the size of the CO_2 removal facilities. The most important difference, however, is the replacement of the large EG power plant with the large OG oxygen plant, Several economic analyses indicate a lower product gas cost when electrothermal gasification is replaced by steam-oxygen or steam-iron gasification. Steam-oxygen gasification now is a more practical route to commercial coal gasification plants, and steam-iron may ultimately prove the most attractive of the three hydrogen processes.

8.7.1.2 Pretreatment

The coal pretreatment step destroys the caking properties inherent in some bituminous coals. This prevents serious solids-handling problems from developing as the coal is heated to the initial gasification temperature.

The capital cost of low-pressure pretreatment is not only expensive, but, during this processing step, about 10% of the feed coal is converted into heat and low-quality tars and oils and a very low-heating-value off-gas. The economics and process efficiency will be substantially improved if alternatives to low-pressure pretreatment can be devised. One alternative investigated at IGT on a laboratory scale is the blending of coal with partially gasified char before heating. The success of these tests indicate that perhaps coal can be raised to reaction temperature without serious agglomeration problems occurring. Such a blending system is installed in the HYGAS pilot plant, where the concept will be tested on a large scale. If successful, untreated caking coal can be fed directly into the gasification reactor and its whole carbon content will contribute directly to the pipeline gas product.

8.7.1.3 Improved Catalysts

Development of improved catalysts for both shift conversion and methanation reactions will simplify the coal gasification process. Desirable characteristics in the shift catalyst are numerous. The catalyst's activity should not be impaired by H_2S contained in the feed gas or by light aromatic oil vapors when present at up to 10% concentration. A regenerable catalyst widens the range of acceptable feed gas constituents. If the catalyst is effective in the hydrogenation of cyanides, phenols, and organic sulfur compounds, and in the dissociation of ammonia, important savings in waste treatment facilities can be obtained. Promotion of a limited amount of methanation by the shift catalyst will simplify the methanation step and reduce process costs.

We believe that the most practical means of performing the methanation reaction is over a catalyst contained in a fixed bed. An improved methanation catalyst should accept hydrogen sulfide in the feed gas at concentrations up to 10 ppm without serious reduction in activity. This improvement will afford savings in the preceding gas cleanup step.

An even more important improvement, however, is a methanation catalyst which retains its activity at temperatures well above the 900°F, at which catalysts currently being used are limited. The aim is to feed high-CO-content gas, containing no recycle, directly to the catalyst. Maximum reactor temperatures will increase until equilibrium is approached. The hot gases are cooled and fed into subsequent reactor stages until the desired CO conversion is obtained. The high-temperature catalyst allows recovery of the exothermic heat of reaction at more usable temperature levels. Furthermore, by eliminating the need for gas recycle, the methanation reactors are smaller and require less catalyst.

8.7.1.4 Acid-Gas Removal

A one-step selective sulfur removal process preferably produces elemental sulfur from the absorbed H_2S to avoid the complications of a Claus plant and Claus plant tail gas treatment. Commercial processes are now available which can perform this sulfur removal step. They require high liquid flow rates for scrubbing and, therefore, are not now considered economical when applied to 1000-psi systems. With improvements in existing processes or by development of new removal processes, improved economics may be obtained.

Removal of CO_2 before methanation may not be necessary. Methanation reaction investigators have shown that carbon monoxide is reacted to very low levels before much carbon dioxide methanation takes place. The presence of CO_2 in the methanation feed gas reduces the amount of recycle gas needed and consumes excess hydrogen, thus increasing product gas heating value. When the Rectisol process is used for CO_2 removal, half of the ethane is absorbed from the gas and produced in the CO_2-rich stream. By methanating first, ethane is converted to methane in the methanator before the scrubbing step and is not lost. By scrubbing after methanation, the CO_2 concentration is about 40% instead of 26% before methanation, thus permitting more economical CO_2 removal when using present day technology.

In summarizing, the following benefits can be obtained when CO_2 removal occurs after methanation:

1. Ethane is retained in the product gas as additional methane.

2. Less recycle is needed for methanation.

3. Excess hydrogen in the methanator reacts with CO_2 to form methane and thereby increases the produce gas heating value.

4. The higher CO_2 concentration at the CO_2 scrubber decreases CO_2 removal costs.

5. A separate gas-drying step may not be needed because many CO_2 removal solvents also dry the gas.

8.7.1.5 Clean Fuel for Boilers

When sulfur-containing fuels such as electrothermal gasifier char or raw coal are used as boiler fuels, the generation of low-Btu gas from these solids should be seriously considered. This gas is cleaned of sulfur before combustion. By incorporating low-Btu gasification with power generation by combined gas turbines-steam turbines, the potential for decreased power generation cost at greater efficiency may result in the benefits of electrothermal gasification outweighing those of steam-oxygen gasification. Initial low-Btu gasification development is now under way, and a practical system for power generation will be demonstrated within another few years.

8.7.1.6 Total Water Recycle

The indicated high rate of water use may cause siting problems for some coal gasification plants in the western states. By providing for total recycle of treated waste water in this demonstration plant design, fresh water makeup to the plant will decrease to 4800 gal/min. Of this amount, 3200 gal/min represents cooling tower evaporation. An overall improvement in process efficiency will decrease this consumption.

A boiler design is needed that accepts condensed process water as boiler feedwater even when the process water contains traces of phenols, acid gases, and oils. By generating high-pressure process steam from this water, the water can be chemically consumed in the coal gasifier and in shift conversion. Decreased water makeup is obtained as well as decreased requirement for waste-water treatment.

8.7.1.7 Ammonia

Ammonia appearing in the raw gas is an annoying problem. It must be recovered and disposed of acceptably. Unfortunately, its recovery and production is more costly than its product value. A desirable solution would be a simple system to convert the ammonia to its elements — perhaps in the shift conversion reactor.

8.7.2 Mechanical Design Improvements

8.7.2.1 Gasifier Vessel

The proposed gasifier design is a double-walled vessel containing a water jacket in which steam is generated at a pressure which is balanced with the intended vessel pressure. The advantages of this design are —

- The pressure shell is external and is at the boiling water temperature, about 570 °F: it can be fabricated of carbon steel.

- Steam condensation behing the internal refractory is prevented because the refractory "cold" temperature is above the steam dew point.

- The inner vessel wall requires less alloy steel.

- If the internal refractory fails, there is less chance of catastrophic vessel failure because of the cooling of the water jacket.

This design is complicated and costly and may be difficult to field fabricate satisfactorily. A single-wall, internally insulated vessel is a method of construction that has much appeal. The problem, of course, is how does one safely contain a process which operates at temperatures to 1900 °F and pressures to 1500 psig. If the simpler single-wall design substitutes for the double-wall design, the single-wall vessel's performance should match the advantages of the double wall.

8.7.2.2 Dry Feed System

The slurry feed system is used to provide a reliable means of introducing the large volume of coal into the high-pressure gasifier. However, the reliability is obtained by adding complicating process features. These include the slurry feed system, the light oil vaporizer, the elaborate raw-gas quench section, the chilled quench section, the oil stabilization section, and the char slurrying section. In addition, the slurry is dried using high-temperature sensible heat contained in gas from the low-temperature reactor. The 600°F temperature of gas exiting from the light oil vaporizer greatly increases the difficulty in usefully recovering the large amount of heat carried by the gas. Without slurry feed, the gas effluent temperature would be about 1200°F.

By using a dry feed system such as lock hoppers, the complications of slurry feeding could be avoided and efficient heat recovery from reactor gas becomes possible. The reason lock hoppers have not been used is because, first, the lock hopper valves are not believed to be reliable at the high-pressure differential involved. These valves pass the dry, dusty, abrasive solid from the hopper into the gasifier, and must operate reliably through a great many cycles. Nearly leak-free operation is required. Second, the power requirement to recompress the lock hopper gas is considerable. If a reliable and economical dry feed system can be demonstrated which will operate from atmospheric pressure to 1200 psig, it could replace the slurry feed system that is now proposed.

8.7.2.3 Coal Crushing

Coal to the fluidized-bed gasifier should be crushed to a size finer than 4 mesh. However, the fraction finer than 100 mesh should be minimal to reduce dust carry-over from the reactor. Although many manufacturers were contacted during the demonstration plant design, we felt that the crushing machinery offered generated excessive amounts of −100 mesh fines. Perhaps improved crushing machinery designs may reduce the production of fines while crushing coal to the desired top size.

8.8 Conclusions

The preliminary design for a HYGAS coal hydrogasification demonstration plant emphasizes several areas which need further attention in either research or in process or equipment development. These include:

1. Develop crushing machinery which produces fewer −100 mesh fines when crushing to 100% −4 mesh.

2. Seek a more economical process for coal pretreatment.

3. Identify reliable methods of introducing dry coal feed into high-pressure systems.

4. Develop basic data in high-pressure fluidization technology and develop devices for control of fluid solids flow at high pressures and temperatures.

5. Improve the mechanical design of gasifier vessels which contain pressures up to 1500 psi and temperatures up to 2000°F.

6. Develop gas-solids separators which are efficient at high pressures and temperatures.

7. Find an improved shift conversion catalyst which retains high activity in the presence of sulfur and aromatic-vapor-containing gas streams. Some methanation activity is desirable. The shift catalyst should be effective in hydrogenating sulfur compounds, cyanides, and phenols.

8. Develop process boilers capable of accepting condensate water from the process which contains trace amounts of ammonia, phenol, and cyanides.

9. Develop an efficient selective hydrogen sulfide removal process for high-pressure systems which produces an elemental sulfur product.

10. Develop an improved carbon dioxide removal process which uses a solvent with greater acid-gas capacity and improved selectivity.

11. Develop a methanation catalyst which will retain its high activity even when subjected to temperatures up to 1600°F for long periods. The catalyst's activity should be unaffected by feed sulfur contents up to 10 ppm.

12. Develop a more efficient process for power generation from solid fuels, one that does not rely on stack-gas cleaning for control of polluting emissions.

As any of the improvements discussed becomes available, the cost and complexity of coal gasification plants will decrease. Even without these improvements, the HYGAS demonstration plant design shows that it is feasible to design large-scale plants for hydrogasification of coal to pipeline-quality gas, with new American approaches to gasification, coupled with existing technology.

APPENDIX 8-A

Volume I

of the

Preliminary Engineering Study
HYGAS Demonstration Plant

by

Procon, Inc.,
A Subsidiary of UOP

Procon Note

This book contains an Introduction section with plant block flow diagrams, and a Summary of the Phase II Report, and Budget Estimate. It also includes sections covering Basic Engineering Design Data, Reactor Design, Process Units Design, Waste Treatment, Utilities, Plot Plans, a Project Schedule, and a Plant Manning Estimate.

Editor's Note

This Appendix 8-A contains all material from the Procon Volume I with the following exceptions:

- Streams data, materials balances, process flow diagrams and other illustrations which are deleted here; however, this material appears in the body of this Part VIII of the IGT HYGAS Final Report covering work performed for OCR under Contract No. 14-01-0001-381 and the contract amendments No. 14-01-0001-381(1) (June 1967) and No. 14-01-0001-381(2) (March 1972).

Pagination

Procon's original numbering, where used, has been retained above the pagination of the present OCR report.

REPORT FOR

PHASE II - PRELIMINARY DESIGN REPORT

AND

BUDGET INVESTMENT ESTIMATE

PRELIMINARY ENGINEERING STUDY

HYGAS® DEMONSTRATION PLANT

FOR

Institute of Gas Technology

3424 South State Street

IIT Center

Chicago, Illinois 60616

IGT Job No. 6063

Procon Job. No. W-1843

PROCON Incorporated
A Subsidiary of
Universal Oil Products Company
30 UOP Plaza
Algonquin & Mt. Prospect Roads
Des Plaines, Illinois 60016

April 3, 1972

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INTRODUCTION

A. BACKGROUND

A contract signed in December, 1969 between the Institute of Gas Technology and Procon Incorporated, authorizes Procon to perform a Preliminary Engineering Study for an industrial prototype, or Demonstration Coal Gasification Plant. The design of this plant is to be based on the IGT HYGAS® process.

The study is divided into three parts, as follows:

- Phase I - Conceptual Design
- Phase II - Preliminary Design Report and Budget Investment Estimate
- Phase III - Revised Preliminary Design Report, Based on IGT-OCR-AGA Pilot Plant Operations.

I. PHASE I REPORT

A report entitled Phase I - CONCEPTUAL DESIGN, PRELIMINARY ENGINEERING STUDY, HYGAS® DEMONSTRATION PLANT, was issued dated March 15, 1971. The design covered in the Phase I Report was the result of a considerable amount of engineering and design work, including the evaluation of numerous process arrangements and technologies. The report presented a conceptual process design for the IGT HYGAS® coal gasification plant which was considered optimum at that time.

However, several major changes have been made in the process design from that covered in the Phase I Report.

The process design covered in the Phase I Report is still valid although the design covered in the Phase II Report includes several improvements.

B. PHASE II REPORT

This report covers PHASE II - THE PRELIMINARY DESIGN REPORT AND BUDGET INVESTMENT ESTIMATE for the Preliminary Engineering Study.

There were several process technologies still being investigated at the time the Phase I Report was issued and as a result of this continuing process investigation, there have been several major changes in the plant process design from that described in the Phase I Report. These changes have improved the process technology, and reduced the capital cost.

These changes are primarily in the coal pretreatment section, Unit 1300, and in the gas treatment sections, Units 2100 through 2900, following the HYDROGASIFICATION REACTOR. These revisions involve the use of a new shift conversion process (Unit 2400) using a catalyst manufactured by BADISCHE ANILIN-and SODA-FABRIK AG, and a change to the LINDE AG "RECTISOL" gas purification process (Units 2600 and 3600) for CO_2 and H_2S acid gas removal from the product gas. This has caused a major rearrangement in the gas cleanup and purification units. Data for the BASF shift conversion catalyst, and the LINDE "RECTISOL" process is proprietary, and therefore detailed information is necessarily omitted from this report.

In addition to the above, information is included in this Phase II Report which was not covered in the Phase I Report. This includes sections on the design of the HYDROGASIFICATION REACTOR and its ELECTROTHERMAL GASIFIER unit, WASTE TREATMENT METHODS, a PLOT PLAN, a BAR CHART PROJECT SCHEDULE, a PLANT MANNING ESTIMATE, and a BUDGET INVESTMENT ESTIMATE.

This report is intended to be used as a preliminary design manual which can serve as the basis for the final design and detailed engineering for construction of a Demonstration Coal Gasification Plant.

