IGT-MPR--7/70

IGT EDUCATION · RESEARCH

INSTITUTE OF GAS TECHNOLOGY - IIT CENTER - CHICAGO 60616

NPC

Project Status Report
For
OFFICE OF COAL RESEARCH
and
AMERICAN GAS ASSOCIATION

Report For July 1970
OCR Report No. 70

Project Title Pipeline Gas From Coal — Hydrogenation (IGT Hydrogasification Process)

OCR Contract No. 14-01-0001-381 (1) A.G.A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

HIGH-PRESSURE METHANATION

The rate expression developed from data at 575°F correlates well with that from data at 740°F.

Shakedown tests were conducted on the laboratory unit built to study the effect of gaseous sulfur compounds on methanation catalyst performance.

ENGINEERING ECONOMICS STUDIES

An examination of the financial factors used in the two Bureau of Mines gasification processes showed some apparent inconsistency in the assumed effective cost of coal.

The 500 billion Btu/day pipeline-gas plant from lignite was revised to include conventional steam-turbine power generation instead of MHD generation. The gas price increases from 33¢ to 40¢/million Btu when the steam cycle is used.

DEVELOPMENT UNIT STUDIES

Two tests were made this month to study the hydrogasification behavior of a New Mexico subbituminous coal from Farmington. The coal feed was dried, but otherwise not pretreated. Agglomeration in the reactor tube stopped both tests. Two hours of normal feeding preceded blockage in the first test.

One of the five electrothermal gasification tests made this month showed indications of the effect of the magnetic flip coil on the bed's electrical behavior. The frequency of the current flicker was noticeably reduced; the amplitude of the flicker was unchanged. In the fifth test this month the steam superheater coil ruptured and is being repaired.

NEW PROCESS STUDIES

The fuel cell engineering study conducted earlier this year was extended to allow the study of alternative process schemes to use the heat from the fuel cell power plant directly in the HYGAS Process. We hope that these modifications will improve the process' economics.

PILOT PLANT CONSTRUCTION

Engineering is 99% complete. Purchasing is 98% complete, with the award of the last major subcontract for painting. Material receipt is 96% complete. Items delayed by the recent truck strike are beginning to arrive. Construction is 77% complete. Of this, piping is 88% complete and instrumentation is 40% complete.

The design of the 2-MW electrothermal gasifier system continues at Procon. Emphasis is placed on revising piping and instrument diagrams and vessel details.

III. Problems

No major problems were encountered this month.

IV. Recommendations

We recommend that the project proceed in the areas defined in the contract amendment.

V. Status of Funding

1. A.G.A. Funding

A.	1970 Funds Allocated	$ 300,000
B.	Funds Expended This Month (estimated)	$ 25,000
C.	Funds Expended to Date (estimated)	$ 233,000

2. OCR Funding

A.	Funds Expended This Month (estimated)	$ 650,000
B.	Funds Expended Since Contract Amendment No. 1 (estimated)	$7,390,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective will be attained within the contract term and the funds allocated.

Approved: Frank C. Schora, Jr.
Director

Signed: Bernard S. Lee
Manager

Jack Huebler
Vice-President

Appendix. Achievements in July

HIGH-PRESSURE METHANATION

Study of the temperature dependence of the rate of methanation continues. Experimental results are presented in Table 1. The rate expression —

$$r = \frac{k_1 p_{CO} p_{H_2}^{1/2}}{1 + k_2 p_{H_2} + k_3 p_{CH_4}} \qquad (1)$$

was developed based on extensive experimental work at 575°F, and was tested with data obtained at 740°F. Theoretically, k_1, k_2, and k_3 are all functions of temperature. The rate constant, k_1, is traditionally expressed as —

$$k_1 = k_0 \exp\left(-\frac{E}{RT}\right) \qquad (2)$$

Previous experience indicated that the effect of excess H_2 and CH_4 is small, and if the rate expression, Equation 1, is representative of the methanation kinetics, it should apply at other temperatures and low pressures without modification of k_2 and k_3. As shown in Figure 1, the rate expression works well at 740°F.

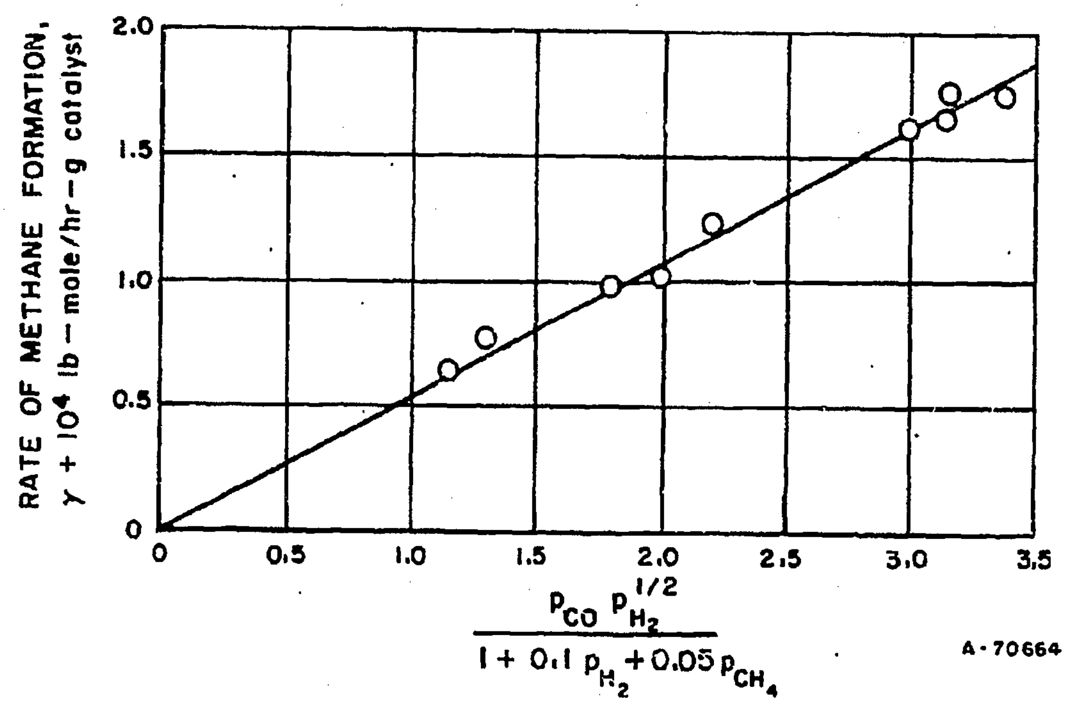

Figure 1. RATE OF METHANE FORMATION AT 740°F

Table 1. METHANATION RUN DATA
Catalyst: Harshaw Ni 0104-T; 1/4-in. pellets

Run No.	307	308	309	310	311	312	313	314	315	316	317	318
Catalyst Wt, g	2.0521	2.0318	2.0318	2.3448	2.3448	2.3448	2.3448	2.3448	2.3448	2.3448	2.3448	2.3448
Feed Gas Rate, SCF/hr	2.4556	2.2087	2.8437	1.8673	3.1487	2.3752	1.3530	3.2841	2.5327	1.6800	1.6588	1.3712
Feed Gas Composition, mole %												
Hydrogen	91.92	91.07	92.48	90.56	89.8	90.87	94.24	90.48	95.31	91.26	92.36	90.96
Carbon Monoxide	8.0	8.85	7.45	9.4	10.2	9.07	5.7	9.5	4.65	8.7	7.6	9.0
Carbon Dioxide	0.08	0.08	0.07	0.04	0.0	0.06	0.06	0.02	0.04	0.04	0.04	0.04
Methane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Reactor Temperature, °F	606	747	746	638	642	740	740	742	742	742	740	737
Reactor Pressure, psig	109	108	108	55	75	85	85	47	57	57.5	67	67
Product Gas Rate, SCF/hr	2.0725	1.6935	2.4638	1.4128	2.4403	1.8831	1.2019	2.7236	2.3267	1.3354	1.3891	1.0930
Product Gas Composition, mole % (dry basis)												
Hydrogen	88.95	90.69	91.9	82.35	85.23	87.06	92.6	87.73	94.6	89.14	91.02	89.39
Carbon Monoxide	3.5	3.5	3.25	2.65	4.85	3.4	1.4	5.5	2.0	3.4	2.5	2.8
Carbon Dioxide	0.2	0.21	0.15	3.7	0.42	0.34	0.1	0.27	0.1	0.31	0.18	0.21
Methane	7.35	5.6	4.7	11.3	9.5	9.2	5.9	6.5	3.3	7.15	6.3	7.6
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.0	100.00	100.0	100.00	100.00	100.00
Feed H_2/CO Ratio	11.5	10.3	12.4	9.6	8.8	10.0	16.5	9.5	20.5	10.5	12.2	10.1
Water Produced, lb/hr X 10^4	0	0	0	39	0	46	58	94	29	60	39	24
Rate of Methane Formation, (lb-mole/hr-g catalyst) X 10^4	1.49	1.72	1.66	0.95	2.12	1.77	0.67	1.79	0.77	1.11	0.99	1.01

Several pieces of equipment were repaired or replaced during shakedown tests on the laboratory unit built to study the behavior of methanation catalysts in the presence of various sulfur compounds. As soon as calibration is completed, testing will begin.

ENGINEERING ECONOMICS

At the request of the OCR we studied two plant cost estimates by the Bureau of Mines. They are for 250 million SCF/day pipeline gas from coal by two processes: 1) fluidized gasification followed by methanation, and 2) two-stage hydrogasification followed by cleanup methanation. Both plants include costs for the coal mining operation integrated with the gas plant. We were interested in the financial aspects, rather than in a study of the investment and operating costs. For the same investment and operating costs, differences between the Bureau's and IGT's calculations are from 1¢ to 2¢/1000 CF for 5-7.5% interest rates and a return in rate base of 7-9%. Larger differences occur in the factors used by the Bureau and IGT to calculate fixed investment from previously determined construction costs. From our analysis it appears that the effective cost of coal in process 1 is about $3.10/ton and for process 2 is $3.80/ton. However, this difference is unexplained since coal requirements and mining methods are the same. Such a difference enhances process 1 relative to process 2 by about 4¢/million Btu.

In the Second Quarter Report, June 1970, water and air cooling were compared for the design of a 500 billion Btu/day pipeline-gas plant from lignite. To continue this comparison, we revised the power plant section to produce power by conventional steam-turbine generation. In the original design, most of the total plant requirements of 741 MW were supplied by the MHD unit. Spent char from the electrogasifier plus 95,100 lb/hr lignite supplied all the fuel for the power plus an excess of 126.6 MW as by-product power. High-pressure process steam was also generated in the power plant by waste heat.

In the conventional system, gas plant power and process steam are also generated, but extra lignite is required and there is no by-product power. To summarize briefly —

	MHD + Steam Power Cycle	Conventional Steam-Power Cycle
Power Plant Bare Cost, $	76,820,000	116,646,000
By-product Power, MW	126.6	none
Fuel, lb/hr		
Spent Char	777,840	777,840
Lignite	95,120	317,115
Overall Efficiency, %	74	54
Gas Price, ¢/10^6 Btu (with lignite at 8¢/10^6 Btu)	33	40

Further details will be given when the comparison of air and water cooling is completed.

We prepared a paper, "Hydrogen: A Key to the Economics of Pipeline Gas From Coal," for presentation at the American Chemical Society Fuels Symposium in Chicago in September 1970.

DEVELOPMENT UNIT STUDIES

Hydrogasification Tests

The experimental investigation of the hydrogasification behavior of Western subbituminous coals in the high-temperature, balanced-pressure development unit was extended to tests with New Mexico subbituminous coal from several seams in the Farmington area. Two tests, Runs HT-249 and HT-250, were performed with this subbituminous coal at the standard processing conditions of 1000 psig pressure and 1700°F coal bed temperature.

The Pit "A" coal was prepared for hydrogasification by crushing and screening to a −10+80 mesh size range, and drying to a 1-2% moisture level. An as-received analysis of this coal is given in Table 2.

The first test, Run HT-249, was partially successful. It had to be terminated after a brief steady-state period when the coal began to agglomerate in the reactor. The second test, Run HT-250, had to be shut down before steady state was reached because the coal agglomerated at the outlet of the coal feed tube. Significant features of the two tests are given in Table 3.

In both tests, the coal was gasified in a 3.5-ft fluidized bed with a mixture of hydrogen and steam. Nominal flow conditions for Run HT-249 were 66.6 lb/hr coal, 530 SCF/hr hydrogen, and 25.3 lb/hr steam. At these flow conditions

Table 2. CHEMICAL ANALYSIS OF AS-RECEIVED NEW MEXICO SUBBITUMINOUS COAL, PIT "A," FARMINGTON, NEW MEXICO

Proximate Analysis, wt %	
Moisture	13.8
Volatile Matter	34.9
Fixed Carbon	13.2
Ash	38.1
Total	100.0
Ultimate Analysis (dry), wt %	
Ash	15.28
Carbon	65.1
Hydrogen	4.90
Sulfur	0.55
Oxygen	12.93
Nitrogen	1.24
Total	100.00

Table 3. FEATURES OF HYDROGASIFICATION TEST RESULTS FOR RUNS HT-249 AND HT-250

Run No.	Temperature, °F	Purpose of Run	Results
Feed Solids: Dried New Mexico Subbituminous Coal, Pit "A"			
HT-249	1300-1700	To investigate the hydrogasification behavior of this coal	Partially successful; moderate agglomeration in reactor
HT-250	1300-1700	Same as HT-249	Coal agglomerated at coal feed tube outlet

the hydrogen-to-coal ratio was 25% of the stoichiometric ratio and the steam concentration in the feed gas was 50 mole percent. Coal feeding proceeded uninterrupted from the start through four bed-level control discharge cycles before agglomeration in the reactor began to affect its flow through and feeding to the reactor. Coal blockage resulting from the agglomeration cleared only temporarily after the initial holdup. Coal feeding was resumed for a period of 4 minutes before the coal feed screw jammed. The test lasted over 2 hours, during which coal was fed, with 17 minutes at nearly steady-state conditions. Residue removed from the reactor contained agglomerated coal 1-3 inches in diameter. More detailed hydrogasification results of Run HT-249 will be presented when the analyses of this test are completed.

