTION - Steam for Condensing Turbines, Condensate
Return, & Cooling Water for Turbines

	<u>CASE 1 - 600 PSIG</u>		<u>CASE 2</u>	<u>CASE 3</u>
	<u>Case 1A</u>	<u>Case 1B</u>	<u>800 PSIG</u>	<u>1200 PSIG</u>
	<u>Selexol</u>	<u>Benfield</u>	<u>Selexol</u>	<u>Selexol</u>
<u>Condensing Turbine Consumption</u>				
1500 psig Steam, Superheated @ 950°F, 1b/hr	964,200	964,200	976,500	1,001,400
600 psig Steam, Superheated @ 800°F, 1b/hr	318,200	306,800	292,600	231,600
<u>Condensate-Production (+)/Consumption (-)</u>				
Condensate Production, GPM (From cond. turbine @ 109°F)	+ 2,700	+ 2,600	+ 2,700	+ 2,600
Condensate Consumption, GPM (Net Make-up to Gasifier Plant)	- 1,500	- 1,700	- 1,500	- 1,500
Net Condensate Production, GPM	+ 1,200	+ 900	+ 1,200	+ 1,100
<u>Cooling Water, GPM</u> (Turbine Condensers)	206,300	161,100	189,200	187,200

TABLE VI-2

ANNUAL OPERATING COSTS
(In Millions of Mid 1979 Dollars)

BASIS: 33,400 Tons of Dry Coal per Stream Day. On Stream Factor - 0.9.

	<u>CASE 1 - 600 PSIG</u>		<u>CASE 2</u>	<u>CASE 3</u>
	<u>Case 1A</u>	<u>Case 1B</u>	<u>800 PSIG</u>	<u>1200 PSIG</u>
	<u>Selexol</u>	<u>Benfield</u>	<u>Selexol</u>	<u>Selexol</u>
1. <u>RAW MATERIALS</u> (a)				
SRC-II VB from Kentucky 9/14 Coal	73.92	73.92	73.92	73.92
2. <u>UTILITIES</u> (Cost +, Credit -)				
1500 psig superheated steam	+32.48	+32.48	+32.77	+33.36
600 psig superheated steam	+ 6.27	+ 6.05	+ 5.77	+ 4.56
600 psig saturated steam	- 7.38	- 7.38	- 8.11	- 8.15
50 psig steam	-12.42	- 9.18	-14.51	-16.01
Condensate	- 0.28	- 0.21	- 0.28	- 0.26
BFW	+ 0.61	+ 0.47	+ 0.71	+ 0.76
C.W.	+ 2.50	+ 2.86	+ 2.37	+ 2.35
Net Heat in Export Preheated BFW @ \$1/MM Btu	- 3.11	+ 1.32(Import)	- 1.85	- 0.94
Electrical Power	+ 0.46	+ 0.68	+ 0.46	+ 0.54
UTILITIES NET TOTAL	+19.13	+27.09	+17.33	+16.21
3. <u>CATALYSTS & CHEMICALS</u>	+ 1.79	+ 1.70	+ 1.58	+ 1.45
SUBTOTAL (1+2+3) Cost	94.84	102.71	92.83	91.58
4. <u>LABOR</u> - operating, maintenance & supervision	10.1	10.4	10.0	10.2
5. <u>ADMINISTRATION</u> & GENERAL OVERHEAD	6.1	6.2	6.0	6.1
6. <u>SUPPLIES</u> Operating & Maintenance	4.6	5.0	4.7	4.8
7. <u>LOCAL TAXES & INSURANCE</u> (2.7% of Plant Investment)	9.5	9.7	9.3	9.5
Subtotal (4+5+6+7) Cost	30.3	31.3	30.0	30.6
TOTAL NET ANNUAL OPERATING COSTS	125.14	134.01	122.83	122.18

(a) HHV = 11,500 Btu/lb (SRC-II Residue from Kentucky 9/14 Coal)

$$\text{Cost} = 815,200 \text{ lb/hr} \times 11,500 \text{ Btu/lb} \times 7,884 \text{ hr/yr} \times \$1.00/10^6 \text{ Btu}$$

The results of Table VI-2 shows the following:

1. At 600 psig, use of Selexol for acid gas removal results in a reduction of 7% in overall Net Annual Operating Cost when compared to Benfield.
2. The overall Net Annual Operating Costs show an insignificant reduction as Gasifier pressure is increased from 600 to 1200 psig.

VII. PROCESS DISCUSSION

Acid Gas Removal by Physical and Chemical Absorption Processes

The syngas from the Texaco Gasifier contains about 90 mol% of CO + H₂ (dry basis) with 6-7 mol% CO₂. The CO/H₂ ratio for the commercial plant is about 1.4. Since H₂ is the required product, most of the CO is shifted by steam to H₂ and CO₂. Thus, the CO₂/H₂ ratio of the product gas from the shift reactor is quite high. Removal of CO₂ from this stream is a significant factor in the cost of the H₂ product.

In general, there are two types of CO₂ removal processes - physical and chemical. Chemical absorption processes such as Benfield are favored when the partial pressure of CO₂ in the gas to be purified is low, while the physical processes such as Selexol are usually chosen for high CO₂ partial pressures. There is no clear-cut value for choosing one process over the other, as the economics depend on a number of factors which vary from case to case.

In the present study a comparison between the use of Selexol and Benfield processes was made for the case of 600 psig gasifier pressure. The partial pressure of CO₂ in the feed to the acid removal system was 206 psi (dry basis). From Section V the plant investment costs, excluding contingencies, were estimated to be \$105.8 MM for the Benfield facilities and \$96.6 MM for the Selexol facilities. The difference is about 10% in favor of Selexol.