C. OBJECTIVES OF STUDY

The purpose of this Preliminary Engineering Study is to serve as a basis for establishing the process design, capacity, physical configuration, delivery time, and cost for an industrial prototype, or Demonstration Coal Gasification Plant based on the IGT HYGAS® process.

The largest feasible, single train, initial Demonstration Plant unit, with some provisions for expansion to an ultimate plant with a capacity of 250 MM SCFD of pipeline gas, was determined during Phase I of the study. This work set the capacity of the Demonstration Plant at 80 MM SCFD which is considered the maximum feasible capacity of a single reactor.

The project has provided an opportunity to review and compare numerous alternative processing techniques, and operating sequences.

The study has resulted in this preliminary design manual, which can be revised or reworked based on knowledge acquired from operation of the IGT Pilot Plant, which is in the process of initial start-up and operation. This Preliminary Design Report and Budget Investment Estimate can serve as the basis for a final design to be used for the detailed engineering and procurement of equipment and material for the Demonstration Plant.

It is believed that this Preliminary Engineering Study will allow a minimum saving in time of from 10 to 14 months in the availability of a final design for a Demonstration Coal Gasification Plant.

D. CONTRACT REQUIREMENTS

The basic contract requirements for this study are listed below:

Scope of Work

The scope of work shall be as follows:

Phase I - Scope of Study (Conceptual Design)

A. Hydrogasification Reactor System.

B. Optimization of maximum size unit systems included in Gasification Train.

C. Site selection (by others) or establishment of site criteria.

D. General Study Plan - to include flow sheets that show the units (systems) in their processing sequence, the rate and composition of raw material and product flows, the rate and composition of flows between units (systems) and complete heat and material balances for the plant. This study shall reasonably represent the client's optimum processing technique and sequence.

Phase II - Preliminary Design Report and Budget Estimate

This shall include:

A. Process system description.

B. Support facilities description.

C. Process system flow diagrams.

D. Preliminary piping and instrument diagrams (less line sizing except critical lines).

E. Utility requirements and single line diagrams.

F. Process equipment data sheets (preliminary).

G. Equipment lists and description (less exchanger details).

H. Preliminary plot plans and equipment layout sketches.

I. Site criteria.

J. Bar chart project schedule; to cover engineering, material delivery and construction.

K. Plant manning estimate.

L. Budget type capital estimate.

Phase III - Revised Preliminary Design Report - Revisions based upon actual operation data available from IGT-OCR-AGA Pilot Plant Operations.

A. Hydrogasification system and related systems.

B. Electrogasification system and related systems.

NOTE: By mutual agreement between IGT and Procon, no work will be done on Phase III until significant operating experience has been obtained from the HYGAS® plant.

The plant design criteria will provide for expansion of the initial Demonstration Plant to an ultimate plant of 250 million cubic feet per day capacity.

E. BASIC CRITERIA & ASSUMPTIONS AFFECTING PLANT DESIGN

1. COAL USED

This study is based on the use of a bituminous coal with the following ultimate analysis (dry basis):

	Feed (Wt.%)	Pretreater Pretreated Char (Wt.%)
Carbon	71.50	71.34
Hydrogen	5.02	4.02
Sulfur	4.42	3.83
Nitrogen	1.23	1.00
Oxygen	6.53	7.51
Ash	11.30	12.30
Total	100.00	100.00

Heating Value: 13,186 BTU/LB Dry Coal (HHV)
12,670 BTU/LB (LHV)

2. PLANT CAPACITY

The initial Demonstration Plant will be the largest feasible single train plant. This has been set during Phase I of the study at 80 MM SCFD. Provisions (as required) will be made for expansion to an ultimate plant with a capacity of approximately 250 MM SCFD.

3. OTHER BASIC CRITERIA

a. The plant will be a coal "mine mouth" plant, using "unwashed" and "untreated" coal, as a basic assumption. The extent of impurities in the coal, particularly rock and dirt, will probably determine whether coal washing or other pretreatment is required. Operating experience from the Pilot Plant will no doubt help in making this decision.

b. Coal requirements for the ultimate plant of 250 MM SCFD capacity, with a 20-year production life will approximate 100 million tons of bituminous coal. The coal can be furnished from a strip mine, or from a below ground type mine.

c. Although the plant will be designed to minimize water requirements, river (or other) water will be available for cooling water make-up.

d. The plant will be designed to make maximum use of air cooling, especially in the process sections to minimize cooling water requirements. The power plant will utilize cooling towers.

e. An "on-site" Power Plant will generate the power for the Electrothermal Gasifier Unit. The DC power requirements for the Electrothermal Gasifier Unit will be obtained from an AC power conditioning (rectification) unit. Other plant electrical requirements will be supplied with purchased power, for this study.

f. The plant design will utilize available waste heat from the process as much as possible to provide the maximum efficiency.

g. A site location on a navigable waterway will expedite shipment of the large reactor sections, allow more shop fabrication of large equipment, and reduce field erection time, and overall cost.

An inland site will require suitable access by road. A road for delivery of large equipment should be at least 12-14 feet wide, without excessively sharp turns, and if there are any bridges they must be suitable for carrying heavy loads.

A railway siding serving the plant would be very helpful during construction, and for later plant operation.

h. No particular shape of the site is required, although something approaching a rectangular area would probably be best and allow more economical spacing of units.

A total area of at least 200-250 acres will be required.

F. UNIT NUMBERING SYSTEM FOR PLANT AREAS

In order to identify units of the plant, and for later equipment identification, the following unit numbering system has been used for the various plant areas. The process function and equipment included is also described for each plant unit.

1000 Series: PROCESS SOLIDS HANDLING UNITS

Unit No.	Name	Description
1100	Coal Handling	Coal receiving, breakers and classification, coal storage including handling equipment to storage and reclamation, and delivery to coal preparation.
1200	Coal Preparation	Coal grinding, preparation and delivery to pretreatment.
1300	Coal Pretreatment	Coal feed storage, feed facilities, flash drying, pretreatment vessel, char cooling and storage vessels, air blower, start-up heater, off-gas treatment facilities, and inert gas compression facilities.
1400	Char Feed Preparation	Char feed storage, mix tanks, slurry oil facilities, recirculation and slurry feed pumps.
1500	Reactor Section	Reactor vessel, foundation and structure.
1600	Char Recovery	Char recovery and pressure letdown equipment.

2000 Series: PROCESS GAS TREATMENT UNITS

Unit No.	Name	Description
2100	Raw Gas Quench	Raw gas oil quench.
2200	--	Not used.
2300	--	Not used.
2400	Shift Conversion	Equipment for the catalytic reaction of carbon monoxide with steam to produce hydrogen.
2500	Ammonia Scrub & Gas Preconditioning	Equipment for water scrubbing & chilling of gas to remove ammonia & reduce the oil content.
2600	Methanol Scrub (Rectisol)	Equipment for "Rectisol" methanol scrub.
2700	Sulfur Clean-up Guard Beds	Fixed bed treatment, hydrogen sulfide clean-up.
2800	Methanation Section	Equipment for the catalytic reaction of carbon monoxide with hydrogen to produce methane.
2900	Product Gas Drying	Gas drying with conventional ethylene glycol system.

3000 Series: AUXILIARY UNITS TO THE GAS TREATMENT UNITS

Unit No.	Name	Description
3100	Oil Stabilization & Scavenge Gas Compression	Equipment for light oil stabilization and scavenge gas compression.
3200	Claus Sulfur Plant	Split-flow type modified Claus oxidation of hydrogen sulfide to sulfur.
3300	--	Not used.
3400	--	Not used.

3000 Series (continued)

Unit No.	Name	Description
3500	Ammonia Separation (Phosam)	Stripping of volatile gases from foul water, phosphoric acid scrubbing of acid gas stream, stripping, and dehydration of ammonia.
3600	Acid Gas Stripping (Rectisol)	Equipment for "Rectisol" methanol CO_2 stripping, methanol H_2S stripping, and dehydration.

4000 Series: WASTE TREATMENT UNITS

Unit No.	Name	Description
4100	Power Plant Stack Gas Scrubbing	Equipment for scrubbing the power plant boiler stack gas.
4200	--	Not Used.
4300	Incineration & Tail Gas Treatment	Equipment for incinerating and scrubbing the Claus sulfur recovery plant tail-gas effluent.
4400	Limestone Slurry Supply	Equipment for limestone grinding, slurrying, pumping, and gypsum disposal.
4500	Foul Water Disposal	Equipment for treating the various plant foul water effluents.
4600	--	Not Used.
4700	Spent Catalyst Disposal	Handling facilities for disposing miscellaneous solid waste materials.
4800	Ash Handling	Equipment for handling the power plant bottom ash and fly ash.

5000 Series: UTILITIES

Unit No.	Name	Description
5100	Power Plant	Boiler(s) and generating unit(s), coal & char handling facilities, boiler feed pumps, and auxiliaries.
5200	Water Treatment	Water treatment including boiler demineralization equipment, cooling tower water treatment, pumps and accessories.
5300	Cooling Towers	Cooling towers, pumps and accessories.
5400	Electrical Substation	Transformers and switchgear for generator output and distribution.
5500	Power Conditioning for "EG" Unit	AC power rectification, transformers, and accessories.
5600	Refrigeration	Refrigeration equipment for "Rectisol" process, ammonia scrubbing, and other plant requirements.
5700	Inert Gas Generator	Inert gas for purging, blanketing, etc.

6000 Series: ELECTRIC POWER DISTRIBUTION

Unit No.	Name	Description
6100	Electric Power Distribution	Substations, switchgear and cabling not located at power plant or operating unit.

7000 Series: YARD LINES AND TANKS

Unit No.	Name	Description
7100	Yard Lines & Tanks	Steam, water, and boiler feedwater distributing piping, sewers, instrument air lines, gas lines, product and by-product lines between non-continuous units, to and from storage, or to product delivery manifold; and all storage tanks.

8000 Series: OFF-SITES

Unit No.	Name	Description
8100	Off-Sites	Roads, bridges, fences, and buildings, mobile equipment.
8200	Sewage Disposal	Equipment and facilities for sewage treatment.

9000 Series: BUILDINGS

Unit No.	Name	Description
9100	Buildings	Control house(s), electrical distribution, switch houses, administration building, étc.

G. PLANT BLOCK FLOW DIAGRAM

Drawing #1843-1.00-1G is a block flow diagram which shows the plant units in their processing sequence.

The units, and applicable data, are shown in greater detail on the drawings listed below and on the process flow and P & I diagrams included in the process sections of this report.

H. BLOCK FLOW MATERIAL BALANCE
SOLIDS HANDLING UNITS

Drawing #1843-1.00-2G is a block flow diagram which shows the weight and material flows between plant units, for the solids handling units of the plant (Units 1100-1600, essentially).

I. BLOCK FLOW DIAGRAM & MATERIAL BALANCE
GAS TREATMENT UNITS

Drawing #1843-1.00-3G is a block flow diagram which together with the material balance sheet shows the weight and material flows between plant units, for the gas treatment units of the plant (Units 2100-2900, 3100, 3200, 3500, and 3600, essentially).

J. BLOCK FLOW MATERIAL BALANCE
UTILITIES & MISCELLANEOUS

Drawing #1843-1.00-4G is a block flow diagram which shows some of the weight and material flows between plant units for the utilities and miscellaneous units of the plant (Units 4100-4400, and 5100, essentially).

K. DRAWING NUMBERS & TITLES

Drawing No.	Unit No.	Title	Section/Unit
1843-1.00-1G	-	Block Flow Diagram	I
1843-1.00-2G	-	Block Flow Material Balance Solids Handling Units	I
1843-1.00-3G	-	Block Flow Diagram Gas Treatment Units	I
1843-1.00-4G	-	Block Flow Material Balance Utilities & Miscellaneous	I
-	-	Reactor for Coal Gasification	IV
1843-11.00-1G	1100 & 1200	Coal Handling & Coal Preparation	V-1100
1843-13.00-1G 1843-13.00-2G	1300	Coal Pretreatment	V-1300
1843-14.00-1G	1400	Char Feed Preparation	V-1400
1843-15.00-1G	1500	Reactor Section	V-1500
1843-16.00-1G	1600	Char Recovery	V-1600
1843-21.00-1G	2100	Raw Gas Quench	V-2100
1843-24.00-1G	2400	Shift Conversion	V-2400
1843-25.00-1G	2500	Ammonia Scrub & Gas Preconditioning	V-2500
1843-26.00-3G	2600	Methanol Scrub (Rectisol)	V-2600
1843-27.00-1G	2700	Sulfur Cleanup Guard Beds	V-2700
1843-28.00-1G	2800	Methanation Section	V-2800
1843-29.00-1G	2900	Product Gas Drying	V-2900
1843-31.00-1G	3100	Oil Stabilization & Scavenge Gas Compression	V-3100
1843-32.00-1G	3200	Sulfur Recovery	V-3200
1843-35.00-4G	3500	Ammonia Separation & Acid Gas Removal	V-3500
1843-36.00-7G	3600	Acid Gas Stripping (Rectisol)	V-3600
1843-51.00-1G	5100	Steam & Water Utilities	VII-5100
1843-56.00-1G	5600	Refrigeration	VII-5600
1843-1.01-1F	-	Proposed Site Plan	X
1843-1.01-2F	-	Proposed Plot Plan, Process Area	X

SUMMARY - PHASE II REPORT

A. STATUS OF STUDY AND BUDGET ESTIMATE

The complete preliminary engineering design of an 80 MM SCFD Demonstration Coal Gasification Plant using the HYGAS® process is presented in this report. The basic design for auxiliaries such as waste treatment facilities and steam, electric, and water utilities are also included. A budget-type capital cost estimate has been made, and is presented in detail in the budget estimate volume of this report. The estimate shows a capital cost of $62,000,000 for the Process Units, from receipt of coal to pipeline gas, but exclusive of waste treatment, steam, electric power, and cooling water supplies. The entire plant cost including the major utilities, engineering, and all other charges is estimated to be $171,000,000.

Summary sheets covering the budget estimate for the complete plant follow this Summary of the Phase II Report.

The design and cost estimate are considered to be conservative. Most items of major equipment have been priced by equipment vendors. Operating data from the pilot plant may alter these cost estimates, particularly in the area of the main Hydrogasification Reactor, and the Electrothermal Gasifier Unit.

B. COAL HANDLING AND PRETREATMENT

The coal handling system, including the conveyors, stacking, coal pile, reclaiming, and grinding operations for handling the incoming run-of-mine coal are fairly standard. No discussion is necessary here.