For the second test, Run HT-250, with the same coal, the feed-gas flow rates were set so that the steam concentration was 30 mole percent. This allowed for operation with a greater hydrogen concentration in the feed gas than in Run HT-249, and reduced the coal's tendency to agglomerate. Coal feeding was started at approximately one-half the steady-state rate of 66.6 lb/hr, with a feed gas-steam concentration of less than 30 mole percent. After 30 minutes of feeding coal, the feed screw stopped as coal agglomerated at the outlet of the coal feed tube. Coal feeding was resumed after the plug was cleared, but for only 27 minutes before another plug formed. The run was shut down when the plug could not be cleared. Agglomeration in this test was less severe than in Run HT-249. It appeared to be mainly confined to the zone at the outlet of the coal feed tube. Closer control of the coal heat-up rate in the upper part of the reactor may be necessary to minimize the agglomerating tendency of the coal.

Coal Preparation

Crushing, screening, and drying operations were conducted with the New Mexico subbituminous coal to make it suitable for a feed to the hydrogasification development unit. About 425 lb of Pit "A" bituminous coal was crushed in a swing hammer mill, screened to a -10+80 mesh size range, and dried in the coal pretreatment unit. The coal was dried with a mixture of air and nitrogen at 275°F in a fluidized bed from an as-received moisture level of 13.8% to 1-2%. In similar operations, about 500 lb of Pit "B" bituminous coal was prepared.

ELECTROTHERMAL GASIFICATION

Five tests were conducted during the month to determine the effect of the magnetic flip coil on the electrical characteristics of the pilot unit. Operating problems caused the termination of four of the runs before steady state was attained. In the fifth test a 30 minute steady-state period was achieved.

Pressure cycling in the unit during the heat-up period of Run EG-57 caused erratic fluidization and subsequent plugging of the gas offtake line with char. After clearing the plug, pressure cycling continued. Then the discharge screw jammed and the test was terminated. Inspection of the unit following the run showed that the electrode tip was melted along several inches and metal pellets had lodged in the discharge screw; no damage was done to the 6-inch reactor wall. The melted tip was apparently caused by erratic fluidization during heat-up.

Pressure upsets and erratic fluidization were evident during the heat-up of Run EG-58. The test was terminated when the discharge screw jammed and arcing occurred through the bed. However, the electrode was only slightly pitted after the run and the discharge screw was clear of metal pellets. The discharge screw packing bound when the screw housing became warm and was replaced. The pressure letdown regulators were fitted with new diaphragms to prevent the pressure cycling which occurred during the two tests.

The gas offtake line became plugged during the heat-up period of Run EG-59; after clearing it we were unable to move solids through the reactor. The char bed became packed due to the plug in the gas offtake line and could not be fluidized. The low resistance of the packed bed prevented the control of power to the unit and the test was terminated.

A steady-state period of 30 minutes was maintained in Run EG-60, during which data were collected on the oscillograph at conditions outlined by our electrical consultants for magnetic coil operation. These data will be analyzed to determine what effect the magnetic coil has on the electrothermal operation. Observation of the direct-current ammeter during the flip coil's operating period showed that the frequency of the current "flicker" was noticeably reduced. However, the amplitude of the flicker still varied over a range of about ±1.5 times the average current — similar to the variation without the flip coil. Further results from the oscillograph's data will be reported when they become available. Nominal conditions during steady state were —

Run No.	Char Feed Rate, lb/hr	Steam Feed Rate, lb/hr	Reactor Temp, °F	Reactor Press., psig	Power Input, kW	Overall Resistance, ohm
EG-60	125	125	1800	1010	50	0.57

Since there was a noticeable effect on the current's behavior during the flip coil operation, Run EG-61 was conducted to obtain additional oscillograph data at various power settings of the magnetic flip coil and thus provide a range of variables for study. As the switch from fluidizing nitrogen to steam was being made a sudden loss of pressure in the steam superheater plus the loss of steam flow to the reactor caused the shutdown of the test. Inspection of the superheater coil following the test showed that the coil was ruptured. It was set to the manufacturer for repair, if possible, or replacement. Since several months could pass before getting the superhea back on-line, IGT is fabricating a coil of 9/16-inch stainless steel for placement in the present nitrogen preheat furnace for use as a steam superheater. Although this heater will have a much lower heating capability, it should put the pilot unit back in operation in 7-10 days.

NEW PROCESS STUDIES

Fuel Cell Engineering Studies

Estimated electrical energy costs for a fuel cell power plant were reported in the First Quarter Report, March 1970. The cost figures were based on a 793-MW power plant with a 402-MW output from the fuel cell plant and a 391-MW output from a heat recovery turbogenerator plant. The energy cost was estimated between 4.5 and 5.4 mills/kWhr. However, if the heat from the fuel cell plant can be directly utilized, the economics of the plant may be improved, resulting in a lower energy cost.

The following schemes will be examined for utilization of heat output from the fuel cell plant:

1. Generation of high-pressure steam which can be directly used in the hydrogasifier, electrogasifier, etc. Since the hot gases coming out from fuel cells are about 1370°F, steam at 1200 psig and 1025°F can be generated. Steam credit may be taken in the cost estimate for the fuel cell plant.

2. Hot gases from the fuel cell plant contain 15% CO_2, 9% O_2, 7% H_2O, and 69% N_2. These gases can be fed to the producer gas unit supplying fuel gas to the plant. Certain portions of the gases will have to be purged to avoid N_2 buildup in the system.

3. In Scheme 2 the possibility of supplying enriched air or oxygen will also be examined to see if any benefits are realizable.

Preliminary schemes and cost estimates will be presented in the next report.

PILOT PLANT CONSTRUCTION

Engineering

Engineering work is continuing on recent additions to the project. Several of the most recent additions concern tie-ins with the electrogasifier unit.

Field changes and corrections are being recorded and "as built" drawings will be made after completion of construction.

Procurement

The painting subcontract was the last major subcontract to be let. During the recent truck strike, several critical items that were caught in the boycott of Chicago were reordered and air freighted or cancelled and bought locally.

Several specifications were sent out for bid for items that are part of recent extra work orders.

Construction

Major field activities during this report period have been area piping, pipe pressure testing, electrical work, and instrumentation. Piping is 88% complete and instrumentation is 40% complete. The electrical subcontract work, particularly the instrument electrical work, is behind schedule. On the present straight-time basis, this work will extend beyond the scheduled mechanical completion date. IGT and Procon are reviewing the possibility of overtime or an additional shift for this subcontract work.

We have experienced a total of 27 inclement weather days, three of which occurred in this report period. On these days progress was negligible.

IGT-MPR--8/70

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Project Status Report For OFFICE OF COAL RESEARCH and AMERICAN GAS ASSOCIATION

Report For August 1970

OCR Report No. 71

Project Title Pipeline Gas From Coal — Hydrogenation (IGT Hydrogasification Process)

OCR Contract No. 14-01-0001-381(1) A.G.A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

HIGH-PRESSURE METHANATION

The study of the methanation reaction was extended to 850°F. The rate expression developed at 575°F still applies at 850°F.

After shakedown, the sulfur reactance study equipment was modified to improve operation.

ENGINEERING ECONOMICS STUDIES

Details of four cases for producing pipeline gas from lignite using electrothermal gasification are presented: power generation with the MHD system or a conventional steam-turbine system, each with air cooling or water cooling. Air cooling shows about a 1¢/million Btu cost advantage on the gas price over water cooling at a 3.5% makeup water rate, and greater advantage at higher makeup.

DEVELOPMENT UNIT STUDIES

Two more tests were made this month to study the hydrogasification behavior of dried but otherwise untreated New Mexico subbituminous coal. One test was successful; the coal was first reacted with hydrogen alone and then with a hydrogen-steam mixture. Difficulties encountered to date with this coal can be attributed to equipment problems, and not the nature of the coal.

Another test with the magnetic flip coil on the electrothermal gasifier was made, which confirmed the findings of the earlier test. Although some additional tests with the coil may be made later, no flip coil will be used in the 2-MW unit. The reasons are that the fabrication and installation of the coil can be difficult, and the coil requires significant power that only reduces the frequency of current flicker but not the amplitude.

PILOT PLANT CONSTRUCTION

Engineering is 99% complete, except for field changes. Purchasing is 99% complete. Material receipt is 98% complete. Construction is 92% complete. Of this, piping is 96% complete and instrumentation is 85% complete. Sections of the plant are expected to be turned over to IGT by September.

The design of the 2-MW electrothermal gasifier system continues at Procon. The gasifier vessel has been placed on order with Struthers-Wells Corporation.

III. Problems

No major problems were encountered this month.

IV. Recommendations

We recommend that the project proceed in the areas defined in the contract amendment.

V. Status of Funding

1. A.G.A. Funding

A.	1970 Funds Allocated	$ 300,000
B.	Funds Expended This Month (estimated)	$ 25,000
C.	Funds Expended to Date (estimated)	$ 258,000

2. OCR Funding

A.	Funds Expended This Month (estimated)	$ 340,000
B.	Funds Expended Since Contract Amendment No. 1 (estimated)	$7,750,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective will be attained within the contract term and the funds allocated.

Approved ______________________
Frank C. Schora, Jr.
Director

Signed ______________________
Bernard S. Lee
Manager

____
Jack Huebler
Vice-President

Appendix. Achievements in August

HIGH-PRESSURE METHANATION

The rate of the methanation reaction was studied at 850 °F. The results are presented in Figure 1 together with data obtained at 740 ° and 575 °F.

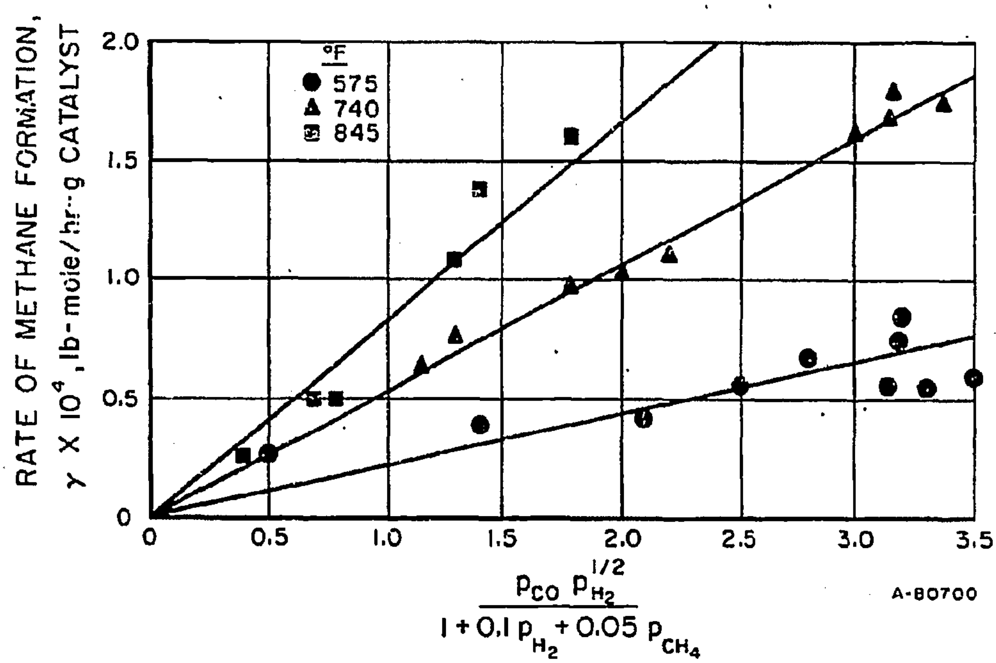

Figure 1. RATE OF METHANE FORMATION AT 575°, 740°, AND 845°F

Most of these data were obtained at pressures of 300 psig or less and away from equilibrium conditions. An Arrhenius plot (Figure 2) was constructed based on these experimental data to show the temperature dependence of the methanation rate. Since more data are available for better estimation and analysis, Figure 2 supersedes that presented in the Second Quarter Report.

Sulfur Resistance Studies

Several instruments were added to the apparatus, and the sampling system was modified. A schematic diagram of this apparatus is shown in Figure 3. The instruments are being calibrated and tested.

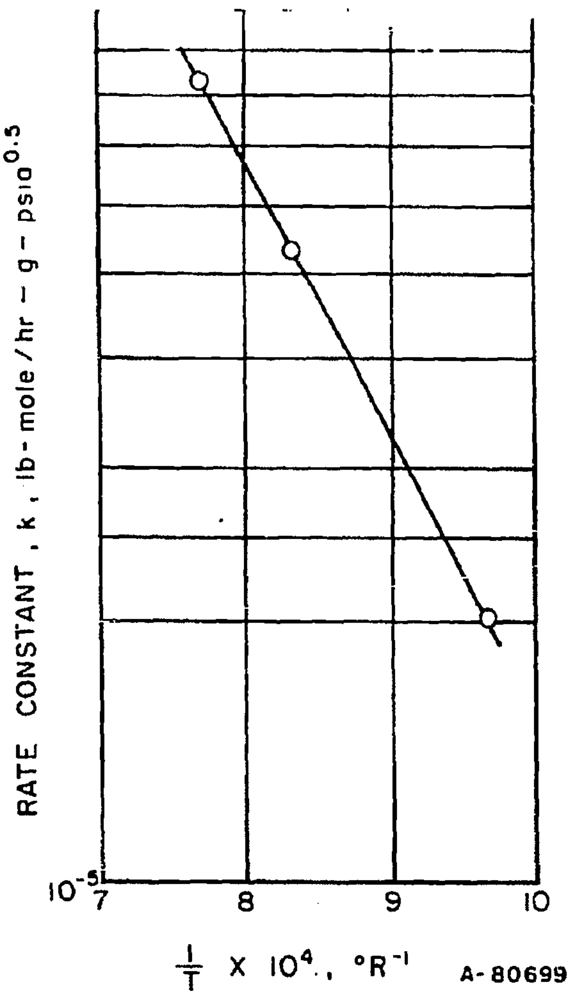

Figure 2. ARRHENIUS PLOT FOR METHANATION

ENGINEERING ECONOMICS

Air and Water Cooling in Pipeline Gas From Lignite Plants With MHD and Conventional Steam Power Plants

The June work report presented results of using air cooling for the pipeline gas from lignite plant. In that design the proven and economic effects for three alternatives to the base case were presented. Compared to the base case a large savings in makeup water resulted, and for this design the