Section VI shows that Selexol is much more favorable than Benfield when their heat economies are compared. Thus, Selexol recovers in waste heat boilers about 300,000 pounds per hour of 50 psig steam more than Benfield, and it has the capability of recovering low-level heat in the form of preheated boiler feed water amounting to about 600 million Btu per hour. The reason for this difference in heat recovery is that the Benfield process uses low-pressure steam to regenerate the rich absorption solution whereas the Selexol process regenerates the rich solvent by CO_2 flashing and stripping with by-product nitrogen gas. This difference in heat economy in favor of the Selexol process more than offsets the relatively small difference in power consumption, which is about 17,000 BHP in favor of the Benfield process.

Another important advantage of Selexol is that it selectively absorbs H_2S in preference to CO_2 . This selectivity results in a much higher H_2S content in the regenerator acid gas for Selexol than for Benfield. This increased H_2S concentration is extremely helpful when the regenerator off-gas is treated in a Claus plant after combining with other H_2S -bearing streams from the SRC-II plant.

Since Benfield was found to be not as favorable as Selexol at a Gasifier pressure of 600 psig, only Selexol was studied for the 800 and 1200 psig cases as the higher CO_2 partial pressure in the shifted syngas will make physical absorption processes still more favorable.

Optimum Texaco Gasifier Pressure

Although there are a number of operating parameters which will affect the cost of syngas production from the Texaco gasifier, only a few are subject to independent control. As discussed previously, the oxygen/residue and steam/residue ratios used for the gasifier are important variables. But within the constraints of the required high carbon conversion and the high operating temperature necessary for slag disposal, these ratios can be varied only within narrow limits. The most important independent parameter for the optimum production of syngas is the operating pressure of the gasifier. Pressure is important because, among other things, it determines the relative costs of oxygen and hydrogen compression. This is because the oxygen is produced from the air fractionation plant at essentially atmospheric pressure and the hydrogen has to be compressed and ultimately delivered at higher than 2000 psig. The gasifier pressures selected for this study are 600, 800 and 1200 psig. The 600 psig case favors the oxygen compressors, while the 1200 psig case favors the hydrogen compressors. It should be pointed out, however, that available commercial oxygen compressors of two-casing design are limited to a maximum discharge pressure of about 950 psig. They are suitable for use with the 600 and 800 psig cases. For the 1200 psig case, an oxygen compressor discharge pressure of about 1400 psig will be necessary. This will require a three-casing oxygen compressor which has gone through pilot operation but has not yet been commercialized.

Besides oxygen and hydrogen compression, gasifier pressure also affects the relative equipment costs and utility production/consumption rates of the CO shift conversion and acid gas removal systems. It also determines the capacity of a gasifier or the number of gasifiers required for a given syngas production rate.

From Table V-I in Section V it is seen that the plant investment costs for the three pressures, Cases 1A, 2 and 3, are very close to one another, with the 800 psig case showing a very small cost advantage. Table VI-2 in Section VI shows that the three cases are essentially a standoff in estimated annual operating costs.

The results of this study indicate that the plant investment and operating costs are insensitive to variations in operating pressure. The 800 psig gasifier pressure case is recommended because this pressure is within the reach of commercially available oxygen compressors and appears to result in minimum product cost.

Rationale for the Low H_2S Content in Selexol Regenerator Off-Gas

The H_2S recovered from the Selexol Regenerator of the hydrogen plant is sent to the SRC-II plant for sulfur recovery. It is first mixed with the H_2S -bearing streams from the coal liquefaction plant before feeding to the Claus plant. For a Claus plant of the split-flow design in which one third of the feed H_2S is burned to SO_2 to react with the rest of H_2S to produce sulfur, it is necessary to have a minimum H_2S content of about 20 mol % in the feed gas.

Based on Forth Lewis test results, it was estimated that the total H_2S in the feed streams from the SRC-II plant to the Claus plant was about 2.0 times the H_2S in the gas generated from the residues. Also from Fort Lewis tests, the concentration of H_2S in the combined feed stream from the SRC-II plant was about 70 mol %. From these data it was calculated that the concentration of H_2S in the Selexol regenerator off-gas must be about 8 mol % in order to give the desired 20 mol % H_2S in the final gas mixture fed to the Claus plant.

VIII. CONCLUSIONS

Based on tests for the gasification of SRC-II residues from Kentucky 9/14 coals, which were conducted at the Montebello Research Laboratory, we conclude the following:

- The Texaco Synthesis Gas Generation process is suitable for producing synthesis gas from the SRC-II coal liquefaction residue. However, due to the short duration of the tests, the lives of refractory and burner remain to be defined.
- Because of the simple Texaco Gasifier design and the close control of its operating variables that was obtained smooth trouble-free operation of the Gasifier can be achieved. The fact that the SRC-II residue can be pumped to the Gasifier as a molten slurry is a contributing factor to the smooth operation.
- A conversion of 99% of carbon to syngas can be achieved by close control of the operating variables.

Based on Texaco test results, flowsheets were prepared for hydrogen production at gasifier pressures of 600, 800 and 1200 psig. We conclude as follows:

- The effect of pressure on the total plant investment and operating costs is minor within the range of 600 to 1200 psig. However, the cost at 800 psig appears to be optimum.

- Operation of the Texaco gasifier at 800 psig is further recommended because this pressure is about the maximum that can be accommodated by use of existing, commercially available, two-casing oxygen compressors.
- A physical absorption process (Selexol) is more economical than a chemical process (Benfield) for accomplishing acid gas removal at operating pressures as low as 600 psig. Higher operating pressures are even more favorable for the Selexol process.