The pretreater reactor is a fluidized bed vessel, operating at 20 PSIG. It is the second largest single vessel in the coal gasification train; 35' - 6" ID by 45' TT. The purpose of pretreatment is to oxidize raw bituminous coal to destroy its agglomerating tendency, and to facilitate later handling. Air is the oxidizing reagent. The "off-gas" from the pretreatment operation contains some fuel value, (39 BTU per cu. ft. after quenching) which is utilized in the power plant. Approximately 290,000 lbs/hr of 250 PSIG saturated steam is generated in the pretreater reactor. This steam, with an additional 37,000 lbs/hr of saturated steam from other sources, is superheated to 456^{O}F in the pretreater reactor. The coal solids from the pretreater are called "char". After cooling the char is mixed with recycled oil to produce a slurry for pumping to the gasification reactor.

Sub-bituminous coals, and lignite, do not require pretreatment prior to gasification.

C. THE HYDROGASIFICATION REACTOR

Considerable study and thought have been devoted to the mechanical design of the hydrogasification reactor. Although several designs have been proposed, for the sake of brevity only one of these designs is described in this report. Other arrangements, involving multiple vessels in series and in parallel, are under consideration, but will not be discussed in this report. This report describes a single shell reactor containing four fluidized beds.

The size of the reactor is impressive; 24 feet in diameter by 240 feet tall, including skirt. The reactor weighs approximately 2750 tons. Naturally, a vessel of this size will have to be fabricated in the field. It will require 33 months to build, and cost about $14,000,000.

The reactor will generate 200 million cubic feet per day of raw gas, which becomes, after downstream processing, 80 MM SCFD of product gas. The reactor is fed 183 tons per hour of pretreated char, equivalent to 204 tons per hour of raw coal. This reactor size, which is considered the largest feasible single reactor vessel, establishes the size of all other equipment in the initial train of the Demonstration Plant. (All other major equipment except the pretreater reactor can be shop fabricated.) Later, two more identical trains may be added at the same location to give an ultimate plant capacity of 250 MM SCFD (nominal). The full size plant will consume 16,488 tons per day of raw coal, a figure considered feasible for the output of a single mine with reserves of at least twenty years.

The reactor contains four fluidized beds, through which the char flows downward in series, in counter-flow to ascending steam and gas. All beds operate at high pressure, 1200 to 1250 PSIG.

The beds, from top to bottom, are:

	Function	Char Residence Time	Temperature
1.	Slurry Oil Evaporation	10 Minutes	600°F
2.	First Gasification Stage	10 Seconds	1200°F
3.	Second Gasification Stage	85 Minutes	1750°F
4.	Electrothermal Gasification	20 Minutes	1900°F

The bottom two beds are surrounded by a pressurized-water jacket which generates steam at 1250 PSIG.

Power requirements for the Electrothermal Gasifier (EG Unit) are estimated at 110,000 kilowatts. This power is supplied as DC at 12,500-13,000 volts and 8,400-8,800 amperes. A single cathode will enter through the bottom head of the reactor. The anode will be a metal liner shrouding the inner surface of the EG zone electrically connected to the pressure shell and to ground.

Solids feed to, and discharge from, this high pressure reactor pose real challenges to materials handling technology. Lock hoppers have been considered for both services, but no designs with commercial operating experience at such extreme conditions are available.

The solids feed will be in the form of an oil slurry, of 33% by weight concentration. High-pressure reciprocating coal slurry pumps are in successful operation today and a pump of the same manufacture will be used for the HYGAS ® Plant.

The solid product discharged from the bottom of the Electrothermal Gasifier zone, is called "Spent Char" rather than "Ash", since it contains a residual carbon content of 58 percent by weight and is used as the principal fuel for the power plant. The spent char is slurried in water and depressurized through four throttling valves in series. Interstage cooling is achieved by flashing water vapor. Because the throttling valves are expected to wear rapidly duplicates are installed in each service, with block valves upstream and downstream so that the throttling valves can be replaced without reactor shutdown.

D. GAS PROCESSING FROM REACTOR TO PIPELINE

Modern commercially-proven gas technology has been selected for this coal gasification plant design wherever possible. Three of the process operations are proprietary and are available through license. It is felt that the overall process design is completely operable, and practical, and represents the optimum design that can be furnished today.

Several gas treatment areas deserve special mention.

a. Unit 2100 - Raw Gas Quench

The design of the quench system takes advantage of a unique feature of the HYGAS ® process. The heavy loading of slurry oil (oil used as a medium for charging feed to the Reactor) in the raw gas from the Reactor permits collection of tars in manageable form. The oil condensate is used to cool the raw gas leaving the Reactor at 600°F. Slurry oil is generated in the process, but the amount recirculated between the slurry mix tank (Item 14.06-41) and the quench nozzle (Item 21.22-01) greatly exceeds the amount generated. Special attention has been made in the design to prevent the collection of dust, and buildup of tars. The raw gas will not be exposed to cool metal surfaces. Tar will be absorbed in the recirculated oil. Eventually, the tar in the recycled oil will reach an equilibrium between the amount carried down with the char, and the amount vaporized in the top of the reactor.

The second stage of Raw Gas Quench will be conducted by air cooling, but means will be provided for flushing the air fin fan coolers with light-weight oil condensate to wash out tars if such measures prove necessary.

b. <u>Unit 2400 - Shift Conversion</u>

The reaction between carbon monoxide and steam to produce hydrogen and carbon dioxide is well-known in chemical engineering. There is a wide choice of catalysts available to conduct this reaction. The Badische Anilin and Soda-Fabrik (BASF) catalyst K8-11 was chosen because it can withstand high partial pressures of water vapor, and moderate concentration of hydrogen sulfide and coal oils. Indeed it requires a certain minimum sulfide concentration to achieve shift conversion activity, inhibit the Boudouard reaction,* and suppress runaway methanation.**

The BASF shift conversion catalyst has been proven on commercial scale at Ludwigshafen, Germany, operating on a gas produced by partial oxidation of a reduced crude oil. The catalyst will be available by US manufacture on a straightforward purchase basis without process royalties or performance guarantees. Data for the BASF shift conversion catalyst are proprietary, and therefore detailed information is necessarily omitted from this report.

c. Unit 2500 - Ammonia Scrubbing and Gas Pre-Conditioning

This unit is merely an orderly assemblage of equipment necessary to chill the gas to 70°F, scrub out the ammonia to a residual level of 15 PPM, and condense water and residual oils. Solid ammonia carbonate deposits could cause trouble in downstream processing.

d. Units 2600 and 3600 - Sour Gas Sweetening

Thirty-three different processes were investigated to determine the best method of separating the acid

* $2CO \rightleftharpoons CO_2 + C$

** $CO + 3H_2 \longrightarrow CH_4 + H_2O$

gases, principally hydrogen sulfide and carbon dioxide, which contaminate the desired fuel gas ingredients. These sweetening processes can be grouped into five basic categories:

1. Inorganic alkaline salt absorption (e.g. hot potash scrubbing)
2. Organic alkaline salt absorption (e.g. ethanolamine scrubbing)
3. Physical solvent absorption (e.g. Rectisol, Sulfinol, Purisol, et al.)
4. Solid bed adsorption (e.g. iron oxide, molecular sieves)
5. Chemical reaction (oxidation to elemental sulfur)

These 33 processes were screened, and four were studied in detail. The Rectisol process, offered under license by Linde, A.G., was the final choice for this design. The Rectisol process uses a physical solvent, methanol. It is superior to all other processes in operating costs, selectivity (i.e. segregation of an H_2S-rich stream), product gas purity ($<$ 0.1 PPM H_2S, 0.15% CO_2) and CO_2 off-gas purity ($<$ 10 PPM H_2S).

The Rectisol process has been proven on commercial scale in five plants in Europe and two in the United States. Procon and IGT have received, under secrecy agreement with Linde, process designs for this HYGAS ® sized Rectisol system in sufficient detail to verify equipment sizes and estimate plant costs. The Rectisol process is proprietary and therefore detailed information cannot be published in this Phase II report.

e. Unit 2800 - Methanation

This unit is for conversion of carbon monoxide to methane by reaction with hydrogen.* This reaction raises combustion heat content of the product gas to 954 Btu/cu. ft. (HHV) which approaches that of natural gas, and reduces the carbon monoxide content to less than 1000 PPM.

In the absence of commercially-proven technology for methanation of rich gas (15% CO), this plant is designed with recycle of inert product gas to dilute the feed. Nickel-based catalysts are available from vendors to fill fixed bed adiabatic reactors.

f. Unit 3500 - Ammonia Separation

This unit incorporates a conventional sour water stripper and the PHOSAM process design of USS Engineers and Consultants, a subsidiary of U. S. Steel Corporation. As in the case of other proprietary processes, the design was furnished by the potential licensor to IGT and Procon under secrecy agreement, and only general outlines of the process can be sketched in this Phase II report.

* $CO + 3H_2 \longrightarrow CH_4 + H_2O$

E. UTILITY REQUIREMENTS (UNITS 5100, 5200, AND 5300)

1. Electrical Power

This study is based on an "in-plant" electrical facility of 110,000 KW capacity, it provides electric power for the "EG" Unit of the gasification reactor.

Electric power for other plant requirements, estimated at 40,000 KW, including start-up and emergency shutdown requirements, will be furnished from purchased power.

2. Process Steam

Steam will be generated from waste heat available in the various process units at 250 PSIG, and 50 PSIG. This steam will be used for various turbine drives, feedwater heating, and process requirements.

A high pressure boiler will also be furnished in the power plant to furnish process steam at 1250 PSIG, saturated and at 1000°F, for process requirements. Capacity of this boiler is 500,000 pounds per hour.

3. Water Requirements

Make-up water requirements for the plant are approximately 6500 GPM. This water has been assumed to be clean water, at 70°F or less, available at the battery limits at 35 PSIG.

F. Optimization of Plant Heat Balance

The HYGAS ® process, and associated char preparation, and gas purification processes provide sources of large quantities of low temperature heat. The potential quantities of this available process heat have not been utilized, as there is a practical limit to its use.

As much of this heat as possible has been used for boiler feedwater heating (except for the EG unit boiler).

The use of large quantities of low pressure steam for numerous small turbine drives is not considered economic.

Additional uses of this available process heat should be made the subject of further study, in order to improve the overall HYGAS ® process plant efficiency.

1.0 CUSTOMER

1.1 Client's Name — Institute of Gas Technology Preliminary Engineering Study HYGAS® Coal Gasification Plant

1.2 Project Location — No actual site has been selected.

2.0 PROJECT DESCRIPTION:

This project consists of a Preliminary Engineering Study for an initial unit, or Demonstration Coal Gasification Plant. This plant is to be capable of expansion into an ultimate plant with a capacity of 250 MM SCFD of pipeline gas.

3.0 FEED STOCKS

A Southern Illinois #6 Bituminous Coal has been used for design purposes. IGT has furnished an ultimate analysis for design as follows:

Carbon	71.5%
Hydrogen	5.02%
Sulfur	4.42%
Nitrogen	1.23%
Oxygen	6.53%
Ash	11.30%

Heating Value: 13,186 BTU/LB Dry Coal (HHV); 12,670 BTU/LB (LHV)

4.0 PRODUCTS

A synthetic gas equivalent to pipeline quality natural gas.

5.0 REMARKS

These BEDD Sheets are intended to define the Basic Engineering Design Data for a Coal Gasification Plant based on the IGT Process.

No actual site has been selected. In accordance with instructions from IGT, the design is based on a southern Illinois location.

1.0 SPECIFICATIONS

1.1 Process specifications are to be furnished by:

[X] Procon [X] Client [X] Licensor's

1.2 Engineering detail standards are to be furnished by:

[X] Procon [X] Client

2.0 CODES

All construction shall conform with the latest edition of the applicable sections of ASME, ASTM, NEC, ISA, API, TEMA, AISI, NEMA, AISA, ACI, AISC, JIC, IEEE, ANSI, UL, and other governing codes of standard practice. The following state or local codes, or laws, shall supplement the above:

2.1	Pressure Vessel	State of Illinois & ASME Section VIII
2.2	Boilers	State of Illinois & ASME Section I
2.3	Building and Structural	State of Illinois
2.4	Electrical	IEEE, ANSI, NEC, API-RP-500 & 540
2.5	Sanitary	State of Illinois
2.6	Aircraft Warning	State of Illinois & CAA
2.7	Safety	State of Illinois & U.S. Dept. of Labor
2.8	Water Pollution	State of Illinois & EPA
2.9	Air Pollution	State of Illinois & EPA
2.10	Noise	U.S. Dept. of Labor (Safety & Health Stds.)

3.0 REMARKS

The HYGAS® Process can be used on coal of any rank. Therefore a site location other than Illinois would only require revisions to meet the codes of another state.

Procon Incorporated
BASIC ENGINEERING DESIGN DATA

SCOPE OF WORK

PROJECT W-1843	
SHEET 3	OF 21
BY	
DATE	

1.0 ENGINEERING (STATE BY WHOM & DETAILS)

1.1	Process Design	By IGT & Procon Inc.
1.2	Detail Flow Charts	By Procon Inc.
1.3	Mechanical Design	By Procon Inc.
1.4	Licensed Process	Several are used
1.5	Area Plans & Topography	Clear & level site assumed
1.6	Soil Tests & Analysis	(None) 4000 PSF bearing assumed

2.0 SITE PREPARATION — Not included in study

3.0 SPECIAL & OFFSITE ITEMS

3.1	Field or Flare Stack	Flare Stack
3.2	Oil Water Separator, Type:	☐ API ☒ Other
3.3	Liquid Waste Disposal	Yes, methods are discussed.
3.4	Atmosphere Pollution Control	Yes, methods are discussed.
3.5	Noise Control	Yes, per State of Illinois & EPA Standards.
3.6	Fire Protection	Yes, per NFPA Standards.
3.7	Process Cooling:	☒ Air ☒ Water ☐ Other

Procon Incorporated **BASIC ENGINEERING DESIGN DATA** SCOPE OF WORK	**PROJECT** W-1843 **SHEET** 4 **OF** 21 **BY** **DATE**

4.0 AUXILIARY AND MAINTENANCE FACILITIES (Quantity, Location, Size, or Capacity)

4.1	Loading & Unloading	As Required
4.2	Tankage	As Required
4.3	Telephones	Complete plant telephone & audible paging system.
4.4	Roads, Fences, Parking, Gate or Guard House	As Required
4.5	Davits for	Access openings & equipment handling.
4.6	Monorails for	As Required
4.7	Trolleys for	As Required
4.8	Hoists for	As Required
4.9	Catalyst or Chemical Handling	As Required
4.10	Welding Outlets	Yes
4.11	Steam, Water, Air, Stations	Yes
4.12	Safety Showers & Baths	Yes
4.13	Valve & Instrument Access Platforms and Ladders	As Required

Procon Incorporated **BASIC ENGINEERING DESIGN DATA** UNIT ELEVATIONS	**PROJECT** W-1843 **SHEET** 5 **OF** 21 **BY** **DATE**

1.0 UNIT ELEVATIONS

1.1 Construction site is (assumed at) 500 feet above mean sea level.

1.2 Benchmark for this site is at actual elevation --

1.3 Plant elevation 100'-0" (Base Line) = actual elevation 500 Ft.

1.4 Low point of existing grade = plant elevation --

1.5 High point of existing grade = plant elevation --

1.6 High point finished surface (grade) = plant elevation 99'- 2"

1.7 Design frost line is 3.0 feet below high point of finished surface, at plant elevation 96'- 2"

1.8 Water table is -- feet below high point of finished surface, at plant elevation --

1.9 Finished top of vertical vessel foundations to be at plant elevation 100'- 0"

1.10 Finished top of pump foundations to be at plant elevation 100'- 6"

1.11 Finished top of building foundations and floors to be at plant elevation 100'- 0"

2.0 REMARKS

Plant base line elevation is 0'- 10" above high point of finished surface (grade).