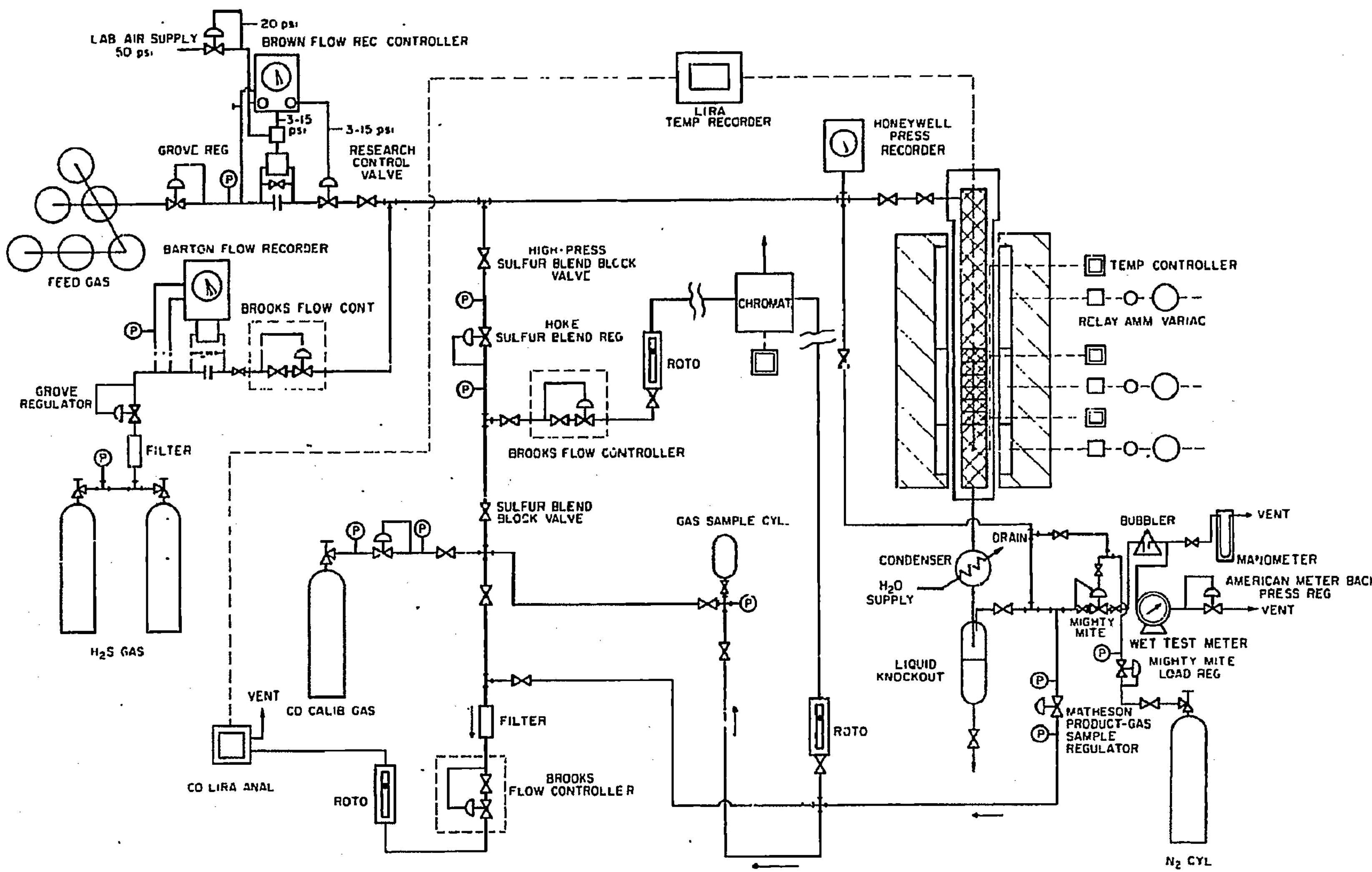

Figure 3. METHANATION CATALYST SULFUR TOLERANCE TESTING APPARATUS

price of gas was reduced by 1¢/million Btu. In these cases the original MHD steam power system was retained. In that design, shown in Figure 4, all of the spent electrogasifier char plus 12% additional lignite were used to fuel the MHD-steam power system, which produced all plant power plus 126,600 kW of by-product power.

Since then, a conventional steam-power system has been designed to produce required power and process steam, again on an integrated basis. In this design, no by-product power and an additional 39% more lignite are required in addition to the spent char. This is because of lower efficiency for the conventional system. Table 1 compares overall energy balances for the two systems. Note that the numbers are slightly different for the MHD steam-power system from those in the original report.[1] These numbers were given by Avco based on char feed to the MHD unit. For producer gas feed to MHD, we found that additional lignite was needed to achieve the desired gas production rate and temperature. In calculating the process economics, this additional lignite was included in the raw material requirements. Total output of power and process steam generation is 67.8% of fuel input. The original report showed an efficiency of 74% for the MHD-steam cycle. These are Avco's figures and do not include the added lignite fed to the producer. The economics did include this, however. For the conventional system the output is 53.6% of input. Conventional power is less efficient than the combined MHD-steam turbine system. Integrating process steam generation with the power plant increases the efficiency of both systems.

The need for an estimate of a steam power system was discussed with representatives of General Electric Co. Figure 5 shows the system based on their recommendations. Two turbines are used. A small turbine extracts 65,000 kW in depressurizing 2,429,970 lb/hr of steam from 3500 to 1250 psig. This steam is then sent to the gas plant as process steam. As in the original design, 1,597,130 lb/hr are reheated to 1025°F before being sent to the gasifiers. Boiler feed water, preheated to 425°F in the gas plant as before, is used for the steam.

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1 Tsaros, C. L., Arora, J. L., Lee, B. S., Pimental, L. S., Olson, D. P. and Schora, F. C., "Cost Estimate of a 500 Billion Btu/Day Pipeline Gas Plant Via Hydrogasification and Electrothermal Gasification of Lignite," R&D Rep. No. 22, Interim Rep. No. 4. Washington, D. C.: Office of Coal Research, 1968.

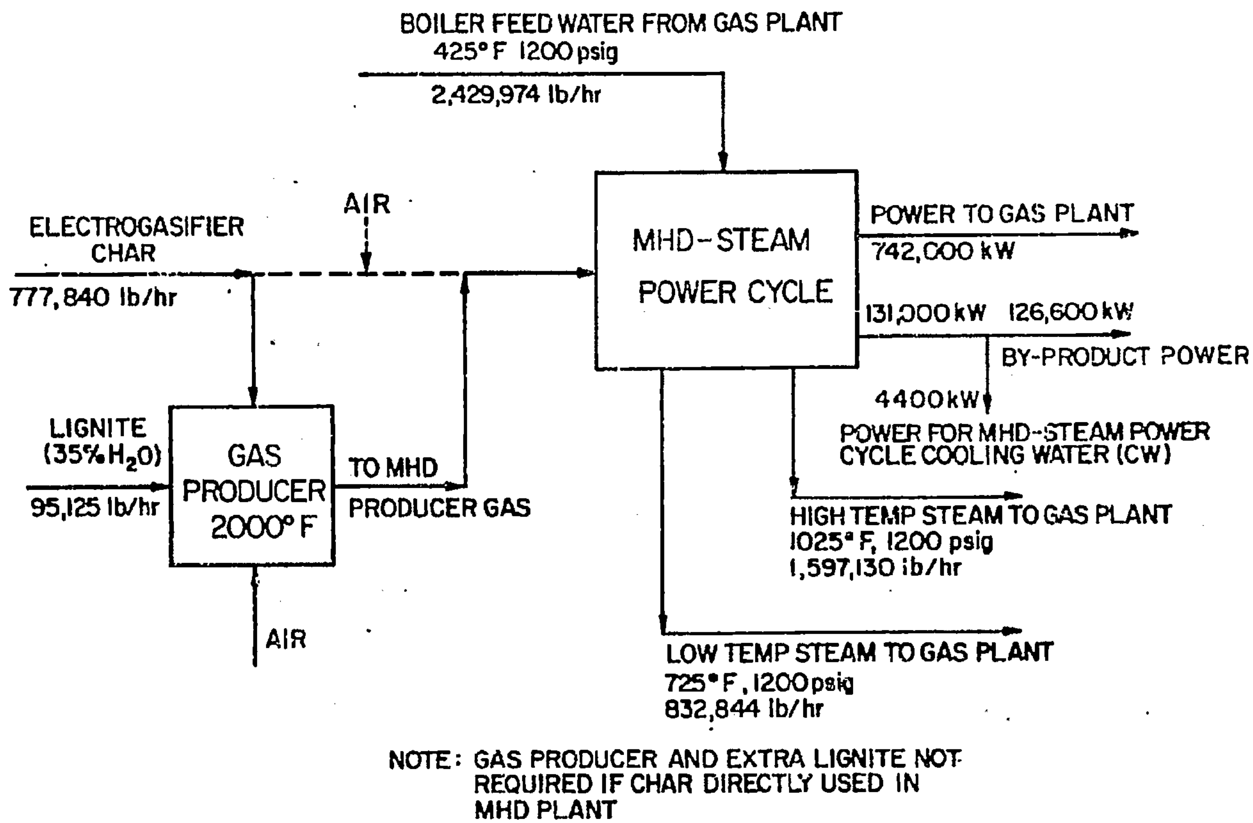

Figure 4. BLOCK FLOW DIAGRAM FOR MHD AND STEAM GENERATION

Table 1. ENERGY BALANCE FOR CONVENTIONAL STEAM-POWER SYSTEM

	10^6 Btu/hr	MW	%
Spent Char, HHV	7448.6	2182	--
Lignite, HHV	2099.3	615	--
Total Fuel Value Input	9547.9	2797	100
Power Output	2576.8	755	27.0
Heat to Process Steam	2540.8	744	26.6
Overall Output	5117.6	1499	53.6
Condenser Heat Rejected	2978.7	873	31.2
	8096.3	2372	
Stack and Other Losses	1451.6	425	15.2
			100.0

ENERGY BALANCE FOR MHD-STEAM POWER SYSTEM

	10^6 Btu/hr	MW	%
Spent Char, HHV	7448.6	2182	--
Lignite*	698.7	205	--
Total Fuel Value Input	8147.3	2387	100
Power Output	2979.5	873	36.6
Heat to Process Steam	2540.8	744	31.2
Overall Output	5520.3	1617	67.8
Condenser Heat Rejected	1324.2	388	16.2
	6844.5	2005	
Stack and Other Losses	1302.8	382	16.0
			100.0

* Input to producer (95,124 X 7345 = 698.7 X 10^6 Btu/hr)

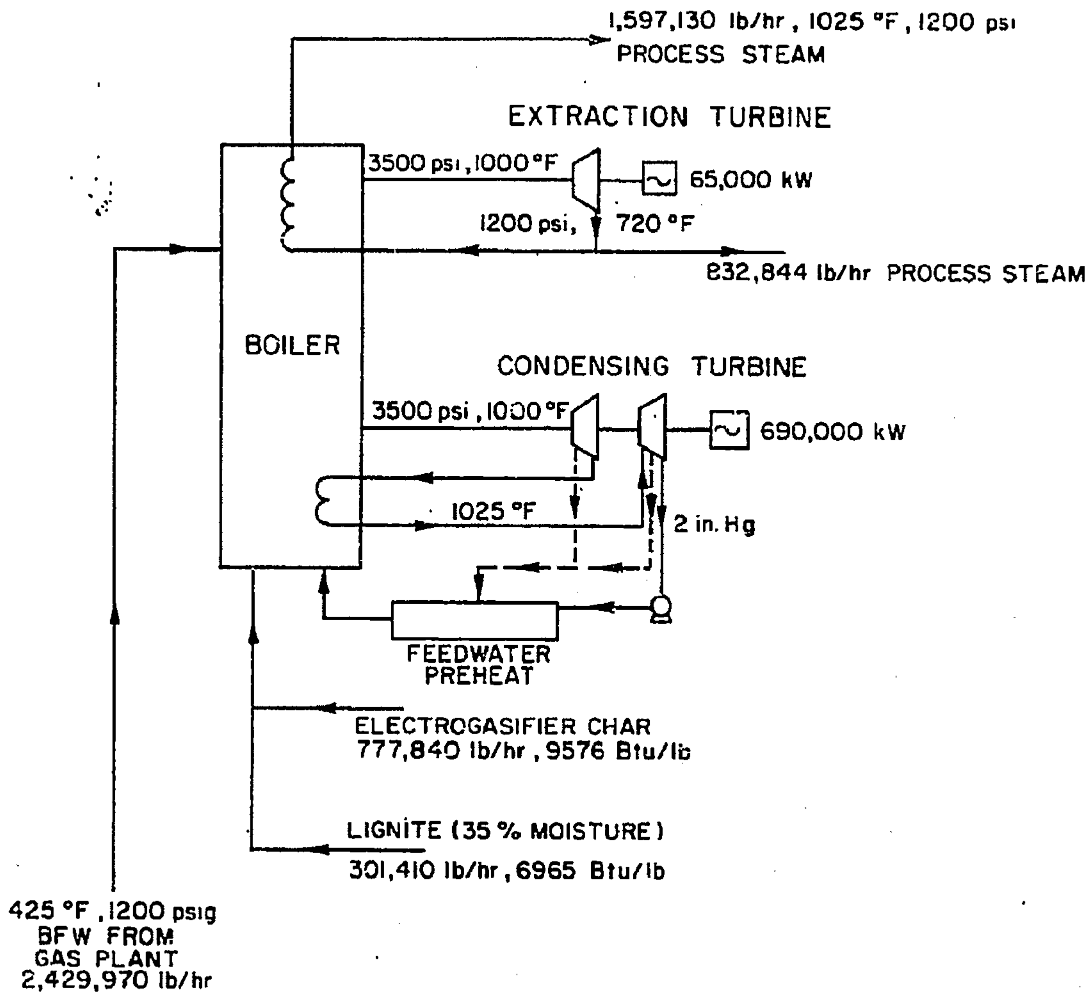

Figure 5. FLOW DIAGRAM FOR POWER AND STEAM GENERATION FOR 500 MILLION SCF/DAY PIPELINE GAS FROM LIGNITE PLANT WITH CONVENTIONAL POWER PLANT AND WATER COOLING

The bulk of the power, 690,000 kW, is generated in a separate, closed steam-turbine system typical of utility operation, with expansion from 3500 psig to 2 in. Hg. Condensate is returned to the boiler.

Installed capacity of the conventional power system is 755,000 kW. Cost of the generating system is $113 million compared to $69 million for the MHD steam-power system.

Costs of four separate systems have been developed based on the original design:

1. Original study — MHD-steam power system with water cooling
2. MHD-steam power with air cooling
3. Conventional power with water cooling
4. Conventional power with air cooling

The use of air and water coolers is applied to the gas plant as a whole as well as to the power section. In this final summary one of the alternatives presented in the Second Quarter work report was used for the air-cooling cases — cooling by air to 140 °F followed by water cooling to 100 °F, with quench tower water part of a closed system cooled in a shell and tube exchanger.