1.0 CLIMATIC CONDITIONS

1.1 Direction of prevailing wind is from:

Northwest in winter

Southwest in summer

1.2 If location is within continental U.S.A. can wind pressure be in accordance with A58.1 [X] Yes No

1.3 Earthquake (seismic) zone 1

1.4 Maximum recorded rainfall in one (1) hour is -- inches.

1.5 Maximum recorded rainfall in twelve (12) hours is -- inches.

1.6 Outdoor design temperatures:

Summer 95 °F DB 80 °F WB

Winter -20 °F

Procon Incorporated
BASIC ENGINEERING DESIGN DATA

UTILITIES

PROJECT	W-1843
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BY	
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1.0 STEAM

	DESCRIPTION	PSIG	°F	LBS/HR QTY. AVAILABLE	COST ¢/1000 LBS.
1.1	HIGH PRESSURE	1250 1250	1000 573 (Sat)		
1.2	MEDIUM PRESSURE	250	406 (Sat)		
1.3	LOW PRESSURE	50	298 (Sat)		

1.4 1800 PSIG, 1000°F/1000°F Stm. will be used for EG Unit Boiler-Turbine Generator

1.5 Use 50 PSIG Steam for Hose Stations

1.6 Use 50 PSIG Steam for Unit Heaters

1.7 Use 50 PSIG Steam for Tracing

1.8 Use 50,250,1800 PSIG Steam for Turbines

1.9 Use 250 PSIG Steam for Snuffing at --

2.0 CONDENSATE

2.1 Condensate from 1250 PSIG steam & B.D. to flash drums.

2.2 Condensate from 250 PSIG steam shall be discharged to flash drums.

2.3 Condensate from 50 PSIG steam shall be discharged to Condensate Return System

3.0 WATER

	DESCRIPTION	PSIG	°F	GPM QTY. AVAILABLE	COST ¢/1000 GAL.	TREATMENT REQUIRED	LOCATION
3.1	COOLING SUPPLY	65	85				
3.2	COOLING RETURN	40	115				
3.3	DOMESTIC	35	70				
3.4	H.P. PROCESS BOILER FEED	1500	400				
3.5	FIRE WATER	190	70				
3.6	DEMINERALIZED MAKE-UP WATER	AS REQ'D	45-80	(to be confirmed when		site selected)	
3.7	L.P. BOILER FEED	100 300	180 MINIMUM				

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BASIC ENGINEERING DESIGN DATA

UTILITIES

PROJECT	W-1843
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4.0 FUEL

	DESCRIPTION	PSIG	°F	QUANTITIES AVAILABLE	COST ¢/MM BTU	BTU
4.1	GAS HEADER	100	70			
4.2	SPENT CHAR *					
4.3	OIL HEADER SUPPLY					
4.4	OIL HEADER RETURN					

5.0 AIR

	DESCRIPTION	PSIG	°F	QUANTITIES AVAILABLE	
5.1	PLANT AIR	100	Amb.		
5.2	INST. AIR	60	Amb.		
5.3	SAFETY AIR				

6.0 ELECTRIC POWER **

Purchased Cost/KW/HR ______________________

Supplier ______________________

Self Produced Cost/KW/HR ______________________

7.0 REMARKS

*Spent char will be the primary fuel for the EG Unit boiler and for the H.P. process boiler. The boilers will also use the low BTU "off-gas" from the coal pretreatment, and supplementary coal will also be fired for fuel balance.

**Except for EG power requirements, plant power requirements will be supplied from purchased power, for the base case.

1.0 RELIEFS

1.1 Relief valves handling Steam ______ shall be vented directly to atmosphere.

1.2 Relief valves handling all process fluids (except CO_2)* ______ shall be vented to a closed relief system discharging to flare

*CO_2 to be discharged to atmosphere via 250 ft. stack

2.0 DRAINS

2.1 Storm drains will be run to ______ and fabricated from steel, concrete, or open ditches.

2.2 Oily water drains will be run to Foul Water Disposal Unit ______ and fabricated from steel (and as required).

2.3 Sanitary drains will be run to Sewage Disposal Unit ______ and fabricated from cast iron.

2.4 Chemical drains will be run to ______

3.0 OVERHEAD PIPE LIMITS

3.1 Minimum clear height is ______ feet to first pipe rack level.

3.2 Overhead caustic lines require the following special treatment:

______

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BASIC ENGINEERING DESIGN DATA

PIPING

PROJECT	W-1843
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4.0 BATTERY LIMITS TIE-INS

The following size lines for the services listed

4.1	(a)	Water Supply*	(b)	-	(c)	-
4.2	(a)	Product Gas	(b)	-	(c)	-
4.3	(a)	Gas Supply to Plant	(b)	-	(c)	-
4.4	(a)	Sanitary Sewer Line	(b)	-	(c)	-
4.5	(a)	Treated Foul Water Effluent	(b)	-	(c)	-
4.6	(a)		(b)		(c)	
4.7	(a)		(b)		(c)	
4.8	(a)		(b)		(c)	

will be located at the ______________ battery limits.

Their dimensional location will be given on a drawing to be furnished by ______________

5.0 REMARKS

*It has been assumed that clean, cold (70°F or less) water will be available at the battery limits, at a nominal pressure of 35 PSIG.

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BASIC ENGINEERING DESIGN DATA

CIVIL/STRUCTURAL

PROJECT W-1843

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CIVIL DESIGN

1.0 The following loading conditions shall be considered:

[X] Erection [X] Operating Dry [X] Operating Wet [X] Hydrostatic Test

Other, specify if required ______

2.0 Allowable stress for anchor bolts 15,000 PSI

2.1 ASTM Designation Carbon Steel A-307

2.2 Corrosion Allowance None

3.0 Minimum Factor of Safety against Overturning (F.S.O.T.)

3.1 Erection 1.5

3.2 Operating 1.5

3.3 Other, specify if required 1.5

4.0 Structural Steel, ASTM Designation

4.1 Support Structures A-36

4.2 Vessel Skirts A-283 (Design < 650°F), A-285C (Design ≥ 650°F)

4.3 Other, specify None

5.0 Concrete, Compressive Strength of

5.1 Table Top Supports 3000 PSI

5.2 Foundations 3000 PSI

5.3 Walls 3000 PSI

6.0 Reinforcing Bar ASTM Designation A-615

6.1 Yield Stress [X] 40 [ ] 60 [ ] 75

7.0 Earthquake Provisions None

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BASIC ENGINEERING DESIGN DATA

CIVIL/STRUCTURAL

PROJECT	W-1843
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8.0 Live Loads

8.1 Operating Platforms; Support Members 50 psf

Floor Cover 50 psf

Floor Cover Type ____________

8.2 Walkways 25 psf, type ____________

8.3 Roofs 20 psf, type ____________

8.4 Others, specify if required Equipment Platforms = 50 psf + Equipment

9.0 Snow Load 10 psf

10.0 Impact Loads

10.1 Trolley Beams - 50% increase in load

10.2 For others - See AISC Specifications

11.0 Tube Bundle Removal Force, Shell & Tube Exchangers:

50% of Bundle Weight or 2000 lbs., Whichever is Greater

12.0 If A58.1 is not used, structural design wind pressure for various height zones shall be as specified in Code -- or, as follows:

12.1 ________ PSF Below ________ ft.

12.2 ________ PSF Above ________ ft. but below ______ ft.

12.3 ________ PSF Above ________ ft. but below ______ ft.

12.4 ________ PSF Above ________ ft.

13.0 Wind velocity used in structural design shall be --

14.0 Shape Factors:

14.1 Flat Surface ____________

14.2 Cylindrical Surface ____________

14.3 Open Framed Structures ____________

Procon Incorporated **BASIC ENGINEERING DESIGN DATA** CIVIL/STRUCTURAL	PROJECT W-1843 SHEET 13 OF 21 BY DATE

15.0 Piling, type ______________ Capacity ______________

15.1 Pile cut off is ________ below high point finished surface (grade).

15.2 Minimum edge distance ______________.

15.3 Minimum distance between piles ________.

16.0 Bearing value of soil is:

16.1 4000 psf at 3' below high point finished surface.

16.2 ________ at ________ below high point finished surface.

16.3 ________ at ________ below high point finished surface.

17.0 Paving

17.1 Roadways, extent and type:

Concrete 6" - Equipment Traffic
4" - Pedestrian Traffic

Asphalt None

Stone and Gravel 6" - Sub Base

17.2 Process area, extent and type: To be determined later.

Concrete ______________

Asphalt ______________

Stone and Gravel ______________

18.0 REMARKS

Procon Incorporated
BASIC ENGINEERING DESIGN DATA

FIREPROOFING, INSULATION, AND PAINTING

PROJECT W-1843
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1.0 FIREPROOFING

1.1 Vessel Skirts: [X] Procon Spec. 211 Other Spec., specify ____

Type and Extent ____ Rating 3 Hours

1.2 Structural Supports: Type and Extent Cast in place up to first principal support level.

1.3 Pipe Racks: Type and Extent Cast in place up to first principal support level.

1.4 REMARKS

2.0 INSULATION

2.1 Specifications: [X] Procon 225 Other, specify ____

2.2 Vessels Type Blanket Weather Covering, type Metal Jacket

2.3 Exchangers Type Blanket Weather Covering, type Metal Jacket

2.4 Piping Type Molded Weather Covering, type Metal Jacket

2.5 Winterizing Type Procon Std. Temperature -20°F

2.6 Tracing Type Steam and Electric

3.0 PAINTING OR COATINGS

3.1 Specifications: [X] Procon 249 Other, specify ____

3.2 Colors As Required

3.3 REMARKS

Procon Incorporated
BASIC ENGINEERING DESIGN DATA

ELECTRICAL

PROJECT W-1843

SHEET 15 OF 21

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DATE

1.0 ELECTRICAL SERVICE* (Purchased Power For General Plant Requirements)

1.1 Voltage (nominal 13.8 KV/4160 V Phase 3

Freq-CPS (Hertz Hz) 60

☐ Undergrounded ☐ Grounded, Define Grounding Method

1.2 Maximum no-load voltage ______ Minimum no-load voltage ______

1.3 Three-Phase short circuit symmetrical contribution from utility system ______

1.4 Maximum line-to-ground short circuit contribution from utility system ______

1.5 Minimum line-to-ground short circuit contribution from utility system ______

1.6 Metering requirements As Required

1.7 Incoming line protection requirements As Required

2.0 UTILIZATION LEVELS

SERVICE	VOLTAGE	PHASE	FREQ-CPS (HERTZ-HZ)	TRANSFORMER CAPACITY
POWER MEDIUM VOLTAGE	4160	3	60	As Required
POWER LOW VOLTAGE	480	3	60	As Required
LIGHTING	120/240	1/3	60	As Required
INSTRUMENTATION	120	1	60	As Required

*On-site power generation for "EG" Unit, details to be determined later.

Procon Incorporated
BASIC ENGINEERING DESIGN DATA

ELECTRICAL

PROJECT W-1843

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BY

DATE

3.0 SERVICE VOLTAGES

SERVICE	HORSEPOWER RANGE from	to	VOLTAGE	PHASE	FREQ-CPS (HERTZ-HZ)
MOTORS	Smallest	1/2	115/230	1	60
	3/4	250	460	3	60
	300	Largest	4000	3	60
INSTRUMENTS			115	1	60
LIGHTING DIST.			115/230	1	60 *

4.0 EMERGENCY POWER

4.1 [X] Required [ ] Not Required

4.2 Voltage 4160 Phase 3 Freq-CPS 60

4.3 Service

4.4 Type system required Turbine or Diesel driven generator (480/3/60), (100 KW) AC-DC Rectifier, and DC-AC Inverters for selected services which cannot tolerate power outages, and emergency lighting.

5.0 LIGHTING

5.1 Illumination intensities Process Areas - 0.5 f.c.; Roads - 1.5 to 3.0 f.c.; Platforms - 5 f.c.; Compressor & Pump Shelters - 15 f.c.; Control Room & Building - 50 f.c.

5.2 Special considerations Installation, & equipment suitable for Group B, D, & F areas present.

6.0 POWER

6.1 Medium Voltage ________, [X] Grounded [ ] Ungrounded

6.2 Low Voltage ________, [X] Grounded [ ] Ungrounded

6.3 Power wiring shall be installed: [X] Overhead [X] Underground

6.4 Special Conditions

* Other voltages may be used for special lighting, if required.

7.0 RECEPTACLES

7.1 Type 120 volt convenience receptacle (Catalog No.) ____

7.2 Type 460 volt welding receptacle (Catalog No.) ____

7.3 Special Conditions ____

8.0 AIRCRAFT WARNING REQUIREMENT

8.1 [X] Required [ ] Not Required

8.2 Special Conditions To be determined by CAA for particular site.

9.0 ELECTRICAL AREA CLASSIFICATION

9.1 Indoor areas Buildings in hazardous areas to be pressurized.

9.2 Outdoor areas Class I, Division 1 and 2, Group B, D, & F as determined.

9.3 Special Conditions Non-Ventilated - pits, sumps, etc. in outdoor areas to be Class 1, Division 1, Group B or D.

10.0 COMMUNICATION SYSTEMS

10.1 [X] Required [ ] Not Required

10.2 Type system or systems required Complete plant telephone and audible paging system.

11.0 ELECTRICAL WINTERIZING (ELECTRICAL HEAT TRACING)

11.1 [X] Required [ ] Not Required

11.2 Define conditions Electric heaters and pipeline tracing, as determined. For (-) 20°F design.

Procon Incorporated **BASIC ENGINEERING DESIGN DATA** ELECTRICAL	PROJECT W-1843 SHEET 18 OF 21 BY DATE

12.0 SPECIAL CLIMATIC CONDITIONS

12.1 Insulation As Required

12.2 Altitude 500 ft. Ambient Temperature -20° to +95°F

12.3 Vermin-proofing None

12.4 Special conditions None

13.0 REMARKS

Some of the above electrical requirements will be altered due to the laws prevailing at the actual site, and different climatic conditions.

1.0 BASIC INSTRUMENTATION SYSTEM DETAILS

1.1 [X] Electronic [ ] Pneumatic

1.2 If electronic, field installation and instrument equipment shall be: [X] Explosion proof [X] Intrinsically safe

1.3 If electronic, should installation be arranged for future computer control or data logging? [X] Yes [ ] No

1.4 If yes, to what extent? [X] Data logging [ ] Supervisory (Central computer adjusts set points of individual controllers). [ ] Direct digital control (Central computer controls, [ ] Individual controllers take over in emergency).

2.0 PROCESS DATA

2.1 Heat and Weight balances, line summaries, hydraulic calculations, and similar process data required in order to specify instruments of the proper range, strength and material of construction, capacity etc. shall be provided by: [X] Customer [ ] Procon [ ] Other

3.0 GENERAL

3.1 Will customer resident Instrument Engineer be available? [ ] Yes [ ] No At Procon? [ ] Yes [ ] No

4.0 MAIN CONTROL BOARD

4.1 Control board shall be: [ ] Flat panel [X] Console [X] Cubicle [ ] Other, type ______

4.2 Control board layout shall be: [ ] Conventional non-graphic [ ] Semi-graphic [X] Full graphic

4.3 Control board instruments shall be: [ ] Large case [X] Miniature [ ] Miniature and high density layout [ ] Other, type ______

4.4 Control board instruments shall be: [X] General purpose enclosed [ ] Class 1, Group D, Div. 2 [ ] Other, type ______

4.5 A multipoint temperature indicator [X] is [ ] is not required.

4.6 Multipoint temperature indicator shall be located on: [X] Main control board [ ] Console or desk.

4.0 MAIN CONTROL BOARD (continued)

4.7 Multipoint temperature indicator shall be: [X] Digital readout [ ] Dial readout. Point selection shall be: [X] Pushbutton address [ ] Lever switches.

4.8 Control board annunciators [X] are [ ] are not required.

4.9 Annunciators are required on [X] The main control board [X] On other control board(s).

4.10 Annunciators shall be located: [X] In graphic display [ ] In one or more group enclosures [ ] Built into board mounted instruments. [ ] Other, type ______

4.11 Shall there be field horns? [X] Yes, how many? ______ [ ] No

5.0 INSTRUMENT SPECIFICATION

5.1 Specification forms for data and purchase shall be: By [ ] Procon [X] Other, type ______

5.2 Specification standards describing details of quality, construction, installation, etc. shall be: By [ ] Procon [ ] Client [X] Other ______

5.3 Specification forms for data and purchase may be written so that:
[ ] Several items are specified on one page (without crowding).
[ ] Only one vital item is specified on one page.
[X] Other, type ______

6.0 INSTRUMENTATION HARDWARE DETAILS

6.1 Three-valve prefabricated manifolds [X] may [ ] may not be used with dp instruments. (In applications involving special materials or very high pressure, pre-fab three-valve manifolds will not ordinarily be used.)

6.2 When control valves are not blocked and bypassed, they [X] shall [ ] shall not be equipped with handwheels for manual override. Conditional guidelines for providing handwheels for control valves are ______

6.3 Control valve types shall be: [ ] Globe type only [ ] mostly Globe type but, Butterly, "V-Ball", "Camflex", or other for large size or special applications. [X] Globe, Butterfly, "V-Ball", "Camflex", or other for economic advantage.

6.4 Globe type valves [X] may [ ] may not have cage trim.

6.5 Control valve actuators shall be: [X] Pneumatic, spring and diaphragm type [ ] Other, type ______

7.0 INSTRUMENTATION HOOK-UP

7.1 Pneumatic tube fittings shall be: [ ] Imperial Hi-duty [X] Crawford "Swagelok" [ ] Parker Hannifin [ ] Other, type ______

7.2 Single strand tubing shall be: [ ] Plain copper [X] PVC coated copper [ ] Plain aluminum [ ] PVC coated aluminum [ ] Other, type ______

7.3 Multitube bundle tubing shall be: [X] PVC over copper [ ] PVC over aluminum [ ] Other, type ______

7.4 Electronic transmission wire shall be: [ ] Shielded [ ] Non-shield [X] Other, type As Required

7.5 Thermocouple extension wire shall be: [ ] Parallel lay [ ] Twisted pair [ ] Shielded [ ] Non-shield [ ] Solid [ ] Stranded [X] Other, type As Required

7.6 The average transmission distance (straight line) of measurement and control signals is ______

7.7 Pneumatic controllers for control board stations shall be located on: [ ] Control board (2 pipe system) [ ] In field (4 pipe system for flow or fast pressure control loops).

A. HYDROGASIFICATION REACTOR DESIGN

NOTE: The reactor design covered in this report has been furnished by IGT, and is the work of Mr. L. S. Daniels, of the Bechtel Corporation.

1. REACTOR SIZE & ARRANGEMENT

a. During Phase I of the study, a detailed investigation was made to determine the size and construction of a reactor which would provide the largest feasible initial single train plant.

Three different reactor sizes and arrangements were studied in detail as follows:

(1) A 24'-0" O.D. Reactor, 1-Unit - field erected.

(2) A 13'-6" O.D. Reactor, 1-Unit - shop fabricated and field erected.

(3) A 13'-6" O.D. Reactor, 3-Unit - shop fabricated and field erected, with interconnecting piping.

b. The 24'-0" O.D. Reactor size was selected as it was felt that the technology and experience in the field construction of such large pressure vessels is now available. Capacity of this size reactor is 80 MM SCFD.

The 13'-6" O.D. Reactor size was selected as this was considered the largest shop fabricated vessel that could be shipped by railroad. Reactor capacity equals 20 MM SCFD; therefore, four would be required.

c. Several well-known vessel manufacturers, experienced in the fabrication of such large vessels, were contacted for their recommendations on methods of manufacture. These fabricators were requested to study the design, manufacturing methods, delivery time, and estimated costs for vessel arrangements (a) and (b) above. The reactor arrangement per (c) above did not prove feasible because of the difficult interconnecting piping and expansion joint requirements for interconnecting the several units.

2. REACTOR SELECTION

As a result of the cost estimates of the vessel, support structures and foundations, and consideration of delivery and erection time, fabrication methods, and probable types of shipment required depending on site location, the following selection was made:

The initial Demonstration Plant will consist of one 24'-0" O.D. Reactor - field erected including welding, heat treating, and radiographing. The vessel will be built from shop fabricated rings, if the site location allows shipment by water, or half-rings or smaller if the site requires rail shipment. Entire delivery and field fabrication time for the reactor will require approximately 33 months.

The selection of this reactor size has set the capacity of the Demonstration Plant at 80 MM SCFD. This, in turn, has basically set the size and capacity of the other equipment required for the initial plant. The ultimate plant will consist of three reactor trains.

3. OTHER REACTOR DESIGN FEATURES

The Electrothermal Gasifier section and the second stage reaction bed section of the reactor will be designed with an internal water jacketed type construction.

This decision is based on the conviction that this is a "safer" method of construction, which will materially reduce the possibility of reactor metal "hot spots" leading to failure of the pressure shell.

4. FUNCTION OF REACTOR

Satisfactory operation of this reactor will be a major factor in the success of the IGT HYGAS® process. This vessel, operating at pressures of 1000-1200 PSIG, and temperatures of 600°F-1900°F, produces CH_4 by reaction (1), and substantial amounts of CO & H_2 by reaction (2), below

(1) $\text{Coal} + H_2 \longrightarrow CH_4$

* (2) $\text{Coal} + H_2O \longrightarrow CO + H_2$

* Additional CH_4 is formed in a later methanation reaction step:

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$

Hydrogasification is carried out in two stages: in a First Stage Reaction Zone operating at 1200°F, and in a Second Stage Reaction Bed operating at 1750°F. Of the coal fed, about two thirds is reacted in the Reactor, and one-third is sent as char fuel to the power plant. Of the coal reacted, about one-half is gasified in the two reaction stages, and the other half is used for hydrogen generation in the ELECTROTHERMAL GASIFIER (EG) Bed, at the bottom of the reactor.

The design utilizes four fluidized solids beds, with means for successively passing the char feed solids from the Light Oil Vaporizer Bed at the top of the reactor, downward to the First Stage Reaction Zone, then to the Second Stage Reaction Bed, and then to the Electrothermal Gasifier Bed. Spent char is discharged at the reactor bottom.

Spent char removed from the EG Bed is used for fuel in the power plant, which generates the large amounts of electric power used for operating the EG unit.

Gas flow passes upward through the various beds, hydrogasifying the feed char, and the product gases together with the gasified slurry oil used for feeding the char exit at the top. Provision is made for recycle of 1200°F char with fresh solids feed to the First Stage Reaction Zone.

5. PROCESS MATERIAL BALANCE

The basis for the process heat and material balance of the reaction system is shown in Figures 1 & 2, attached. This information was furnished by IGT, and used in the Daniels' reactor design shown. A slightly different reactor balance was used for the Procon Process Design.

Calculations for the heat and material balance are not included in this report.

6. DESCRIPTION OF FLOW THROUGH REACTOR

The attached Bechtel Corporation drawing entitled "Conceptual Design - Reactor for Coal Gasification", and accompanying calculations indicate a proposed reactor design, furnished by IGT.

A brief description of the operation and general construction features follows:

> The coal/benzene slurry is admitted to the top of the reactor through a ring header. In this top bed known as the Light Oil Vaporizer (LOV) section, operating at 600°F, benzene is vaporized and leaves the reactor with the product gas. The dried char enters the coal feed standpipe for transfer to the FIRST STAGE REACTION (L?R) section, which operates at 1200°F.

The coal feed standpipe is a single pipe with internal insulation and an external metal shell which passes through the reactor's jacket water steam separator. The feed coal is at 600°F so insulation is needed between the vaporizer and the water jacket side at about 550°F to prevent the possible condensation of hydrocarbon vapors on the coal side. The feed rate of coal to the first stage reactor is controlled by a throttling slide valve. As the standpipe, slide valve pipe "bonnet", and the steam separator walls are held at the same 550°F temperature of the equilibrium steam at reactor system pressure, there are no thermal expansion problems with these carbon steel parts. The feed slide valve hopper and slide could be in alloy and hard faced to resist erosion, but here, too, the temperature is low, only 600°F. The char is carried upward in the first stage reaction section.

The first stage reactor terminates in an alloy cyclone which has a working temperature of 1,200°F and has refractory lining for erosion protection. The solids discharged from the dust hopper of this cyclone fall into a "Y" shaped hopper having a vertical plate divider on its centerline. A controlled "splitter" valve above this hopper sets the distribution of solids alternatively between a "recycle dipleg" and a "second stage reactor feed dipleg", as desired. A "trickle" valve on each dipleg allows solids to be discharged whenever there is a sufficient fluidized solids height accumulation in that dipleg to balance the pressure differentials. The arrangement thus allows the solids recycle rate to the First Stage Reaction section to be set at any desired ratio to Second Stage Reaction Bed (HTR) section feed.

The diplegs have refractory insulation on their exterior surface within the first stage reactor so that they will operate at about 1,200°F metal temperature even though the first stage reactor temperature at the hot gas inlet end is much higher. The feed dipleg to the second stage reactor passes through the shell of the first stage reactor and through the steam-water separator and into the second stage reactor vapor space. Within the water jacketed section this dipleg must have a bare metal exterior wall and a refractory liner. This will avoid thermal expansion problems between the metal walls, and the internal insulation will decrease the heat transfer between the 1,200°F fluidized solids and the 550°F jacket water. There will be differential expansion between the diplegs and the first stage reactor shell. This is to be handled by an expansion joint at the cyclone where the temperature will be 1,200°F and the pressure across the joint about 1 to 2 PSI.

Coal char produced in the First Stage Reactor flows down via cyclone dipleg and "trickle" valve into the Second Stage Reaction Bed, for additional gasification with preheated feed gases. The Second Stage Reaction Bed operates at 1750°F. About one-half of the coal gasification takes place in this bed.

Char then passes through the dipleg with "trickle" valve from the second stage reactor section to the lower, or ELECTROTHERMAL GASIFIER (EG) section. In this section char is reacted with steam to form hydrogen, for use in the above hydrogasification sections. Heat for this reaction is supplied by electric power, via the electrode arrangement indicated.

The spent char from the EG Bed is removed through an external seal leg equipped with a conventional plug valve, for subsequent transport to heat exchange, quenching, and/or pressure-letdown system.

Details of the electrical design of the "EG" section are included in the following section.

DANIELS REACTOR DESIGN

PRESSURE BALANCE

Pressure at Vaporizer Dilute Phase	1015 PSIA
Δ P Vaporizer Fluid Bed $\frac{16\ ft \times 18\ lb/ft^3}{144}$ =	2.9 PSI
Press at Gas Dist. Elev.	1017.9 PSIA
Δ P Vaporizer Nozzles	1.0 PSI
Δ P Hot Gas Piping from Cyclone	0.1 PSI
Δ P Cyclone Body thru Vapor Outlet	1.3 PSI
Pressure inside Cyclone	1020.3 PSIA
Δ P Cyclone Horns to Cyclone Interior	0.7 PSI
Pressure at Top of First Stage Reactor	1021.0 PSIA
Δ P First Stage Reactor	1.5 PSI
Δ P Lift Line, Say	0.1 PSI
Pressure below Coal Feed Slide Valve	1022.6 PSIA

Pressure at Vaporizer Distributor	1017.9 PSIA
Δ P to Top of Coal Feed Standpipe $\frac{3' \times 18}{144}$ =	0.3 PSI
Δ P Standpipe $\frac{40 \times 25}{144}$ =	7.0
Pressure above Slide Valve	1025.2 PSIA
Pressure below Slide Valve	1022.6 PSIA
Δ P Available for Slide Valve	2.6 PSI

(This Δ P is barely workable, and must be checked later with densities from pilot plant experience.)