Table 2 summarizes the overall results. Air cooling saves 30% over rates with conventional power than with the original MHD-steam power system.

In calculating cooling water makeup for these cases we used 3.5% of the circulation rate. This is based on 3% evaporation in the cooling tower, a maximum of 0.2% windage (recommended by a cooling tower manufacturer), and the rest blowdown. For a higher percentage makeup, the savings with air cooling will be even larger.

Our studies show no economic penalty for the use of air cooling. Although the air cooling units themselves cost more than shell and tube exchangers, other savings in the plant counterbalance these costs. This is particularly so with reduction in the cost of the quench system — $7.9 million. Other savings are in the reduction of the plant cooling water system and in savings in annual power consumption. For both MHD and conventional steam-turbine power systems, overall investment is reduced slightly by using air cooling.

Table 2. SUMMARY OF WATER VERSUS AIR COOLING FOR DIFFERENT POWER SYSTEMS: 500 BILLION Btu/DAY PIPELINE GAS FROM LIGNITE PLANT

	MHD-Steam Power		Conventional Power	
Coolant	Water	Air	Water	Air
Makeup Water, gpm				
Process	4252	4252	4252	4252
Process Coolers	4929	785	4929	785
Power Plant Coolers	3094	--	6950	--
Quench Tower	3640	--	3640	--
Total	15,915	5037	19,771	5037
Recovered From Lignite Dryer	--	2075	--	2075
Net Makeup, gpm	--	2962	19,771	2962
Makeup, gal/day	22,917,600	4,265,280	28,470,240	4,265,280
Savings With Air Cooling, gal/day	--	18,652,320	--	24,204,960
Savings With Air Cooling, acre-ft/yr, 90 % sf*	--	18,808	--	24,408
Total Investment, $\$10^6$	228.1	220.6	273.7	269.2
20-Year Average Gas Price, ¢/10^6 Btu	32.9	31.8	40.4	39.5
Value of Water Saved at 10¢/1000 gal, ¢/10^6 Btu	--	0.19	--	0.24

* Stream Factor

Reduction in gas price is about 1¢. The large savings in water does not have a large cost effect per se. The main thing is availability of water and its effect on plant location with respect to fossil-fuel supply. If water costs 10¢/1000 gal, the effect on gas price is only 0.2¢/million Btu.

Tables 3-6 give details of the economic comparison of the four cases. These generally follow the format of the tables for the base case given in the original report.

Table 3 summarizes the power generation sections. Operating and maintenance costs for the MHD and conventional power systems were received from Avco and General Electric, respectively. A 50% general overhead charge was added in accordance with our usual procedure. Both investment and operating costs plus the lack of significant by-product credit result in an increase of 7.5¢-7.7¢/million Btu product gas price, from 32.9¢-40.4¢/million Btu. This is essentially a doubling of the power plant contribution to the gas price. For the air-cooled conventional system there is excess power because on an annual basis the fans average about one-third of the design base power, as described in the Second Quarter Work Report.

For the generators, including condensers and cooling water facilities, costs for the MHD-steam turbine system are $88/kW, compared to $155/kW for conventional steam-turbine systems. These figures do not include the cost of coal storage and preparation and ash disposal, which are charged to the gas plant. Table 4 summarizes the investment for the complete offsite system.

Table 5 is an investment summary for the entire plant. Differences in the gas plant costs are due mainly to reductions in the quench tower system.

Table 6 summarizes annual charges and revenue requirements. Changes in the power system have a greater effect than changes in the cooling system.

DEVELOPMENT UNIT STUDIES

Errata

Table 2 on page 8 of the July IU-4-1 Progress Report contains an error. The column under "Proximate Analysis, wt %," should read:

Moisture	13.8
Volatile Matter	34.9
Fixed Carbon	38.1
Ash	13.2
Total	100.0

Last month the numbers for the last two items were reversed.

Hydrogasification Tests

We continued our experimental investigation of the hydrogasification behavior of an untreated New Mexico subbituminous coal in the high-temperature, balanced-pressure development unit. Runs HT-251 and HT-252 were performed with this coal from the Farmington area at the standard processing

Table 3. SUMMARY OF POWER GENERATION SECTIONS

Power System	MHD-Steam Turbine		Conventional Steam Turbine	
Condenser Coolant	Water	Air	Water	Air
Fuel	Producer Gas	Producer Gas	Char-and-Lignite-Fired Boiler	
Design Net Power Output, MW	873	873	755	750
Bare Cost, $\$10^6$				
Generating Plant	69.000	73.645	113.000	122.903*
Char Combustor	6.300	6.300	--	--
Turbine Cooling - Water Facilities	1.520	--	4.146	--
Subtotal	76.82	79.945	117.146	122.903
Bare Cost, \$/kW	88	92	155	164
Lignite, lb/hr	95,120	95,120	301,410	294,900
Annual Operation and Maintenance, \$	2,673,000	2,673,000	4,985,000	5,083,000
By-Product Power, MW	126.6	139.9	--	19.55
Value of By-Product Power, \$/yr	2,994,500	3,308,900	--	462,500
Component of Pipeline Gas Price, ¢/10^6 Btu	7.05	7.14	14.60	14.88

* Includes \$13.800 X 10^6 for air-cooled turbine condensers less \$3.403 X 10^6 for water-cooled condensers.

Table 4. SUMMARY OF INSTALLED EQUIPMENT COSTS FOR OFFSITES

Power System	MHD-Steam Turbine		Conventional Steam Turbine	
Condenser Coolant	Water	Air	Water	Air
	Cost, $			
Spent Char Combustor and Auxiliary Equipment	6,300,000	6,300,000	--	--
Power Generator	69,000,000	73,645,300	113,000,000	122,896,000
Cooling Towers	2,400,000	313,100	3,570,000	313,100
Cooling Water Circulating Pump	1,144,000	106,000	1,560,000	106,000
BFW and Process Water Treatment and Deaeration	2,300,000	426,800	2,840,000	433,700
General Facilities	5,000,000	5,000,000	5,500,000	5,000,000
Total Bare Cost*	86,144,000	85,791,200	126,470,000	128,748,800

* Investment for power section in Table 3.

Table 5. INVESTMENT SUMMARY FOR 500 BILLION Btu/DAY PIPELINE GAS FROM LIGNITE PLANT WITH DIFFERENT POWER AND COOLING SYSTEMS

Power System	MHD-Steam		Conventional Steam Turbine	
Coolant	Water	Air	Water	Air
	Cost, $			
Gas Plant, ISBL*	115,514,000	109,196,200	115,514,000	109,196,200
Offsite Equipment (including Power Generation† Sections; See Table 4)	86,144,000	85,791,200	126,470,000	128,748,800
Subtotal, Bare Cost	201,658,000	194,987,400	241,984,000	237,945,000
Contractor's Overhead Profit	15,588,000	15,072,500	18,705,400	18,393,100
Subtotal	217,246,000	210,059,900	260,689,400	256,338,100
Interest During Construction, 5% of Subtotal	10,862,000	10,503,000	13,034,500	12,816,900
Total Fixed Investment	228,108,000	220,562,900	273,723,900	269,155,000

* ISBL: Inside battery limit.

† Cost of power section alone is given in Table 3.

Table 6. ANNUAL OPERATING EXPENSES AND REVENUE REQUIREMENTS FOR 500 BILLION Btu/DAY PIPELINE GAS FROM LIGNITE PLANT WITH DIFFERENT POWER AND COOLING SYSTEMS

Power System	MHD–Steam		Conventional Steam Turbine	
Cooling	Water	Air	Water	Air
	Cost, $			
Raw Materials (Lignite) at $1.17/ton	21,478,500	21,478,500	22,434,000	22,403,[illegible]
Other Direct Materials*	1,007,100	1,007,100	1,007,100	1,007,100
Direct Operating Labor*	2,299,500	2,299,500	2,299,500	2,299,500
Maintenance, % Bare Cost*	5,745,100	5,451,200	5,745,100	5,451,200
Supplies, 15% of Maintenance*	861,700	817,600	861,700	817,600
Supervision, 10% Direct Operating Labor*	229,900	229,900	229,900	229,900
Payroll Overhead, 10% Direct Operating Labor and Supervision*	252,900	252,900	252,900	252,900
General Overhead, 50% Direct Operating Labor and Supervision and Maintenance and Supplies*	5,418,100	5,249,200	5,418,100	5,249,200
Power Generation Operation Maintenance**	2,073,000	2,073,000	4,985,000	5,083,000
Depreciation	11,405,400	11,028,000	13,686,100	13,457,600
Local Taxes and Insurance	6,845,100	6,616,800	8,211,600	8,074,600
Operating Expenses	53,914,300	52,803,700	60,831,000	60,026,500
Contingencies, 2% Operating Expenses	1,078,300	1,056,100	1,216,600	1,200,500
Total Operating Expenses	54,992,600	53,859,800	62,047,600	61,227,000
By-Product Credit	12,783,400	13,098,900	9,788,900	10,251,400 ‡
Net Operating Expenses	42,209,200	40,760,900	52,258,700	50,975,600
Gross Return, 7% Rate Base, 20-Year Average	8,080,500	7,817,800	9,683,800	9,521,000
Federal Income Tax, 48%, 20-Year Average	3,741,600	3,620,600	4,483,600	4,408,400
Total Revenue Requirements	54,031,300	52,199,300	66,426,100	64,905,000
20-Year Average Price of Gas, ¢/10^6 Btu	32.9	31.8	40.4	39.5

* For gas plant only.

** Based on information from Avco and General Electric plus 50% added for general overhead.

‡ Includes $[illegible] savings in annual power consumption.

conditions of 1000 psig and 1700 °F coal bed temperature. Run HT-251 was partially successful, with an abbreviated steady-state operating period curtailed by agglomeration of the coal at the feed tube outlet. Run HT-252 was successful, yielding data at two different operating conditions. In the early portion of the run, Part A, the coal was gasified with hydrogen only. The last portion of the run, Part B, was conducted with hydrogen and steam feed gas mixture.

Both tests were conducted with coal from Pit B. For hydrogasification use the coal was crushed and screened to a −10 +80 mesh size and dried to a 1-2% moisture level.

Significant features of the two hydrogasification tests are given in Table 7. Hydrogen and steam to coal ratios are somewhat modified from those

Table 7. FEATURES OF HYDROGASIFICATION TEST RESULTS FOR RUNS HT-251 AND HT-252

Feed Solids: Dried New Mexico Subbituminous Coal, Pit B

Run No.	Temp., °F	Purpose of Run	Results
HT-251	1300-1700	To study the hydrogasification behavior of New Mexico subbituminous coal at a nominal 50% stoichiometric hydrogen-to-coal ratio and a steam concentration of 28%.	Partially successful. Light coal agglomeration at feed tube outlet.
HT-252A	1300-1850	Same as HT-251, but with no steam in feed gas.	Successful.
HT-252B	1300-1700	Same as HT-252A, but with a steam concentration of 30% in the feed gas.	Successful.

scheduled to facilitate operating the reactor with untreated coal.

In the three tests, the coal was gasified in a 3.5-ft fluidized bed maintained at the upper temperatures cited in Table 7. Flow conditions for Run HT-251 were 30 lb/hr coal, 460 SCF/hr hydrogen, and 8.3 lb/hr steam. For this test, coal feeding to the reactor was started with only hydrogen feed gas to the bottom of the reactor. This is a departure from the normal start-up procedure of feeding both hydrogen and steam to the reactor before coal feeding is started. By initially not feeding steam, a higher hydrogen partial pressure can be maintained in the reactor, which reduces the agglomerating tendency of the coal in the upper portion of the reactor. However, even before steam was introduced to the reactor bottom, coal feeding was interrupted three times by light agglomeration at the coal feed tube outlet. The first of these interruptions was 39 minutes after coal feeding started. Each time the plugs cleared themselves in 5-10 minutes with no change in flow rates or other operating conditions. After steam was admitted to the bottom of the reactor, coal feeding continued for 38 minutes before another plug formed. The test was terminated before this plug was given a chance to clear itself as the hydrogen feed supply was nearly used up. Only a few small agglomerated coal particles were found in the residue, attesting to only light agglomeration during the test. Total coal feed time in this test was 2-1/4 hr, with about 15 minutes of this time at steady-state conditions.

The hydrogasification tests with New Mexico subbituminous coal were conducted without any electrical heat input to the uppermost reactor heating section, Zone No. 1. This zone has been inoperative for several months because of a shorted power input electrode. It cannot be repaired without dismantling the reactor, which would require a long shutdown. With no heat input at this zone it is difficult to keep the upper 30 inches of the reactor at the desired 1300°F temperature level. Although hydrogasification operations with pretreated bituminous coal were not affected significantly by the reduced temperature at the point of coal inlet, operation with the untreated New Mexico subbituminous coal was influenced, based on the results of three runs. In these runs, the coal agglomeration was restricted for the most part to the zone at the coal feed tube inlet, with little or no agglomeration in the coal bed. To provide for more rapid coal heat-up in the reactor, the 1-inch-diameter coal feed tube was lengthened by 30 inches for the next hydrogasification test, Run HT-252. With the longer feed tube, the coal entered the reactor at the top of heating Zone No. 2, where temperatures of at least 1300°F could be maintained.

Planned run conditions for Run HT-252 called for fluidized-bed operation with a hydrogen-to-coal ratio of 25% of stoichiometric and a steam concentration of 50 mole percent in the feed gas. However, coal feeding was started with only a hydrogen feed and no steam to minimize chances of coal agglomeration. After the 3.5-ft coal bed level was reached, steam feed was introduced at a reduced rate. The addition of steam was sufficiently disruptive to result in a light plug at the end of the coal feed tube within 16 minutes. The plug was cleared 1-1/2 hr later, only after steam feed to the reactor was turned off. When coal feeding was resumed, the test was continued with hydrogen feed only to establish the effect of steam on agglomeration. In this portion of the test, Run HT-252A coal was fed at a rate of 34 lb/hr and the hydrogen at a nominal rate of 460 SCF/hr so that the hydrogen-to-coal ratio was about 43% of stoichiometric. Linear gas velocities through the reactor were lower than normal, but still above minimum fluidization requirements. Without steam to moderate the heat of reaction, bed temperatures rose to 1870°F at the top of the coal bed. Hydrogasification proceeded without interruption at steady-state conditions for 3 hr before steam was again admitted to the reactor. The steam was fed at a rate of 9.9 lb/hr so that the concentration in the feed gas was 31 mole percent. After flow rates were again lined out, Run HT-252B was started. The coal feed rate was kept substantially the same as in the A portion of the test.