Pressure below Coal Feed Slide Valve	1022.6 PSIA
Δ P Lift Riser, Lower Section, Say	0.2 PSI
Pressure above Second Stage Fluid Bed	1022.8 PSIA
Δ P Second Stage Fluid Bed $\frac{54 \times 20}{144} =$	7.5 PSI
Pressure at Bottom of Second Stage	1030.3 PSIA
Δ P Support Deck, Say	1.5 PSI
Pressure above Electrothermal Fluid Bed	1031.8 PSIA
Δ P Electrothermal Fluid Bed $\frac{20 \times 15}{144} =$	2.1 PSI
Pressure at Steam Ring	1032.9 PSIA
Δ P Steam Nozzles, Say	2.0 PSI
Δ P Steam Line from Reactor Jacket	0.1 PSI
	1035.0 PSIA

	WT %
C	71.35
H_2	4.02
O_2	7.51
N_2	1.00
S	3.81
Ash	12.31
Total	365,820 lb/hr
L.Oil	737,130 lb/hr

	WT %
C	71.35
H_2	4.02
O_2	7.51
N_2	1.00
S	3.81
Ash	12.31
Total	365,820 lb/hr

	WT %
C	77.40
H_2	5.06
O_2	--
N_2	0.41
S	1.67
Ash	15.46
Total	278,980 lb/hr

	WT %
C	74.89
H_2	0.87
O_2	--
N_2	0.56
S	2.31
Ash	21.37
Total	210,690 lb/hr

	WT %
C	57.00
H_2	0.66
O_2	--
N_2	0.98
S	4.04
Ash	37.33
Total	120,590 lb/hr

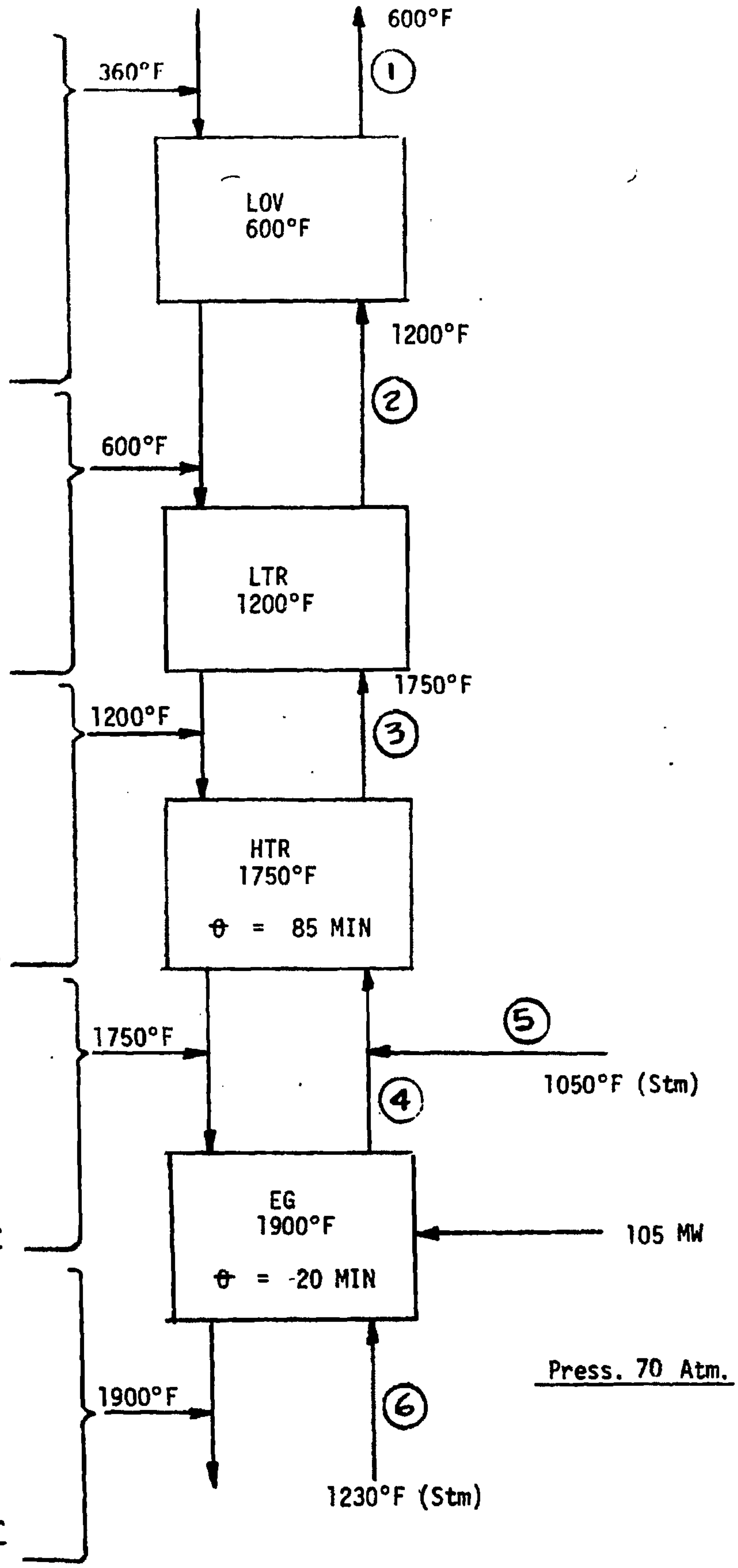

Figure 1 of 2
Process Material Balance
For Daniels Reactor Design Only

	①		②		③		④		⑤	⑥
TEMP, °F PRESS, PSI	600°F 1000 PSI		1200°F 1010 PSI		1750°F 1030 PSI		1900°F 1050 PSI		1050°F 1500 PSI	123[illegible] 1500 [illegible]
	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL %	MOL/HR	MOL/[illegible]
CO	5610	15.68	5610	21.30	5044	24.18	4797	26.78	--	--
CO_2	3793	10.60	3793	14.40	3445	16.51	1570	8.76	--	--
H_2	6382	17.83	6382	24.23	3747	17.96	6360	35.51	--	--
H_2O	4493	12.55	4493	17.06	4081	19.56	4140	23.12	3940	12,[illegible]
CH_4	5241	14.64	5241	19.90	4545	21.79	1044	5.83	--	--
C_2H_6	197	0.55	197	0.75	--	--	--	--	--	--
C_6H_6	65	0.18	65	0.25	--	--	--	--	--	--
NH_3	174	0.49	174	0.66	--	--	--	--	--	--
H_2S	280	0.78	280	1.06	--	--	--	--	--	--
L.Oil	9556	26.70	106	0.40	--	--	--	--	--	--
Total	35,512	100.00	26,340	100.00	20,860	100.00	17,910	100.00	3940	12,[illegible]
SCF/Hr.	13,564,580		9,982,920		7,906,950		6,788,530		1,493,170	4,57[illegible]
ACF/Hr.	414,760		478,030		504,080		462,140		39,970	142,5[illegible]
ACF/Sec.	115		134		140		128		11	39

Total Coal Req'd = 366,380 lb/hr = 4400 Ton/Day

Total Slurry Oil= 737,130 lb/hr ; Oil and Solids Total = 1,106,547 lbs/hr

Total Steam = 288,540 lb/hr = 6.9 MM lb/Day

Total Power = 108 MW.

Figure 2 of 2
Process Material Balance
For Daniels Reactor Design Only

B. ELECTROTHERMAL GASIFIER POWER SUPPLY DESIGN

NOTE: The Electrothermal Gasifier Power Supply design included in this report has been furnished by IGT, and is the work of their consultant, Dr. Joseph TENO, of the AVCO EVERETT Research Laboratory.

The following material consists of excerpts from a longer report by Dr. TENO, entitled, "COAL ELECTRO-GASIFIER BEDS AND POWER SUPPLIES."

1. INTRODUCTION

The purpose of this investigation was (1) to summarize the electrical characteristic of a coal electro-gasification unit, (2) to apply these characteristics to the general design and analysis of power supplies for these units, (3) to make a detailed analysis of the power supply for the first 110 MW prototype unit and (4) to present recommendations and cost data to aid in the selection of power supply for electrogasifier units.

The power levels contemplated for the initial 110 MW prototype unit are large even by comparison with the largest similar loads (electric arc and vacuum arc melting furnaces) now in operation. Such loads push the capability of power systems, especially when the high power level is combined with high harmonic content, voltage flicker and phase unbalance resulting from the load characteristics. Additional important considerations here are concerned with the load itself and include the integrity of the gasifier and the power density at which it can be operated.

Some important considerations for the design of the power supply include:

a. Voltage-current (V-I) characteristic of the load including details on linearity and expected symmetry or phase unbalance in the case of an AC supply.

b. Flicker (both 3Ø and 1Ø) arising from load instability or fluctuation.

c. Capacity and other details (proximity of other users) of electric system to be used for the supply.

Load nonlinearity leads to harmonic currents which in some instances are difficult to handle if AC is used on the load. If $I \sim V^n$, where $n > 1$, the triple harmonic current content increases rapidly as n increases. Four wire systems are required if triple harmonic voltage fluctuation is to be prevented. Load asymmetry leads to production of even order harmonics which also are very troublesome and must be effectively suppressed. Other harmonic factors include resonance effects and machine heating. If a DC component (0 order even harmonic) results from asymmetrical wave shape with an AC unit, the transformer could saturate, and the power supply would not function. Here it would be necessary to utilize a transformer of substantially increased capacity or employ other methods to suppress the DC component. Triple and even harmonics, phase unbalance and DC components are not factors if a DC gasifier is employed, assuming that current fluctuations occur at a frequency much less than 60 cps, as is the case here, but flicker must still be held to an acceptable level.

Important considerations for the design of the electrogasifier unit itself include the power density at which the unit can be operated (impedance and current density) and protection against arcing and flashover which could destroy or damage the apparatus.

The sections which follow discuss in turn the characteristics of coal electrogasifiers, power supply requirements, the analysis of a 110 MW captive power supply, cost estimates for power supply and finally the conclusions reached on the basis of the investigation performed.

2. COAL ELECTROGASIFIER CHARACTERISTICS

a. Comparison to Arc Furnaces

The arc furnace has been used for many years by the steel industry to melt metals. The size of these furnaces has varied from the very small size to 50 to 60 MW units. (The electrogasifier promises to be much bigger in size in very early time periods.)

The load characteristic of an arc furnace varies from the start of a melt to completion. Until appreciable liquid metal is developed,arcs are generated by short-circuiting the electrodes to the furnace charge. This results in considerable voltage variation at local supply busses and decreasing voltage variation on other system busses as the individual bus becomes more electrically remote from the furnace. As will be discussed, the voltage variation or voltage dip leads to flicker and interference with such things as television sets and computers. Consequently, much effort is taken to reduce these effects to a tolerable level.

As the charge comes to a steady state operating condition, load oscillations become a minimum and the current is steady. In this condition, the load is almost completely resistive with a very small portion of the voltage being used to maintain the arc. The resistivity of the molten metal consequently controls the current.

In contrast, neglecting the wide variation of electrogasifier bed resistance observed in some cases, in steady state the current in an electrogasifier bed is controlled by a nonlinear resistive load. In large sizes it is expected that an electrogasifier bed will respond more or less like an arc furnace load between the extreme operating conditions of initial startup and complete melt down conditions. As a consequence, the technology developed (or developing) for arc furnace power supplies has been borrowed in attempting to make preliminary designs of coal electrogasifier power supply systems.

b. Bed Characteristics

The coal electrogasifier bed is in essence a nonlinear resistive load. Like the arc furnace, because of bed fluctuations, the load is unstable, varying in resistance over wide ratios thus causing the current to vary in the same manner. Figure 1 shows typical traces of voltage and current for a 300 KW bed. In some instances the ratio of maximum to minimum values of current can be as high as 4. The nonsinusoidal character of the current is readily apparent in Figure 1. In contrast to the arc furnace, arcs do not need to be struck during operation of the electrogasifier so that the electrogasifier avoids short circuit operation except during fault conditions. This, of course, makes the load more attractive from the viewpoint of less interference with other electric power users. In the paragraphs which follow, other characteristics of the bed are discussed.

Power Density Variation with Inner to Outer Electrode Radius Ratio

Since the resistivity of an electrogasifier bed is approximately given by

$$P_{e_o} = \frac{K}{\left(J_{e_o}\right)^{1/2}}$$

where J_{e_o} is the current density for the inner electrode; it follows, then, that the current density at any radius, r, in the bed is

$$J_e = J_{e_o}\left(\frac{r_o}{r}\right)$$

This equation has been plotted in Figure 2 for $\frac{r}{r_o}$ from 1 to 100. In particular, the curve shows a power density of 10 for a radius ratio of 4.5 and a power density ratio of 100 for a radius ratio of 21.5. Obviously, operating with power density variations of this magnitude could lead to a non-uniform heating of the bed and probably poor performance. To make a comparison of the various electrogasifiers, points have been included on the curve showing the spread of power density between the inner and outer electrodes corresponding to the ratios of the beds. Data for the various beds are given in Table 1. Three alternates have been shown for the 110 MW bed with inner diameters of 1 foot, 2 feet and 3 feet. Inspection of Figure 2 shows that whereas C and D are completely outside of any operating experience, E (3 ft. diameter inner electrode) will be comparable to the 2 MW bed. (The 2 MW bed is being tested in the IGT pilot plant.) Since the bed volume can be made up by a slight increase in bed height or a slight increase in bed diameter it would seem that this method of grading the power density is the simplest and perhaps the least costly. Application of this method must, of course, await evaluation of the test results on the 2 MW bed.

Alternatives to the above scheme for reducing the variation in power density include the use of concentric electrodes with unequal voltages between corresponding electrode pairs.

Power Equation under AC Operating Conditions

The resistivity of coal electrogasifier bed material is

$$\rho = \frac{K}{(i)^{1/2}}$$

Assuming an average resistivity across the bed can be found, the resistance is proportional to the negative one-half power of the current while the voltage drop across the bed is proportional to the positive one-half power of the current.

If for an AC electrogasifier bed, the voltage is given by $\dot{V} = \sin \sigma$

Then, the current is of the form

$$i = \sin^2 \sigma \qquad (0 \leq \sigma \leq \pi)$$

$$= -\sin^2 \sigma \qquad (\pi \leq \sigma \leq 2\pi)$$

If an harmonic analysis is made of the current, it is found that the expression for the current is

$$i = \sin \sigma - 0.2 \sin 3\sigma - 0.0284 \sin 5\sigma - 0.00972 \sin 7\sigma - 0.00427 \sin 9\sigma \text{-----}$$

The important fact here is that the load causes a 20% third harmonic to flow assuming a sinusoidal input voltage. In an AC scheme provisions must be made to permit the current to flow so as to avoid causing voltage harmonics.

Another issue of some importance with respect to the operation of a bed from an AC source is the possibility that the resulting wave will be completely unsymmetrical with respect to the positive and negative swings of the current. Even more important is the possibility of unequal resistances in the two directions leading to an offset or DC component in the input current. This offset component, if it is found to exist, would saturate transformer cores, causing them to perform poorly as well as cause additional heating in the system equipment where this current might flow. These matters are important in considering the comparison between AC and DC systems.

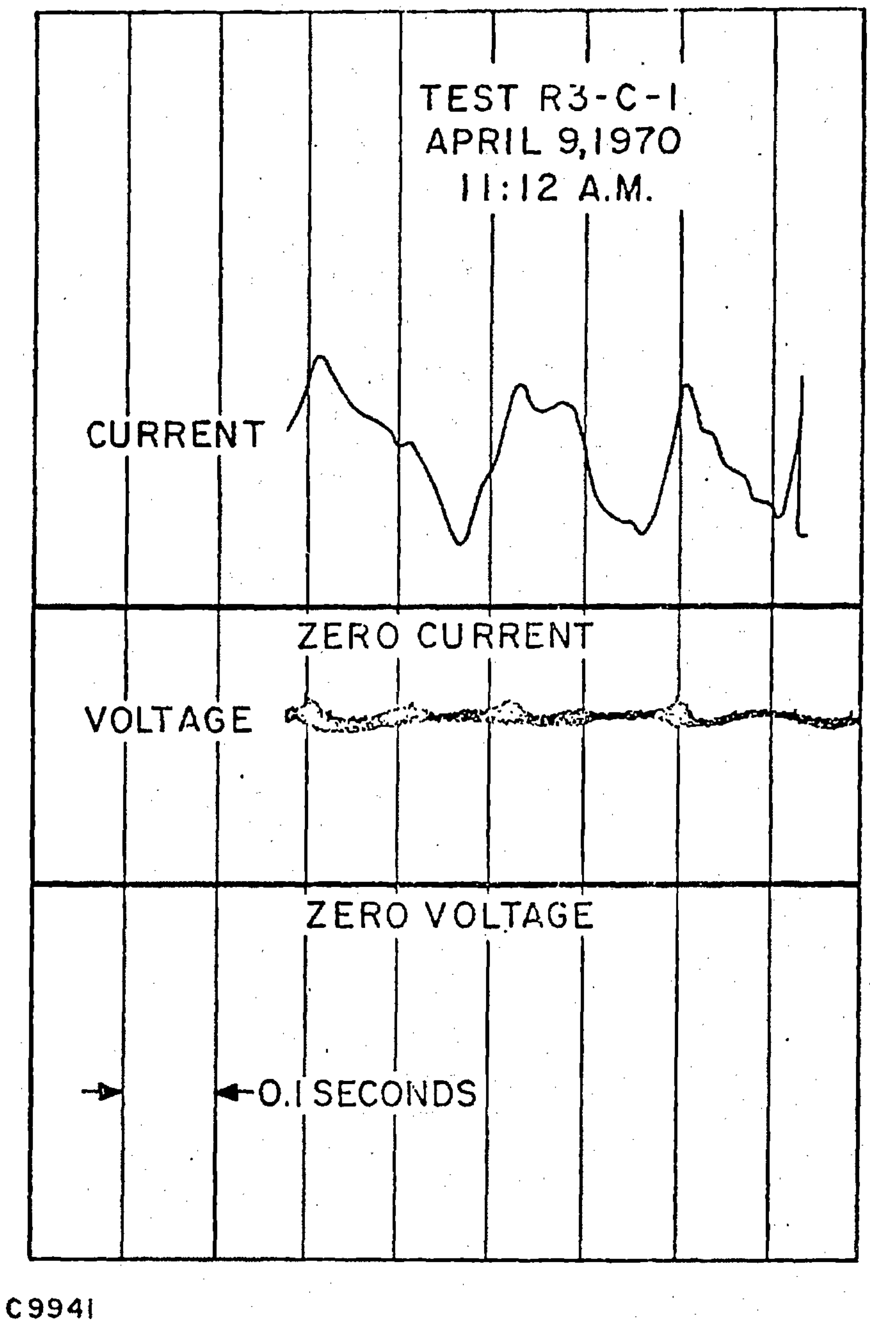
TEST R3-C-1
APRIL 9,1970
11:12 A.M.
CURRENT
ZERO CURRENT
VOLTAGE
ZERO VOLTAGE
0.1 SECONDS
C9941

Figure 1

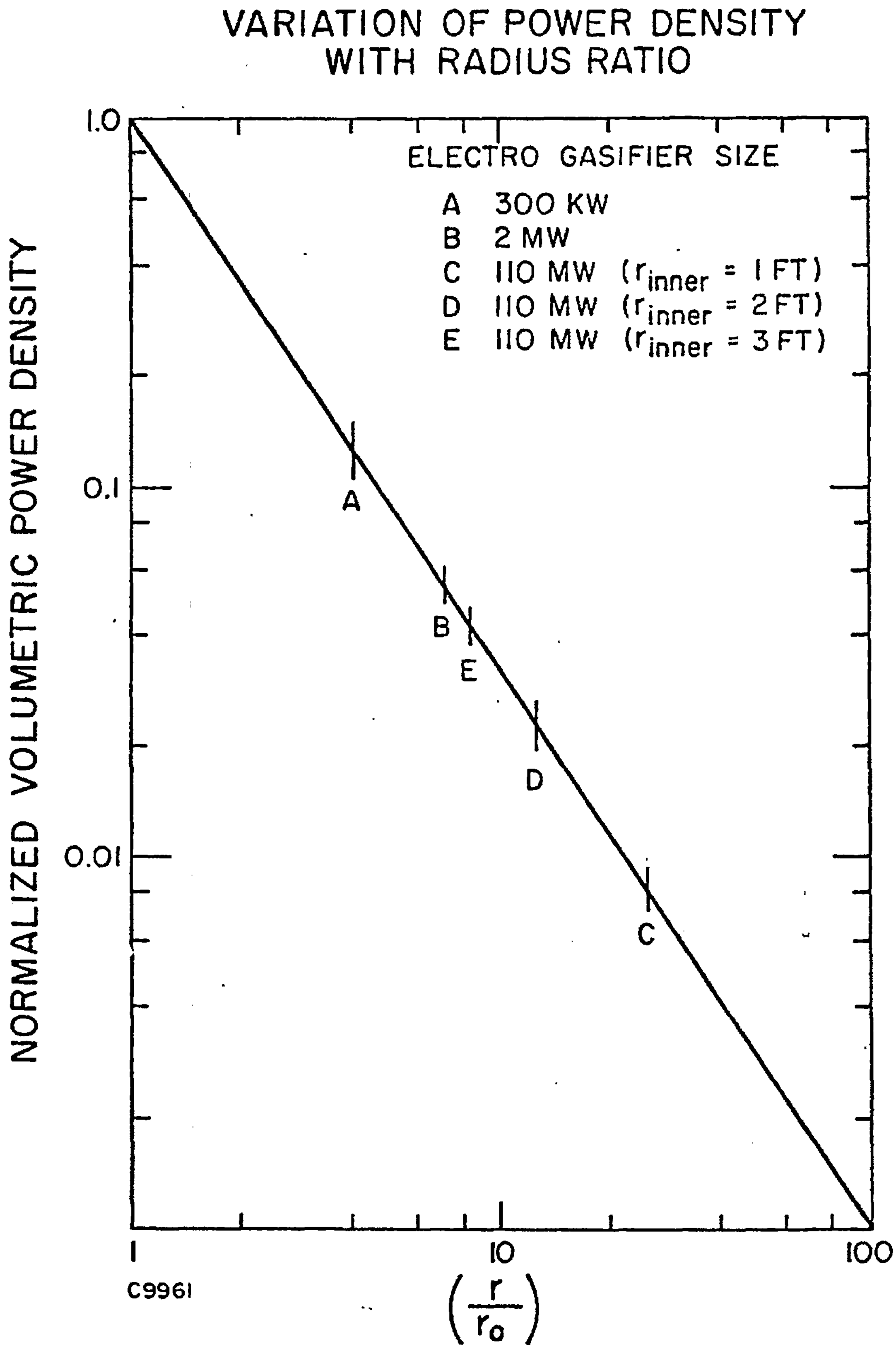
VARIATION OF POWER DENSITY
WITH RADIUS RATIO
ELECTRO GASIFIER SIZE
A 300 KW
B 2 MW
C 110 MW (r inner = 1 FT)
D 110 MW (r inner = 2 FT)
E 110 MW (r inner = 3 FT)
NORMALIZED VOLUMETRIC POWER DENSITY
1.0
0.1
0.01
1
10
100
A
B
E
D
C
C9961
(r/r o)

Figure 2

TABLE 1

DIMENSIONS OF VARIOUS ELECTROGASIFIERS

Point	Capacity	Inner Electrode Diameter	Outer Electrode Diameter	Radius Ratio
A	300 KW	1.5 In	6 In	4
B	2 MW	4 In	28 In	7
C	110 MW	1 Ft	25 Ft	25
D	110 MW	2 Ft	25 Ft	12.5
E	110 MW	3 Ft	25 Ft	8.33

c. Electrode Configurations

The primary considerations which must be taken into account in the design of electrodes are:

1) relatively uniform electric field intensities to avoid insulation breakdown,

2) relatively uniform current density distribution to avoid current concentrations leading to arcing, burning, and possibly catastrophic failure.

A great number of electrode configurations seem possible, but many of these are eliminated from consideration based on the fact that because of mechanical considerations, the vessel components must be circular in contour.

Within this constraint, end-to-end electrodes, concentric electrodes, and semi-cylindrical shapes, in addition to multiple concentric electrodes appear feasible. End-to-end electrodes have been tested with disappointing results (a relatively high number of failures) probably due to the fact that in an end-to-end configuration the current density is high particularly at the electrode edges leading to massive erosion and consummation of the electrodes. If test results from the present 2 MW electrogasifier (a concentric configuration) are unacceptable either the semi-cylindrical electrode configuration, or the multiple concentric electrode configuration must be considered as alternatives. It is expected that the present configuration will yield satisfactory performance results negating the necessity to consider or test other configurations.

d. Insulation Requirements

The proposed 110 MW electrogasifier bed will operate at some 15 KV above zero or ground. A voltage of 15 KV is sufficiently large as to make mandatory stringent requirements on the design of all power take offs as well as electrode design configurations.

Special attention must be given to the interface between the outside and inside of the bed. In particular, it is necessary to exclude any concentration of the electrogasifier working material where conductors at high voltages are adjacent to ground or conductors at low voltage.

3. POWER SUPPLIES

In the previous section a discussion of coal electrogasifier beds was presented. In particular, it was pointed out that the coal electrogasifier bed has many characteristics similar to those of the arc furnace. Consequently, supplying the power to a coal electrogasifier bed involves the same considerations used in designing the power supply to power an arc furnace. It must be noted again, however, that as far as tests have revealed to date, the coal electrogasifier bed will not make as stringent demands on the power supply as its counterpart, the arc furnace. In what follows, the practice followed in the design of power supplies for arc furnaces has been used. In the final analysis additional tests from the 2 MW coal electrogasifier and/or other units will hopefully shed more light on the question of the required electric configuration of the power supplies. It is the author's opinion that large sized loads will tend to be relatively steady loads in which case the power supply requirements can be relaxed. While this may turn out to be true, the author does not feel the need for fast switching to avoid high short circuit currents will be avoided.

a. <u>Arc Furnace Power Supply Requirements</u>

The arc furnace presents a widely fluctuating, nonperiodic load to a power supply particularly during melt down. Further, during melt down, the arc is obtained by momentarily short circuiting the power supply. Drawing large currents up to and including short circuit current causes the bus voltage to go to zero locally and to drop on other busses depending on the system interconnection and proximity of the other bus to the arc furnace bus. This type of load variation leads to two sources of interference as follows:

(1) dropping the voltage or voltage dipping leads to light flicker and television interference. This same dip depending on size, interferes with such loads as computers and control devices.

(2) the currents and/or voltages become non-sinusoidal because of the load characteristics. Consequently, harmonics are generated. Depending on the intercoupling of power circuits and communication circuits sound interference may be encountered.

Arc furnace users prevent this interference by the addition of corrective equipment to their systems. This corrective equipment includes:

(a) buffer reactors and synchronous condensers,

(b) series capacitors,

(c) new transmission lines,

(d) saturable reactors,

(e) static switching networks which incorporate the features of control and protection,

(f) filters

These are more or less the same components proposed presently for the coal electrogasifier bed as shown, for example, in Figure 3 or Figure 4. Field experience may reveal that not all of these components are necessary and therefore can be eliminated.

b. Comparison of Three Configurations for Coal Electrogasifier Power Supplies

Three possible power supply configurations are now discussed. Figure 3 shows a one line diagram for an AC system fed from a utility bus. Figure 4 shows a one line diagram for a DC system fed from a utility bus. Finally, Figure 5 shows a DC system fed from a captive power station. This latter configuration could be AC instead of DC. Each of the diagrams incorporates all of the possible components that might be found in such a system. There is redundancy in some of the equipment functions in which case the final system will be simplified. For example, it may be found that static switches can duplicate the functions of the buffer reactor and synchronous condenser. The diagrams reveal first and foremost that the number of components for each of the systems is more or less the same. This statement is true in greater detail than is apparent at a first glance. For example, in the AC system, AC static switches are proposed for one configuration. The AC switch is simply two SCR's connected back to back. In a three-phase line six elements would be required (dual elements are available in a single housing). For a full wave rectifier bridge six SCR's are also required. In both cases the voltage and current ratings as well as other ratings are more or less identical.

If anything the AC system may require additional elements and elements with much higher ratings. If the utility power system supplying the beds at the feed point is not stiff (meaning that the bus voltage varies considerably with current), then buffer reactor and synchronous condensers must be added to avoid interference with the rest of the system.

Additions of phase shifters or coils are placed in the DC system to reduce the filtering requirements and to provide isolation between various beds. Accordingly, they should be considered in conjunction with the filter system when system costs are considered.

The captive system, of course, avoids the problem of interference except if electromagnetic radiation from the captive system links another system. Also, to avoid mechanical oscillations it may prove necessary to filter even the captive power supply well.

Two additional points should be mentioned in this comparison. First, the previous analysis has shown that a considerable third harmonic is present in the AC current. Provisions must be made to allow this current to circulate locally in such a manner that a third harmonic voltage does not appear in the system.

The second point has to do with the possibility that the current during the positive and negative swings of an AC wave is unsymmetrical. Clearly, this latter situation would lead to the circulation of a DC current component in the windings of the main transformer. This would have the effect of increasing the amount of iron required in the core and would accordingly influence the transformer costs to a major extent.