The B portion of the test with steam and hydrogen feed lasted over 2 hr with no sign of agglomeration at the top of the reactor or in the coal bed. Differential pressures across the coal bed indicated unusually smooth coal flows through the reactor and discharges from the reactor in both phases of the test.

Complete hydrogasification results of Runs HT-252A and HT-252B will be presented when analyses are completed.

Complete hydrogasification results and operating conditions of Run HT-251 and Run HT-249, conducted last month, are presented in Table 8. Run HT-249 was the first hydrogasification test conducted in the development unit with the New Mexico subbituminous coal. This initial test was with coal from Pit A. Compositions and screen analyses of the coal feeds and residues of these tests are given in Table 9. Liquid products and their compositions are shown in Table 10.

Table 8, Part 1. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

Coal	New Mexico Subbituminous	New Mexico Subbituminous
Source	Farmington Pit A	Farmington Pit B
Sieve Size, USS	−10+80	−10+80
Run No.	HT-249	HT-251
Duration of Test, hr	2	2-1/4
Steady-State Operating Period, min[a]	165-182	126-137
OPERATING CONDITIONS		
Bed Height, ft	3.5	3.5
Reactor Pressure, psig	1010	1004
Reactor Temperature, °F[b] Inches From Bottom		
62-1/2	1105	1300
67-3/4	1220	1220
73	1365	1470
78-1/4	1280	1545
83-1/2	1420	1795
89	1300	1635
94-1/4	1430	1640
100	1555	1770
104	1440	1665
Average	1345	1560
Coal Rate, lb/hr[c]	63.00	30.38
Feed Gas Rate, SCF/hr	447.6	459.0
Steam Rate, lb/hr	30.00	8.33
Steam, mole % of hydrogen-steam mixture	58.5	27.6
Hydrogen/Coal Ratio, % of stoichiometric[d]	23.1	47.9
Hydrogen/Steam Ratio, mole/mole	0.710	2.622
Bed Pressure Differential, in. wc	--	--
Coal Space Velocity, lb/cu ft-hr	203.6	98.2
Feed Gas Residence Time, min[e]	0.328	0.674
Superficial Feed Gas Velocity, ft/s[f]	0.178	0.0865

Table 8, Part 2. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

Run No.	HT-249	HT-251
OPERATING RESULTS		
Product Gas Rate, SCF/hr	832.3	892.0
Net Btu Recovery, 1000 Btu/lb	3.346	5.467
Product Gas Yield, SCF/lb	13.21	29.36
Hydrocarbon Yield, SCF/lb	3.59	7.40
Carbon Oxides Yield, SCF/lb	2.03	1.35
Net Reacted Hydrogen, SCF/lb	3.19	8.77
Residue, lb/lb coal[g]	0.578	0.543
Liquid Products, lb/lb coal[h]	0.445	0.276
Net MAF Coal Hydrogasified, wt %[i]	31.8	45.5
Carbon Gasified, wt %	31.8	46.2
Steam Decomposed, lb/hr[j]	5.75	0.846
Steam Decomposed, % of steam fed	9.2	10.2
Steam Decomposed, % of total equivalent fed[k]	41.2	46.3
Overall Material Balance, %	93.4	98.3
Carbon Balance, %	101.0	104.3
Hydrogen Balance, %	83.7	97.4
Oxygen Balance, %	83.3	78.4
PRODUCT GAS PROPERTIES		
Gas Composition, mole %	Feed	Product
Nitrogen	27.4	48.5
Carbon Monoxide	7.6	3.3
Carbon Dioxide	7.8	1.3
Hydrogen	29.6	21.6
Methane	24.9	23.7
Ethane	1.9	1.3
Propane	0.4	0.2
Butane	--	--
Benzene	0.4	0.1
Hydrogen Sulfide	--	--
Total	100.0	100.0
Heating Value, Btu/SCF[m]	425	347
Specific Gravity (Air = 1.00)	0.655	0.689
Nitrogen Purge Rate, SCF/hr	228	433

Table 8, Part 3. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

a. From start of coal feed.

b. Tube wall temperatures. Bottom of coal bed at 62 in.

c. Operating conditions and results based on weight of dry feed.

d. Percent of the stoichiometric hydrogen/char ratio — the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. Coal bed volume/(CF/min feed gas at reactor pressure and temperature).

f. (CF/s feed gas at reactor pressure and temperature)/cross-sectional area of reactor.

g. By ash balance.

h. Includes condensed, undecomposed steam.

i. 100 (wt of product gas-wt hydrogen in-wt decomposed steam-wt nitrogen in/wt of moisture-, ash-free coal).

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char and bound water corresponding to oxygen content of feed char) and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

Table 9. CHEMICAL AND SCREEN ANALYSES OF SUBBITUMINOUS COAL FEED AND RESIDUE

Run No.	HT-249		HT-251	
Sample	Feed	Residue	Feed	Residue
Proximate Analysis, wt %				
Moisture	2.1	4.9	2.5	3.0
Volatile Matter	35.7	5.4	38.0	11.0
Fixed Carbon	45.8	62.2	44.8	59.0
Ash	16.4	27.5	14.7	27.0
Total	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %				
Carbon	62.8	66.6	64.3	64.7
Hydrogen	4.68	1.38	4.78	2.23
Nitrogen	1.25	0.65	1.15	0.83
Oxygen	13.95	2.23	14.11	4.00
Sulfur	0.58	0.17	0.57	0.44
Ash	16.74	28.97	15.09	27.80
Total	100.00	100.00	100.00	100.00
Screen Analysis, USS, wt %				
+20	28.6	26.4	24.8	31.8
+30	20.2	21.2	19.8	24.2
+40	15.9	17.7	17.9	17.6
+60	19.1	18.9	22.3	16.7
+80	9.0	7.5	11.3	6.1
+100	3.5	2.8	2.0	1.3
+200	3.4	4.5	1.8	1.8
+325	0.2	0.5	0.1	0.3
−325	0.1	0.5	0.0	0.2
Total	100.0	100.0	100.0	100.0

Table 10. COMPOSITION OF HYDROGASIFICATION LIQUID PRODUCTS

Run No.	HT-249	HT-251
Sample	Condenser	Condenser
Liquid Products,*		
lb/lb coal	0.445	0.276
Composition of Liquid Products, wt %		
Water	86.50	89.40
Oil	13.50	10.60
Total	100.00	100.00
Composition of Oil Fraction, wt %		
Carbon	82.80	86.80
Hydrogen	8.06	7.55
Total	90.86	94.35
Carbon in Oil Fraction		
lb/lb coal	0.0497	0.0254
wt % of carbon in coal	7.92	3.91

* Includes condensed, undecomposed steam.

Carbon gasification of the New Mexico subbituminous coal ranged from 31.8% in Run HT-249 to 45.5% in Run HT-251 (Table 8). The greater carbon conversion of Run HT-251 is due principally to the larger hydrogen-to-coal ratio. Other contributing reasons are a lower coal throughput rate and a higher average bed temperature (1560°F compared to 1345°F). The larger carbon conversion of Run HT-251 also produced a hydrocarbon yield nearly twice that of Run HT-249: 7.40 SCF/lb coal compared 3.59 SCF/lb coal. The lower carbon oxides yield and concentration in the product gas of Run HT-251 reflect the results of operation with a low steam concentration in the feed gas.

Although carbon gasification in Run HT-251 was larger than in Run HT-249, the fraction of carbon connected to it was smaller (Table 10). At the comparatively high hydrogen-to-coal ratio and the low steam concentration of Run HT-251, 3.9% of the carbon appears in the oil fraction of the liquids; in Run Ht-249, 7.9% of the carbon was converted to oil.

The differences in the hydrogasification results obtained with the Pit A and Pit B coals are due mainly to different operating conditions in the two tests and not to differences in the compositions or behavior of the coals.

Coal Preparation

New Mexico subbituminous coal from Pit C, the seam not yet tested in the development unit, was prepared for hydrogasification use by crushing, screening, and drying. Over 1 ton of the coal was crushed in a swing hammer-mill, screened to a –10+80 mesh size, and dried in the coal pretreatment unit. The coal was dried from an as-received moisture level of 17.6% to 1.5-2.5% with a mixture of air and nitrogen at 275°F in a fluidized bed. Over 1500 lb of dried coal was obtained.

Coal Pretreatment

The pretreatment of a Western Kentucky bituminous coal was started (FP-145) to make it suitable for use as a feed in the hydrogasification development unit. This coal, from the No. 9 seam, Ken mine, was crushed and screened to a –10+80 mesh size before pretreatment. Light pretreatment of the coal is conducted at standard conditions in the fluid-bed pretreater with air and nitrogen at 750°-800°F.

ELECTROTHERMAL GASIFICATION

The replacement steam superheater was fabricated and installed in a gas-fired furnace, and three tests were conducted during the month in the pilot unit. The purpose of the first test was to obtain additional data using the magnetic flip coil. The other two tests were run with a silicon carbide tube as the inner reactor liner to observe its electrical characteristics as the outer electrode. A 1-1/2-inch, 316 stainless steel rod was used as the inner electrode in all the runs.

During the 45-minute steady-state period of Run EG-62, our electrical consultants performed various tests with the magnetic flip coil system and traced the results on the oscillograph. Data obtained confirmed the observations reported last month from Run EG-60: The operation of the flip coil noticeably reduced the current fluctuation frequencies of the gasifier; their magnitude was the same as in previous runs. The consultants feel that the effect of the flip coil on smoothing out the current of the operation may have been limited by the coil's power supply and that possibly a larger power supply would produce more favorable results. Following the test we decided against using a flip coil in the 2-MW electrothermal gasifier. The main reasons for doing so are —

1. The flip coil did not compress the magnitude of the system's current fluctuation and thus will not tend to reduce the size of the power supply required to compensate for this in the 2-MW reactor.

2. There are apparently major difficulties in the fabrication and installation of the size coil that would be required, which would prolong the completion of the 2-MW unit.

3. The ratio of power required for the flip coil to that required for the electrothermal gasifier was on the order of 0.1 during the tests conducted thus far and would be prohibitive in the 2-MW unit due to the limit of available power.

To more conclusively define the effects of the flip coil in the pilot unit, either a larger power supply will be installed or the run conditions will be varied to magnify its effect. Also, monitoring the operation of the 2-MW system will reveal data necessary in determining whether a flip coil would be useful in a commercial-sized reactor.

Nominal conditions during the run are as follows:

[illegible]	[illegible]	Steam Feed Rate, lb/hr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	117	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The complete data and results will be reported when they become available.

Following Run EG-62 the 6-in. 316 stainless steel was replaced with a 7-in-OD by 6-in. ID 5-foot length of silicon carbide. The material is the same as the two 3-foot sections used in Run EG-56, (Second Quarter, 1970 Report) supplied by Norton Co. (Crystallon-63).

A cutaway view of the reactor configuration appears in Figure 6. The silicon carbide tube was encased in a 316 stainless steel tube of 8-5/8-in. OD by 1/8-in. wall which was welded to the metal sleeve at the reactor bottom. The annulus between the two was packed with FMC char, which has negligible electrical resistance in the packed state. The purpose of this setup was to obtain a good electrical contact from the silicon carbide tube back to the d-c generator, eliminating the voltage gradient along the silicon carbide tube that was apparent during Run EG-56.

Before applying the power during Run EG-63 the overall resistance of the system was between 100 and 200 ohms. During the heat-up period the overall resistance gradually decreased to 7-10 ohms at 300 volts, accompanied by a power input of 8-10 kW. The test was terminated when erratic bed temperatures indicated arcing in the bed. The average bed temperature at the time was 1000° F, but several thermocouples indicating 1600° F were rapidly increasing. Inspection following the run showed the electrode to be undamaged but there was caked char on the silicon carbide tube in the area of the high temperatures.

Before the next test the panel-mounted temperature recorder was rewired so it would be electrically isolated from the reactor. This was done to eliminate any current path from the reactor electrode to ground through the thermocouples.

The overall resistance of the system before applying the power during Run EG-64 was 45 ohms, or about one-half that in the previous test. During the heat-up the overall resistance decreased to 6 ohms and the temperature recorder appeared to be functioning better. However, after several hours operation the same condition as in Run EG-63 occurred; there was a hot spot several hundred degrees higher than the rest of the bed in the same location. The run was terminated when the ammeter indicated severe arcing

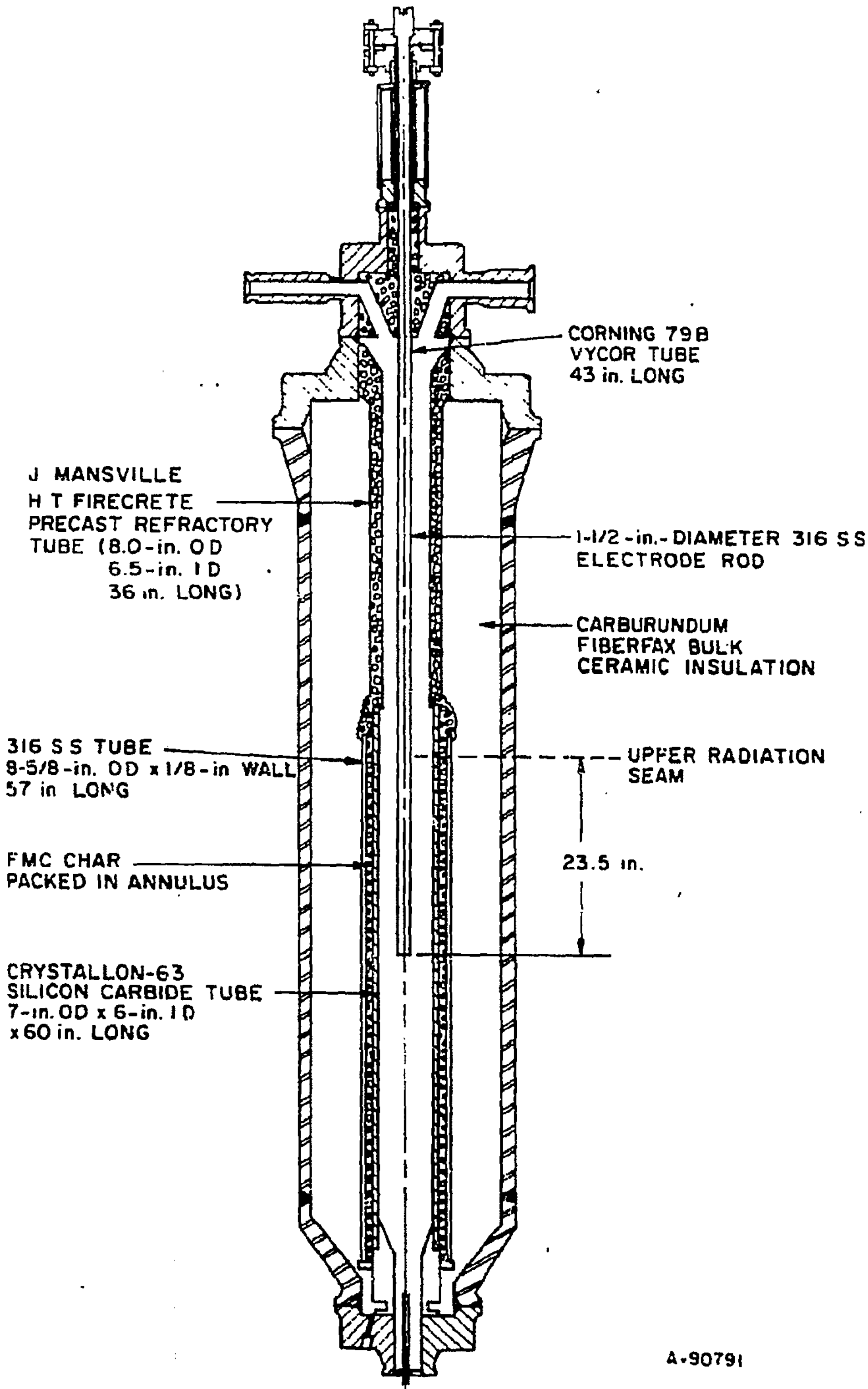

Figure 6. CUTAWAY VIEW OF REACTOR FOR RUNS EG-63 AND EG-64

IGT-QTPR--7-9/70

IGT EDUCATION · RESEARCH

INSTITUTE OF GAS TECHNOLOGY · IIT CENTER · CHICAGO 60616

Project Status Report
For
OFFICE OF COAL RESEARCH
and
AMERICAN GAS ASSOCIATION

Report For Third Quarter, 1970
OCR Report No. 72

Project Title Pipeline Gas From Coal— Hydrogenation (IGT Hydrogasification Process)

OCR Contract No. 14-01-0001-381 (1) A.G.A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

COAL CHARACTERIZATION

Initial results from studying the distribution of minor coal constituents in the HYGAS Process show that all the nitrogen removed from the coal appears as ammonia. The yield of ammonia in Run HT-248 with Montana subbituminous coal as feed was 14.5 lb NH_3/ton of dry coal, corresponding to 64.9% of the nitrogen in the coal. Since over 75% of the ammonia appears in the recycle quench water, if a cooling tower is used, most of the ammonia is released to the atmosphere. We are studying means of recovering the ammonia and avoiding atmospheric pollution. Phenol and cyanide were also found in the effluent.

To date microtumbler tests indicate that the attrition resistance of gasified residue does not change and, in fact, may increase slightly with conversion. It is possible that the expected decrease in strength caused by the removal of material by gasification throughout the particle is compensated for by the increased strength caused by coking or graphitization of the particle.

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HIGH-PRESSURE METHANATION

Results from a series of runs at low flow rates and low pressures agreed well with results at high pressures. An improved correlation was obtained for the methanation rate expression, which was extended to cover regions with large excesses of hydrogen and methane.

$$r = \frac{k_1 p_{CO} p_{H_2}^{0.5}}{1 + k_2 p_{H_2} + k_3 p_{CH_4}}$$

Data at low conversions and near equilibrium are being collected to test this correlation: Initial data indicate that it requires modification for conditions near equilibrium. The temperature-dependence studies of the reaction rate at 740° and 850° F show that the rate expression is still valid up to 850° F.

The laboratory unit to measure the sulfur tolerance of methanation catalysts for use in the pilot plant was completed, and shakedown of the unit is in progress. The two pilot plant process gas chromatographs were tied-in with this unit to check out the analyzers and try them with gases similar to those that will be encountered in the pilot plant.

Ethylene hydrogenation was briefly studied to see if this type of process can be adapted for starting up the pilot plant hydrogasifier. We tested both Ni-Mo and ammonia synthesis catalysts. Ethylene can be hydrogenated to ethane at room temperature over the more active Ni-Mo catalyst: Without a catalyst the reaction does not occur below 800° F. Hydrogenation occurring at 1100° F was accompanied by the formation of carbon and tar.

ENGINEERING ECONOMICS STUDIES

A computer program was developed to estimate the cost of vessels as a function of their dimensions and configurations. The effects of financial factors on the return on equity for gas utility financing were calculated, and the results presented in graphical form.

The economics of lock hopper and slurry systems for feeding pretreated char to the hydrogasifier were compared using recent data. The results indicate that the lock hopper system could show a gas price advantage of 3¢/million Btu if a reasonable life of the control valves can be expected. These valves must seal against 500-psi differential pressure and must handle solids flowing through them. Further probing is planned.

The use of partial or total air cooling for a pipeline gas plant was examined in detail. For a 500 billion Btu/day lignite-based plant total air cooling or air cooling to 140°F, followed by water cooling to 100°F, shows that the plant makeup water requirement can be reduced by 82-88% over a totally water-cooled plant. The capital investment for an air-cooled plant is less than for a water-cooled plant; substantial savings in power consumption should also result. The work was done in cooperation with Hudson Products Corporation, a major supplier of air coolers.

The above scheme was revised to include conventional steam-turbine power generation instead of MHD generation. The gas price increases from 33¢ to 40¢ million Btu when the steam cycle is used. We examined air and water cooling with each mode of power generation. Air cooling shows about a 1¢/million Btu cost advantage in the gas price over water cooling at a 3.5% makeup water rate, and an even greater advantage at higher makeup rates. An examination of the financial factors used in the two Bureau of Mines gasification processes showed some apparent inconsistency in the assumed effective cost of coal.

DEVELOPMENT UNIT STUDIES

Results of a free-fall thermal treatment of lignite at 1300°F, using nitrogen as a sweep gas, showed 14% carbon gasification. The degree of gasification at 280 psi, comparable to another run at 1000 psi, indicates that devolatilization is the only reaction occurring.

Hydrogasification of lignite at 500 psi with hydrogen and steam showed 41% carbon gasification, indicating no significant loss of reactivity from the 1000-psi operation. Results of lignite gasification at 500 psi with synthesis gas-steam and hydrogen-steam mixtures show that about 5% more carbon (36 vs. 41%) was gasified with the hydrogen-steam mixture. Either gas mixture is adequate for the HYGAS Process in terms of obtaining the required gasification.

The study of Montana subbituminous coal showed that a 1000-psi pressure is definitely preferred over 500 psi with either the hydrogen-steam or synthesis gas-steam mixtures. Operation was smooth at 1000 psi, but erratic at 500 psi. Lower methane and higher carbon oxides yields were also obtained at 500 psi.

The study of New Mexico subbituminous coal showed that the coal was similar in behavior and reactivity to the Montana and Colorado subbituminous coals tested earlier. With 13 coals tested to date in the 4-inch hydrogasifier, further study of other coals will be postponed.

Designs are being completed to examine the flow patterns and pressure balance in a model of the upper section of the HYGAS hydrogasifier. The model will permit preliminary study of any future modifications.

After a number of successful runs at 1900°F and 1000 psi using IGT's hydrogasified char, silicon carbide was tried as the central electrode and as the reactor tube. The material withstands hot spots well, but shows a high initial electrical resistance. Upon heating, the resistance gradually drops to an acceptable range. A new low-resistance silicon carbide will be tried as soon as it is received.

A run aimed at defining the electrical characteristics of the bed yielded much data. High- and low-frequency current and voltage fluctuations, along with transient response of the bed to step-changes in power input, should provide the necessary data for designing the power package of the 2-MW electrothermal gasifier unit. Work to date indicates that the 2-MW electrothermal gasifier will have a direct-current power supply and a concentric electrode configuration.

The gasifier was disassembled to install a magnetic flip coil to suppress arcing and reduce current fluctuations. Two tests showed that the frequency of the current flicker was noticeably reduced, while its amplitude remained unchanged. Although some additional tests with the coil may be made later, no flip coil will be used in the 2-MW unit. The fabrication and installation of the coil can be difficult; the coil requires significant power that only reduces the frequency of current flicker but not its amplitude.

The nozzles from Spraying Systems Corp. appear to show no wear when dispersing coal-water slurries. Photographs were taken that should permit measurement of the spray distribution.

NEW PROCESS STUDIES

A fuel cell engineering study to supply power to the electrothermal gasifier was completed, including details of power plant configuration and cost calculations. A bus bar cost of 4.5 and 5.4 mills/kWhr is estimated for fuel cell power densities of 300 and 150 watts/sq ft. Capital investment is estimated at $99 and $123/kW for cell power densities of 300 and 150 watts/sq ft.

Instead of generating additional power from the hot fuel cell waste gases, as in the above study, we considered using the waste gases for 1) raising high-pressure steam or 2) supplying heat to the producer gas generator. Scheme 1 is more attractive than scheme 2, but is not economically as attractive as the original study in which the waste gases generated additional power.

PILOT PLANT CONSTRUCTION

Engineering is 99% complete, except for field changes. Purchasing and material receipt are 99% complete. Construction is 97% complete. Of this, piping and instrumentation are 97% complete, and electrical work is 91% complete. The utility building is the first section of the plant turned over to IGT.

Together with Procon we began the design and construction of a 2-MW electrothermal gasifier system for the HYGAS pilot plant. The reactor will be built aboveground instead of in a pit, where solids transfer might be easier, because the cost of underground construction was prohibitive. For safety purposes, the reactor will have a water jacket similar to the hydrogasifier's. The gasifier vessel has been placed on order with Struthers-Wells Corporation, and delivery date is expected in May 1971. Piping and instrument diagrams are being finalized. A number of critical design areas are under intensive review.

PILOT PLANT OPERATION

The staff of 10 engineers and 16 technicians have been in full-time training for a month. The various utilities in the utility building will be the first shakedown; next in sequence will be the hydrogen plant.

III. Problems

No major problems were encountered this month.

IV. Recommendations

We recommend that the project proceed in the areas defined

V. Status of Funding

1. A.G.A. Funding
   - A. 1970 Funds Allocated — $300,000
   - B. Funds Expended This Month (estimated) — $ 25,000
   - C. Funds Expended to Date (estimated) — $283,000

2. OCR Funding

A. Funds Expended This Month (estimated) $ 62,000

B. Funds Expended Since Contract Amendment No. 1 (estimated) $7,810,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective will be attained within the contract term and the funds allocated.

Approved ____________________
Frank C. Schora, Jr.
Director

Signed ____________________
Bernard S. Lee
Manager

____
Jack Huebler,
Vice-President

Appendix. Achievements in September

DEVELOPMENT UNIT STUDIES

Hydrogasification Tests

Complete hydrogasification results of Runs HT-252A and HT-252B, conducted last month, are presented in this report. The purpose of these tests was to evaluate the hydrogasification preformance at 1000 psig of a dried, but otherwise untreated, New Mexico subbituminous coal from the Farmington area. Both tests were performed as part of the same hydrogasification run operation, but at different conditions. In Run HT-252A the coal was gasified in a fluidized bed with hydrogen only; in Run HT-252B the coal was gasified in a fluidized bed with hydrogen and steam. The coal feed rate in both tests was nearly the same at 33.8 lb/hr. Operating conditions and results of these two runs are presented in Table 1. Compositions and screen analyses of the coal feeds and the residues are given in Table 2. The liquid products and their compositions produced in these tests are shown in Table 3. Although the superficial feed gas velocities in both tests were smaller than the usual 0.18 ft/s for fluidized-bed operation, they were above the minimum velocity of 0.06 ft/s necessary for fluidization.

Carbon gasification in Run HT-252A was 43.2%, as the coal was allowed to react with hydrogen only at a hydrogen-to-coal ratio of 42.9% of the stoichiometric ratio (Table 1). With the addition of 31.4 mole percent steam to the reactor in Run HT-252B and nearly the same hydrogen-to-coal ratio as in Run HT-252A, the carbon gasification increased to 53.5%. The addition of steam also resulted in a moderation of the coal-bed temperature. With no steam the average coal-bed temperature was 1675°F, and the maximum temperature was 1870°F. When the feed gas was a hydrogen-steam mixture, the average coal-bed temperature was 1485°F; the maximum temperature was 1770°F. Except for larger carbon oxides concentrations in Run HT-252B, the product gas compositions in both tests were similar.

The gasified coal residue analyses (Table 2) reflect the larger amount of coal converted in Run HT-252B. Carbon content of the residue is 59.1% compared to 66.1% in Run HT-252A; the ash content is 39.1% compared to 31.9%.