This leads to the general conclusion that the power supply cost at the load end is the same for the AC and DC cases. The real difference is in the utility versus captive generating systems. Redundancy and reliability would probably be less with the captive system. On the other hand, the captive system by proper selection of operating voltages can possibly eliminate transformers and require much less filtering.

ONE LINE DIAGRAM FOR AN AC SYSTEM

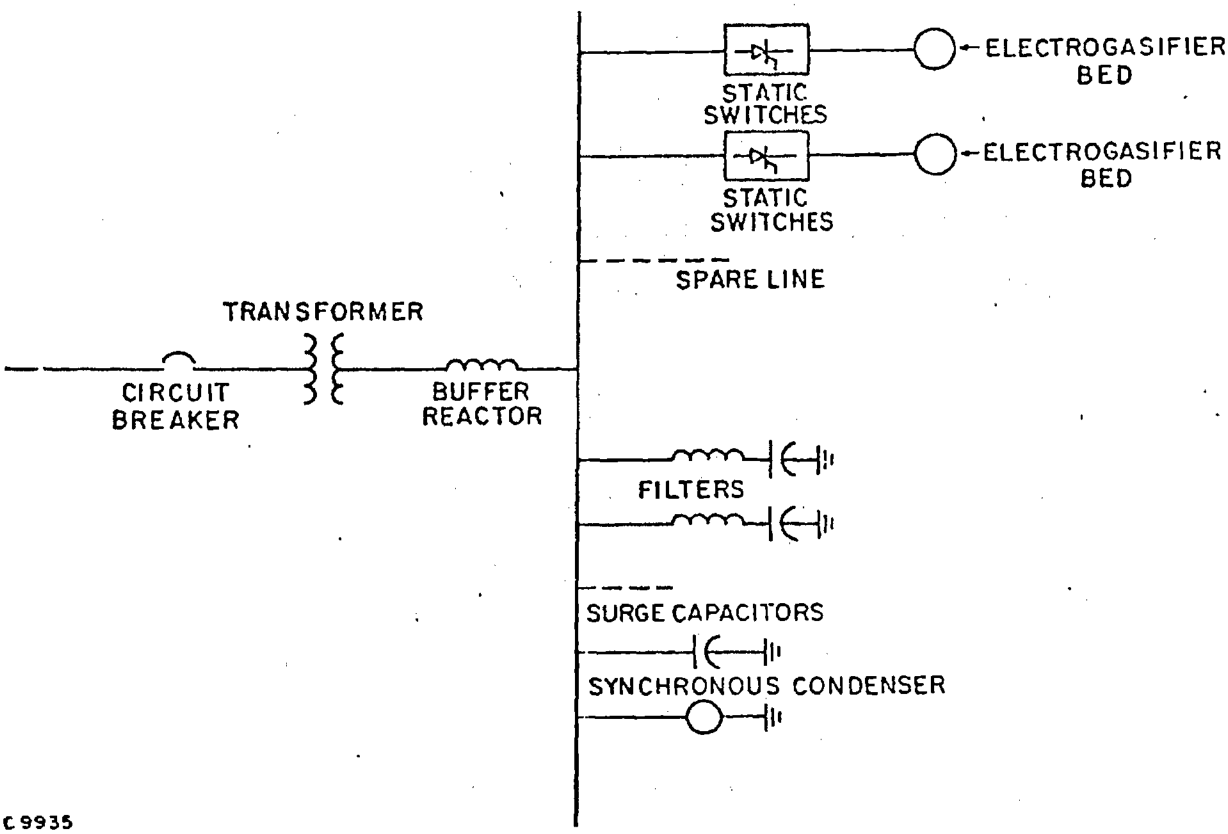

Figure 3

ONE LINE DIAGRAM FOR A DC SYSTEM

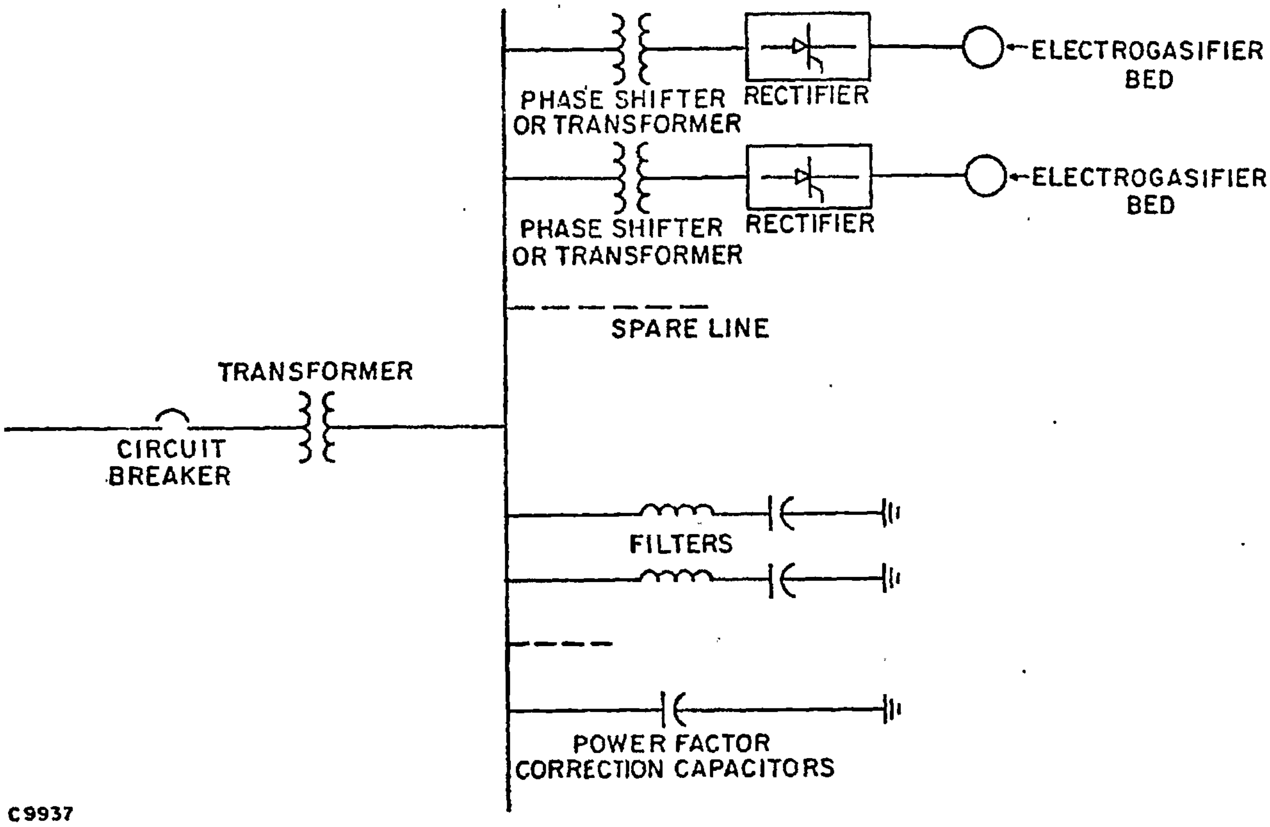

Figure 4

ONE LINE DIAGRAM FOR A 110 MW DC SYSTEM

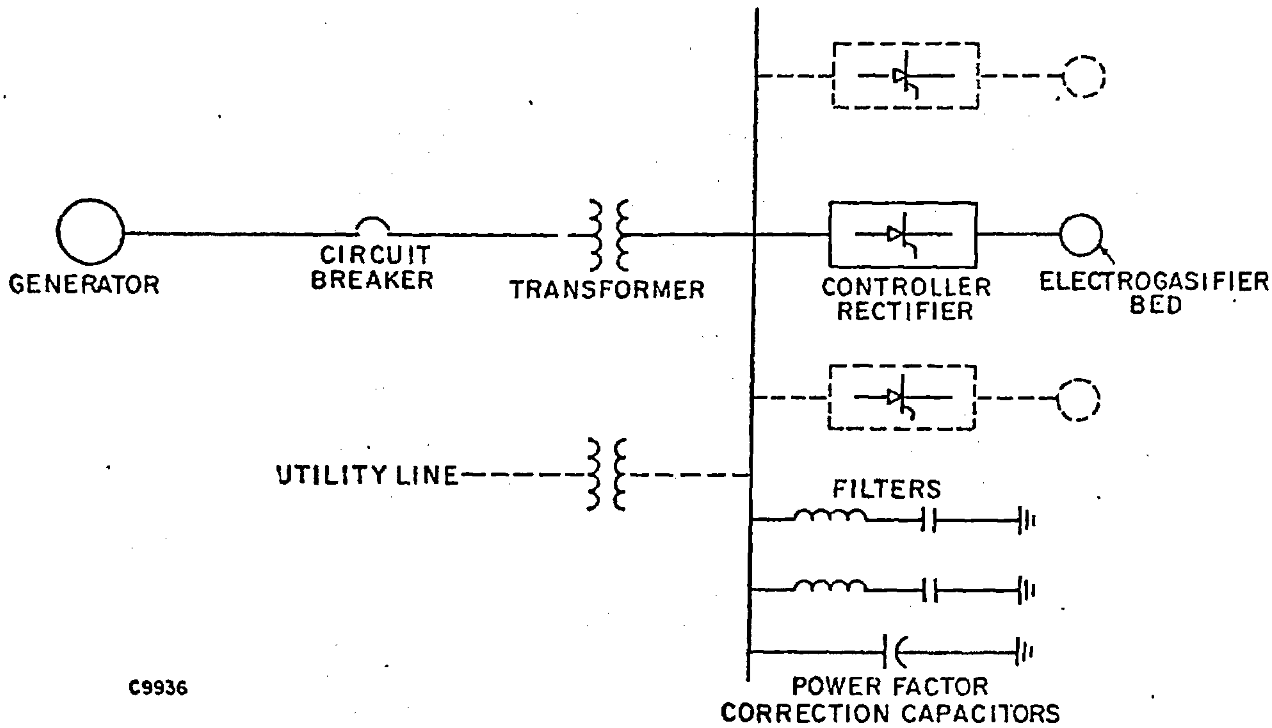

Figure 5

4. SPECIFIC ANALYSIS OF A CAPTIVE ELECTRIC POWER SYSTEM FOR A 110 MW ELECTROGASIFIER

a. As already mentioned, if an electrogasifier is connected to a utility system, it is desirable that the utility system capacity be large compared to the electrogasifier (10 to 100 times) so that electrical load fluctuations caused by the electrogasifier will have a minimum effect on the other utility users. Whereas this is not a consideration (except possibly in a very limited manner) using a captive electric generating system, other aspects of this type of a system need to be considered to obtain an optimum system and optimum performance. The generating equipment capacity of a captive electric generating system is for reasons of economy comparable to the load requirement. As a consequence, it becomes important to examine the dynamic response of interconnected systems to establish that acceptable performance can be obtained. This is particularly true in the present case since the load can vary with time in the worse case. The matter of harmonics and their effect on generator performance and size is equally important. As part of the design effort, an analysis was performed both to establish the feasibility of achieving acceptable performance and to establish design guidelines for the interconnected system. Since the details of 110 MW power generating systems have not been set at this time, worse cases were analyzed.

Discussion of the Results

In the present analysis the transfer function of the control governor was not taken into account. Typically, the response time of turbine governors varies 0.2 to 2 seconds.

To prevent continuing oscillations or hunting it is expected that the alternator will incorporate damping windings of appropriate size. The response of the turbo-alternator to sudden changes also depends on the inertia of both the turbine and generator rotors. For a captive system, operating alone, it seems that the combined inertias should be as large as possible to counteract changes (in the same manner as inductance does in an electric circuit). If the captive generator is to be paralleled with a utility system, then consideration must be given to the matter of stability before the relative inertias are specified.

b. Analysis of Electrical Performance

The analysis discussed above was macroscopic in nature while the analysis to be discussed now was microscopic in nature. In the previous analysis, harmonics due to rectification, currents induced in the excitation, currents induced in the damping windings and other detailed effects were neglected. In the present analysis a system composed of a salient pole synchronous machine connected to a full wave bridge rectifier which feeds a nonlinear resistive load is analyzed. The foremost goals of the analysis included:

1) determining exact current and voltage wave forms to determine what harmonics are present

and

2) determining the effect of rectification on rotor oscillation.

The analysis was performed using Sceptre with the appropriate electric models for the machine, rectifier, nonlinear load and filters being used. Not only was the electrical response calculated, but at the same time, equations of the type used in the previous analysis were added to the program to determine the amplitude and characteristics of all generated mechanical transients.

Discussion of Results

The results show that it is mandatory to filter the input to the rectifier so as to avoid buildup of harmonics in the generator. Permitting harmonics to get into the generator could lead to additional heating, degradation of the excitation magnetic field and mechanical oscillations of the rotating masses. Of these, the last is most important. Analysis has shown that the other two effects will cause minimal change in performance of the generator. If other loads are to be supplied, however, filters need to be used to make the output voltage sinusoidal. Adding filters would be preferable in terms of cost to increasing the rating of the generation equipment.

In summary, it can be said that both analyses lead to the conclusion that it is feasible to use a captive electric generating system without incurring serious obstacles or large additional equipment costs.

5. EQUIPMENT CAPITAL COST ESTIMATES

Two important cost elements are required to arrive at power supply costs. These are the cost of a conventional power plant for the case of a captive system and the cost of the AC switch or controlled rectifier for both captive and utility supplied systems. Adequate basis for establishing the price exist for both of these system elements although there is still considerable fluctuation in the price of the solid state converters.

It is expected that as time goes on, this cost is likely to come down.

a. Conventional Power Plant Costs

Table 2 presents the cost of conventional power plants taken from the recent literature. For a plant in the 110 MW size the cost was approximately $200/KW in about 1970. The escalated price for 1972 is $212/KW. For information, bringing in a transmission line for the coal electrogasifier costs $150/MW mile (1970)($159-1972) as given in the last reference of Table 2.

b. Solid State Conversion Equipment

Information on solid state switches and inversion equipment is not as clearly defined. However, applications are increasing and it is only a matter of time before the prices become stabilized and catalogued. Undoubtedly, one or more high voltage DC transmission lines will start construction in the next few years. Once the first starts, others will follow rapidly. In conjunction with MHD for utility systems a cost of $30/KW has been established for the first 50 MW solid state converter (ASEA, Inc.). This price will drop 20% in the same size during the next 10 years. Further in the larger sizes an economy of another 20% can be realized. These prices