Table 1, Part 1. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

Coal	New Mexico Subbituminous	
Source	Farmington Area	
Sieve Size, USS	−10 +80	
Run No.	HT-252A	HT-252B
Duration of Test, hr	6-3/4	6-3/4
Steady-State Operating Period, min [a]	129-285	310-405
OPERATING CONDITIONS		
Bed Height, ft	3.5	3.5
Reactor Pressure, psig	1016	1009
Reactor Temperature, °F [b] Inches From Bottom		
62-1/2	1315	1085
67-3/4	1415	1235
73	1740	1455
78-1/4	1680	1400
83-1/2	1850	1620
89	1695	1500
94-1/2	1690	1570
100	1870	1730
104	1845	1770
Average	1675	1485
Coal Rate, lb/hr [c]	33.76	33.85
Feed Gas Rate, SCF/hr	460.4	454.4
Steam Rate, lb/hr	--	9.89
Steam, mole % of hydrogen-steam mixture	--	31.4
Hydrogen/Coal Ratio, % of stoichiometric [d]	42.9	42.2
Hydrogen/Steam Ratio, mole/mole	--	2.19
Bed Pressure Differential, in. wc	24.0	--
Coal Space Velocity, lb/cu ft-hr	109.1	109.4
Feed Gas Residence Time, min [e]	0.686	0.521
Superficial Feed Gas Velocity, ft/s [f]	0.085	0.112

Table 1, Part 2. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

Run No.	HT-252A	HT-252B
OPERATING RESULTS		
Product Gas Rate, SCF/hr	846.5	937.3
Net Btu Recovery, 1000 Btu/lb	5.028	6.142
Product Gas Yield, SCF/lb	25.07	27.69
Hydrocarbon Yield, SCF/lb	6.67	7.06
Carbon Oxides Yield, SCF/lb	1.25	2.85
Net Reacted Hydrogen, SCF/lb	7.77	6.86
Residue, lb/lb coal [g]	0.509	0.415
Liquid Products, lb/lb coal [h]	0.153	0.347
Net MAF Coal Hydrogasified, wt % [i]	44.9	64.5
Carbon Gasified, wt %	43.2	53.5
Steam Decomposed, lb/hr [j]	--	--
Steam Decomposed, % of steam fed	--	--
Steam Decomposed, % of total equivalent fed [k]	34.3	34.2
Overall Material Balance, %	100.8	99.4
Carbon Balance, %	101.5	97.6
Hydrogen Balance, %	101.3	99.7
Oxygen Balance, %	108.7	106.2
PRODUCT GAS PROPERTIES		
Gas Composition, mole %		
Nitrogen	44.8	40.2
Carbon Monoxide	3.8	7.6
Carbon Dioxide	1.2	2.7
Hydrogen	23.4	23.7
Methane	25.2	24.1
Ethane	1.3	1.3
Propane	0.1	0.1
Butane	--	--
Benzene	0.2	0.2
Hydrogen Sulfide	--	0.1
Total	100.0	100.0
Heating Value, Btu/SCF [m]	371	373
Specific Gravity (Air = 1.00)	0.667	0.677
Nitrogen Purge Rate, SCF/hr	379	377

Table 1, Part 3. OPERATING CONDITIONS AND RESULTS OF THE HYDROGASIFICATION OF NEW MEXICO SUBBITUMINOUS COAL IN HIGH-TEMPERATURE ADIABATIC REACTOR

a. From start of coal feed.

b. Tube wall temperatures. Bottom of coal bed at 62 in.

c. Operating conditions and results based on weight of dry feed.

d. Percent of stoichiometric hydrogen/char ratio — the net feed hydrogen/char ratio required to convert all the carbon to methane.

e. Coal bed volume/(CF/min feed gas at reactor pressure and temperature).

f. (CF/s feed gas at reactor pressure and temperature)/cross-sectional area of reactor.

g. By ash balance.

h. Includes condensed, undecomposed steam.

i. 100 (wt of product gas-wt hydrogen in-wt decomposed steam-wt nitrogen in/wt of moisture-, ash-free coal).

j. Computed as difference between steam feed rate and the measured liquid water rate leaving the reactor.

k. Computed as difference between the total equivalent steam feed rate (includes moisture content of feed char and bound water corresponding to oxygen content of feed char) and the measured liquid water rate leaving the reactor.

m. Gross, gas saturated at 60°F, 30-in. Hg pressure. SCF: dry gas volume in SCF at 60°F, 30-in. Hg pressure.

Table 2. CHEMICAL AND SCREEN ANALYSES OF NEW MEXICO SUBBITUMINOUS COAL FEED AND RESIDUES

Run No.	HT-252A		HT-252B	
Sample	Feed	Residue	Feed	Residue
Proximate Analysis, wt %				
Moisture	2.2	0.8	2.2	0.8
Volatile Matter	37.3	2.2	37.3	2.4
Fixed Carbon	44.6	65.4	44.6	58.0
Ash	15.9	31.6	15.9	38.8
Total	100.0	100.0	100.0	100.0
Ultimate Analysis (dry), wt %				
Carbon	63.2	66.1	63.2	59.1
Hydrogen	4.82	0.84	4.82	0.94
Nitrogen	1.17	0.39	1.17	0.31
Oxygen	13.91	0.54	13.91	0.40
Sulfur	0.68	0.28	0.68	0.14
Ash	16.22	31.85	16.22	39.11
Total	100.00	100.00	100.00	100.00
Screen Analysis, USS, wt %				
+20	33.6	24.2	33.6	27.2
+30	22.2	24.7	22.2	25.2
+40	15.3	20.0	15.3	19.2
+60	18.8	20.8	18.8	19.0
+80	8.3	7.1	8.3	6.5
+100	1.6	1.8	1.6	1.8
+200	0.2	1.0	0.2	0.7
+325	0.0	0.2	0.0	0.2
−325	0.0	0.2	0.0	0.2
Total	100.0	100.0	100.0	100.0

The liquid product analyses (Table 3) show that the carbon conversion to oil did not significantly differ in either test. The fraction of carbon converted to oil was 5.01% in Run HT-252A and 5.27% in Run HT-252B.

Table 3. COMPOSITION OF HYDROGASIFICATION LIQUID PRODUCTS

Run No.	HT-252A	HT-252B
Sample	Condenser	
Liquid Products*,		
lb/lb coal	0.153	0.347
Composition of Liquid Products, wt %		
Water	76.80	89.29
Oil	23.20	10.71
Total	100.00	100.00
Composition of Oil Fraction, wt %		
Carbon	89.15	89.53
Hydrogen	6.84	6.63
Total	95.99	96.16
Carbon in Oil Fraction,		
lb/lb coal	0.0317	0.0333
wt % of carbon in coal	5.01	5.27

* Includes condensed, undecomposed steam.

The results of these tests establish the feasibility of gasifying New Mexico subbituminous coal in a fluidized bed with hydrogen and steam with no prior pretreatment of the coal. Reactivity of this coal is generally the same as the Montana and Colorado subbituminous coals, which had been processed in the development unit.

Coal Pretreatment

We completed the pretreatment of a batch of Western Kentucky bituminous coal to make it suitable for use as a feed in the hydrogasification development unit (Pretreatment Run FP-145). Approximately 840 lb of lightly pretreated coal was produced by treating it with an air-nitrogen mixture in a fluidized bed at 750°-800° F. Laboratory tests showed that the pretreated coal still had traces of agglomerating tendencies, due to short-circuiting of some of the coal through the pretreatment bed. Analyses of the raw and pretreated coals are given in Table 4.

Table 4. PRETREATED WESTERN KENTUCKY BITUMINOUS COAL

Run No.		FP-145
Sample	As Received	Pretreated
Proximate Analysis, wt%		
Moisture	6.6	1.0
Volatile Matter	38.6	27.2
Fixed Carbon	48.5	63.6
Ash	6.3	8.2
Total	100.0	100.0
Ultimate Analysis (dry), wt%		
Carbon	74.4	76.3
Hydrogen	5.29	4.32
Nitrogen	1.54	--*
Oxygen	8.22	--*
Sulfur	3.76	--*
Ash	6.79	8.29
Total	100.00	--

* No analysis.

ELECTROTHERMAL GASIFICATION

Two tests were conducted in the pilot unit during the month. The first, Run EG-65, was a heat-up test with the Crystallon-63 silicon carbide tube; the second, Run EG-66, was conducted with a Type-316 stainless steel tube and a multiple electrode configuration as the inner electrode.

During Run EG-65 the overall resistance of the system was 20-30 ohms at the start of the heat-up period, and remained in that range as the voltage was increased to 300 volts. The bed temperature reached 600°F, and within 15 minutes the resistance decreased to about 6.0 ohms. Immediately following the drop in resistance several thermocouples indicated hot spots in one section of the bed. The overall resistance was 4.5 ohms as the bed temperature reached 850°F, with one thermocouple indicating 1350°F. We continued the heat-up, and bed temperatures continued to increase as the overall resistance decreased to 1.0-2.0 ohms. An average bed temperature of 1800°F was maintained for 1 hour at a 20-25 kW power level before the test was terminated. Examination of the reactor following the test showed that the electrode and the wall of the silicon carbide tube were unaffected by the test.

The fact that we were able to reach 1800°F during the test and the overall resistance of the system leveled out at 1.0-2.0 ohms gave us confidence that the Crystar-type silicon carbide tube (on order), which has a much lower electrical resistance than the Crystallon-63 tube, should allow us to reach operating temperatures in a much shorter time. The power necessary to maintain steady-state operating conditions should also be well within the set limits of the motor generator.

The silicon carbide tube was replaced with a Type-316 stainless steel tube for further testing. Run EG-66 was conducted using a multiple configuration as the inner electrode, Figure 1. The bottom 36 inches of the inner electrode consisted of three 5/8-inch, Type-316 stainless steel rods welded at 120 degree intervals to the 1-1/2-inch, Type-316 stainless steel electrode. The purpose of the test was to observe the electrical characteristics of the system. During the test a leak developed at the base of the reactor and caused the termination of the run due to erratic fluidization. Following the test the electrode tip was melted about 3 inches along one 5/8-inch rod, another was slightly melted at the tip, and the third was undamaged. The temperature of the bed reached 800°F before the leak occurred; observation of its electrical behavior proved inconclusive.

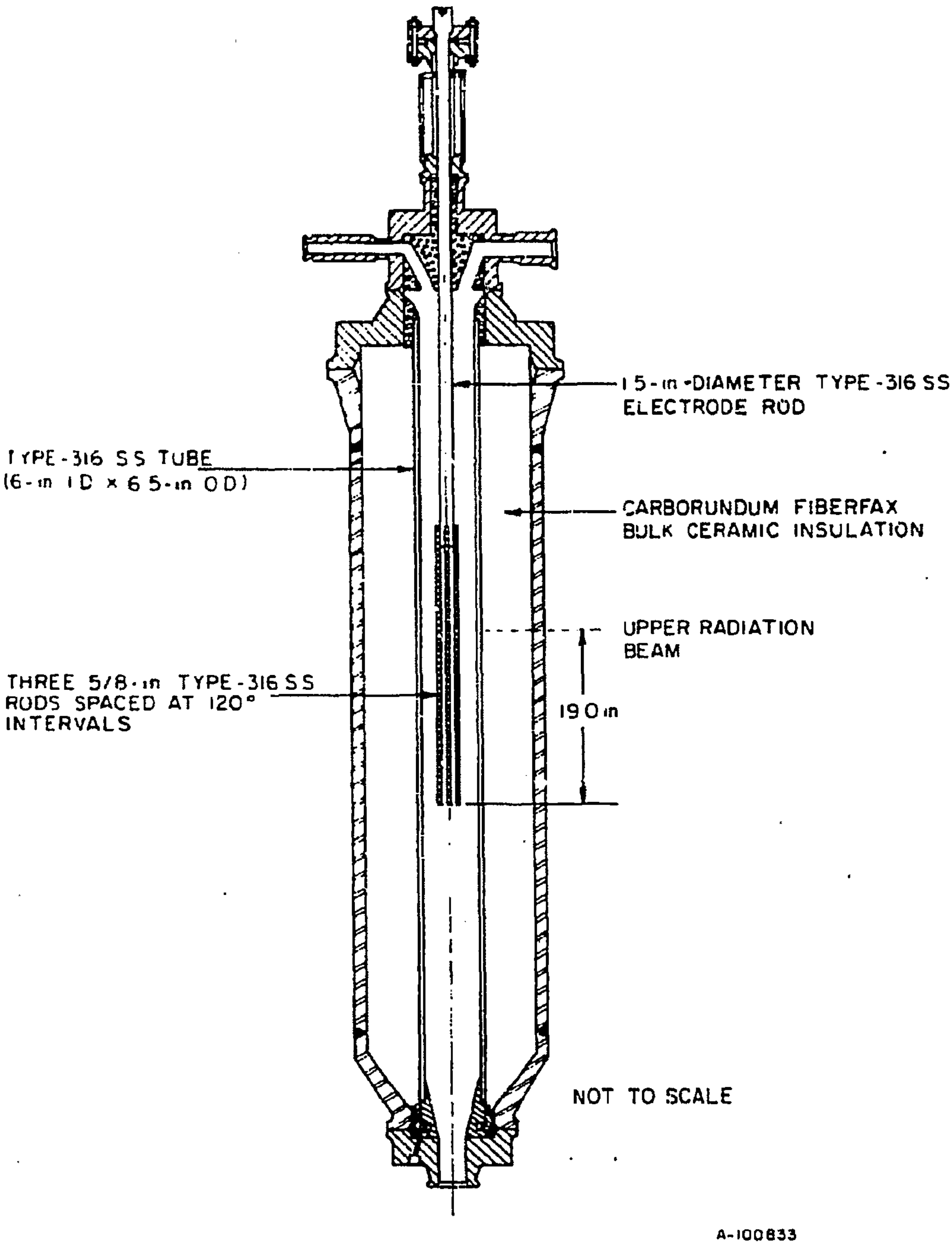

Figure 1. CUTAWAY VIEW OF REACTOR FOR RUN EG-66

The main area of interest in the pilot unit program now centers around the development of a silicon carbide liner for use in the 2-MW reactor that will be incorporated in the HYGAS plant. Since it will be another 6-8 weeks before the low-resistance Crystar silicon carbide tube will be delivered, the test unit has been made available to another A.G.A. project during the interim for a series of four to six tests. The necessary changes and additions to the present system are now in progress.

The complete operating conditions and results of Run EG-62 are reported in Table 5. The chemical and sieve analyses of the char feed and residue appear in Table 6.

NEW PROCESS STUDIES

Fuel Cell Engineering Studies

Three possible schemes for utilizing the waste gases from the fuel cell were outlined in the July Project Status Report:

1. Generation of high-pressure steam
2. Use of the waste gases with fresh air in the producer gas generator unit
3. Use of the waste gases with oxygen in the producer gas generator unit

Investigation revealed that the first scheme appears technically more attractive than the other two; however, none of these are as economically attractive as the electricity generation originallv proposed in the Second Quarter Project Status Report.

Steam Generation

Our fuel cell power plant design was based on 400 MW of power. This plant is capable of supplying power to an electrogasifier that furnishes synthesis gas for handling a 300 billion Btu/day pipeline gas plant. The following are the high-pressure process steam requirements for this plant:

High-Pressure Steam Required, 1200 psig	lb/hr	10^6 Btu/hr
Steam to Electrogasifier, 1025°F	520,000	752
Steam to High-Temperature Zone of Hydrogasifier, 1025°F	438,000	633
Steam to CO Shift Reactor, 570°F	500,000	578
Total	1,458,000	1963

Table 5, Part 1. OPERATING CONDITIONS AND RESULTS OF THE ELECTROTHERMAL GASIFICATION OF COAL CHAR

Feed Char	FMC
Sieve Size, USS	−10+80
Run No.	EG-62
Duration of Test, hr	4.7
Steady-State Operating Period, min	60
Electrode Material	316 SS
OPERATING CONDITIONS	
Bed Height, ft	2.75
Reactor Pressure, psig	985
Reactor Temperature, °F	
Inches From Bottom	
6	1060
12	1420
18	1370
24	1620
30	1620
33	1540
36	1540
39	1780
42	1740
45	1760
51	1850
54	1810
57	1820
60	1820
63	1820
72	1820
84	1810
Average Top 2.75 ft	1800

Table 5, Part 2. OPERATING CONDITIONS AND RESULTS OF THE ELECTROTHERMAL GASIFICATION OF COAL CHAR

Steam Feed Rate, lb/hr	117.0
Steam Residence Time, min*	0.24
Steam Superficial Velocity, ft/s †	0.19
Steam/Char Feed Ratio, lb/lb	2.1
Char Feed Rate (dry), lb/hr	55.3
Char Residence Time, min	17.4
Voltage, V	165
Current, A	368
Power Input, kW	61
Overall Resistance, ohm	0.46
OPERATING RESULTS	
Product Gas Rate (dry), SCF/hr ‡	1525
Product Gas Yield (dry), SCF/lb char	27.6
Hydrogen Yield, SCF/lb char	13.5
Hydrogen + Carbon Monoxide Yield, SCF/lb char	20.9
Carbon Oxides Yield, SCF/lb char	11.9
Char Gasified, %	54.8
Carbon Gasified, %	57.0
Liquid Products, lb/hr	76.1
Steam Decomposed, lb/hr	40.0
Steam Conversion, %	34.5
Overall Material Balance, %	97.4
Carbon Balance, %	94.8
Hydrogen Balance, %	100.0
Oxygen Balance, %	98.7
PRODUCT GAS PROPERTIES	
Composition, mole % ‡	
CO	27.1
CO_2	16.1
H_2	48.9
CH_4	7.7
H_2S	0.2
Total	100.0
Specific Gravity (Air = 1.00)	0.585

Table 5, Part 3. OPERATING CONDITIONS AND RESULTS OF THE ELECTROTHERMAL GASIFICATION OF COAL CHAR

* Coal bed volume, (top 2.75 ft)/SCF steam feed at average reactor temperature and pressure.

† CF/s steam at reactor temperature and pressure/cross-sectional area of reactor.

‡ Dry, nitrogen-free basis.

Table 6. CHEMICAL AND SCREEN ANALYSES OF ELECTROTHERMAL GASIFICATION FEEDS AND RESIDUES

Run No.	EG-62	
Sample	Feed	Residue
Proximate Analysis, wt %		
Moisture	5.4	0.9
Volatile Matter	4.9	1.3
Fixed Carbon	75.6	65.2
Ash	14.1	32.6
Total	100.0	100.0
Ultimate Analysis, wt %		
Carbon	78.20	65.40
Hydrogen	0.99	0.48
Nitrogen	1.19	0.33
Oxygen	2.54	0.59
Sulfur	2.19	0.28
Ash	14.89	32.92
Total	100.00	100.00
Screen Analysis, USS, wt %		
+20	15.6	11.5
+30	23.0	24.2
+40	22.2	23.0
+60	26.7	25.6
+80	10.0	9.5
+100	1.9	3.0
+200	0.6	2.6
+325	0.0	0.3
–325	0.0	0.3
Total	100.0	100.0

The low-pressure steam required in each unit is generated by waste-heat recovery from hot process streams.

Waste gases from the fuel cell plant are at 1370° F. The total heat content of these gases above 300° F is 2.43 billion Btu/hr; therefore, they can be utilized to produce high-pressure steam at 1025° F. Steam required for a CO shift can be produced by desuperheating high-temperature steam by water injection. At a 95% heat exchange efficiency this would require 2.07 billion Btu/hr. The remaining heat can be used for supplying steam (about 270,000 lb/hr) to the gas producer. The gases exit the heat recovery system at about 300° F. Heat recovery below this temperature is generally not economical.

In the earlier power plant design the waste gases were used for generating high-pressure steam and electric power. The economics of these two processes are compared in Table 7. Note that the economics of option A (steam generation) are not as favorable as those of option B (extra electric power generation). A higher initial capital investment for option A per kilowatt-hour of power generated is mainly responsible for the higher bus bar energy cost. Since the average service life of a conventional plant is greater than the fuel cell power plant's, the latter's depreciation is also higher than a conventional plant's.

It should be emphasized that bus bar energy costs are based on conservative estimates, and there exists a potential for the reduced cost of components and an improved average service life. As indicated in the Second Quarter, 1970, Project Status Report, bus bar energy costs as low as 3.7 mills/kWhr are attainable. A life span of nearly 20 years is attained with a power density of 300 W/sq ft.

<u>Utilization of Waste Gases in the Gas Producer</u>

The producer requires oxygen, usually supplied as air, for an exothermic reaction. The waste gases contain 9% oxygen, 15% CO_2, and 68% N_2. Stoichiometric calculations indicate that 15% of the waste gases from the fuel cell power plant can be utilized in the producer gas unit, with about a 50% saving in oxygen requirements. This, however, necessitates the use of pure oxygen. If air is used as a source of oxygen in the producer gas unit, the overall nitrogen balance would not be satisfied. Also, since the waste gases are nearly at atmospheric pressures, the large reactor volumes required would counterbalance the saving in oxygen brought about by directly using the waste gases. This proposition is, therefore, not accepted.

Table 7. ECONOMIC COMPARISON OF HEAT RECOVERY OPTIONS FOR FUEL CELL POWER PLANT *

	Option A, Steam Generation		Option B, Electric Generation	
	W/sq ft			
	150	300	150	300
Power Generation, MW	402	402	793	793
Capital Investment, $/kW total power	191	143	123	99
Total Capital, $ 10^6	77	57	98	79
Effective Service Life, yr	8.8	9.6	9.7	10.7
Depreciation, mills/kWhr	2.471	1.689	1.387	0.993
Operating Cost, mills/kWhr	3.693	3.537	2.008	1.929
Steam Credit (55¢/1000 lb), mill/kWhr	2.363	2.363	--	--
Net Operating Cost, mills/kWhr	1.330	1.174	2.008	1.929
Fixed Charges, mills/kWhr	5.572	4.027	3.378	2.587
Energy Cost, mills/kWhr	6.902	5.201	5.386	4.516

* Refer to Figure 9, First Quarter, 1970, IU-4-1 Project Status Report, p. 28.

At this point it becomes evident that the use of pure oxygen for the whole fuel cell power plant might be worthwhile. This would lead to high power densities, and the purging of gases would be cut down considerably. Increased power densities might offset the cost of producing oxygen. Rough calculations were made to investigate this alternative. Oxygen requirements were estimated at 6000 tons/day of 90% oxygen. The cost of oxygen production for plants having 1000 tons/day capacity is quoted in the literature[1] at $8/ton.

Assuming a very optimistic figure for production cost, $4/ton, the cost of oxygen alone works out to 2.5 mills/kWhr. When this is compared to a bus bar energy cost of about 5-6 mills/k Whr, the impracticality of using oxygen is obvious.

[1] Faith, W. L. and Keyes, D. B., Industrial Chemicals, 2nd Ed. New York: Wiley, 1963.

PILOT PLANT CONSTRUCTION

Engineering work is continuing on recent additions to the HYGAS pilot plant project. Procon is also doing engineering work in connection with IGT's recent plant acceptance check lists. Extras 1-29 to the guaranteed maximum price were discussed and finalized by IGT and Procon. These extras will be formally resubmitted to IGT shortly. IGT has authorized additional work, and requests for an additional guaranteed maximum price are being prepared.

Purchase orders have been issued for items that are part of recent additions to the project.

Major field activities during this report period have been electrical and instrumentation work, testing, insulation, and painting. Piping and instrumentation are 97% complete, electrical 91%, insulation 82%, and painting 75% complete.

To date we experienced a total of 31 inclement weather days; 3 occurred in this report period. On these days progress was negligible.

Original scope work will be mechanically completed within 2 weeks. Procon is presently working on IGT check lists for various areas. It anticipates that work on these will continue through October. Final area paving began on September 28 and will be completed by October 9.

Electrothermal Gasifier Unit

Basic engineering design data sheets were issued on September 10, 1970, for review and comments. The definitive issue, expected by the end of September, will serve as a common basis for all designs to be carried out.

The electrothermal gasifier reactor (8.06-01) was purchased from Struthers Wells; a Telex of intent was sent to them on August 27, 1970. Vessel drawings and requisitions are currently being revised to reflect as-purchased modifications, and contact is being maintained with the vendor on the pending detail designs and materials selection problems, especially concerning the nozzles. A formal purchase order will be issued shortly, but scheduled fabrication is already under way and vendor's delivery commitment is for mid-May 1971. A purchase order for the steam ejector (8.11-01) was placed on September 3, 1970, with Schutte & Koerting; IGT has authorized the placement of an order with Buell Engineering for the cyclones (8.06-43/44) for which a revised requisition is being completed.

The specification for the electrothermal gasifier reactor power feed and control unit has been completed as agreed; the requisition will be issued when IGT's approval is received. The vessel refractory and the materials handling equipment requisitions are being written for issue shortly.

The electrothermal gasifier reactor's foundation and the support steel structure designs have been completed, and requisitions will be issued shortly. The design for the steel structure surrounding the reactor is currently under way.

Some instrument requisitions are ready for release; others are awaiting release, pending technical questions.

Vendor contacts proceeded for the adequate design of suitable cone-type control valves on the high-pressure, high-temperature char drop legs, and also for the critical exit-vent gas-line pipe. Stress calculations were carried out on the proposed configurations and fabrication procedures. A meeting between IGT and Procon was set up to discuss the possible different solutions to these problems, as some of this high-alloy piping can become critical if not ordered in time because of long delivery times.

Project Schedule

The construction work scheduled for the present year and the laying of underground drainage line and electrical conduit runs has been completed.

PILOT PLANT PROGRAM OF IGT HYDROGASIFI

OCR CONTRACT No. 14-01-0001-381(1) AG

1967 — 1968 — 1969 — 1970

1ST YEAR — 2ND YEAR — 3RD YEAR

PILOT PLANT AREAS

a. HYDROGASIFICATION SECTION (HG)
- Bid Specification and Selection — 100%
- Contract Negotiation — 100%
- Detailed Design, Procurement, and Construction HG — 99% 99% 97%

b. ELECTROTHERMAL GASIFICATION SECTION (EG)
- Design, Construction 300-kw Gasifier — 100%
- Shakedown — 100%
- Operation 300-kw Gasifier — 96%
- 2-MW EG Detailed Design, Procurement and — 35%

SECTIONS INTEGRATION

SUPPORT STUDIES

a. COAL CHARACTERIZATION
- Petrographic and Calorimetric Studies — 100%
- 10% Updating and C

b. CATALYTIC METHANATION
- Methanation and Desulfurization Studies — 95%

c. ECONOMIC EVALUATION
- Cost Estimate Based on Current Concept — 100%
- 30% Updating and Correlation of Data

d. GASIFICATION STUDIES
- Tests with Simulated EG Gas — 99%

e. ENGINEERING DESIGN OF COMMERCIAL PLANT

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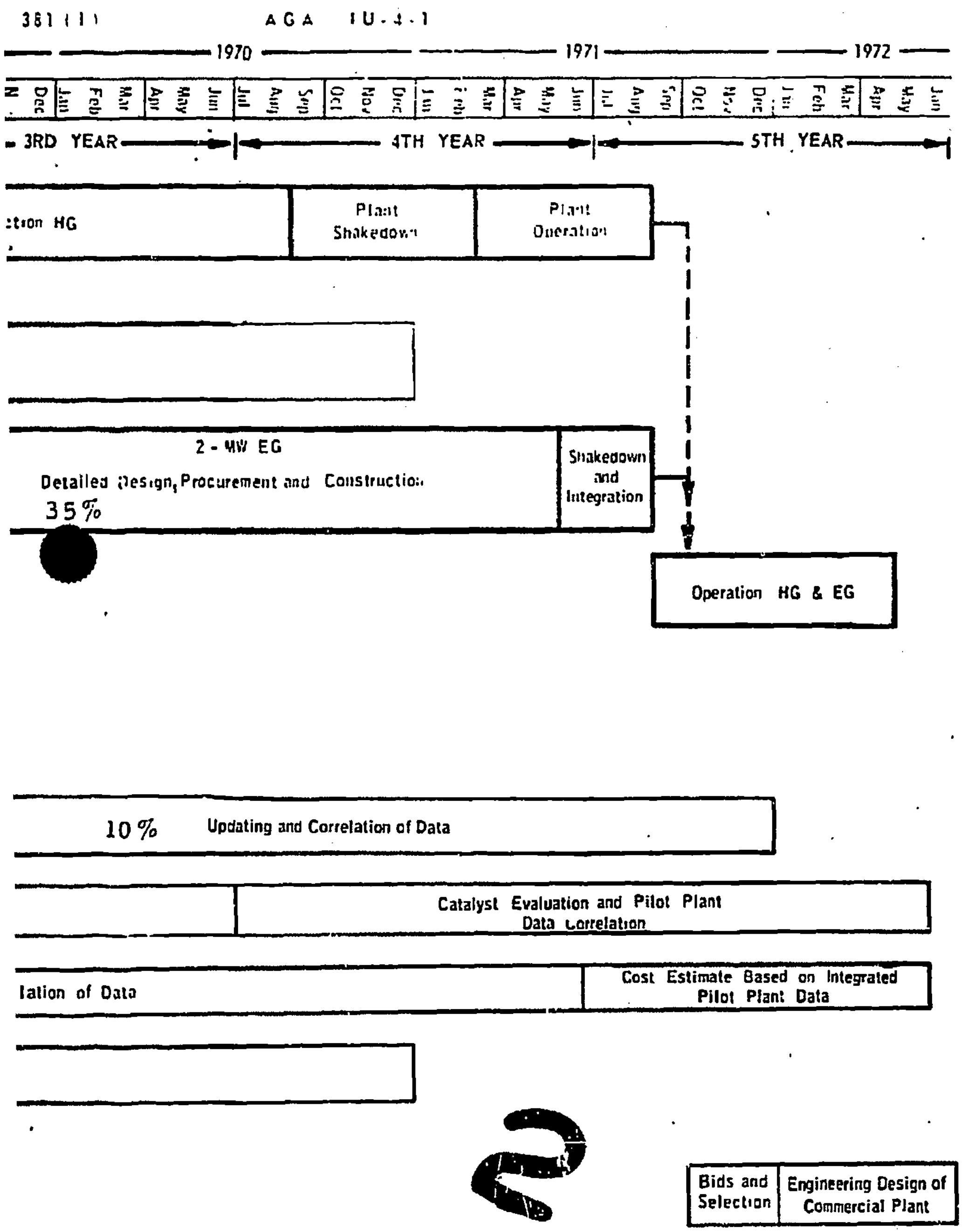
IGT HYDROGASIFICATION PROCESS



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IGT-MPR--10/70

IGT EDUCATION · RESEARCH

INSTITUTE OF GAS TECHNOLOGY - IIT CENTER - CHICAGO 60616

Project Status Report
For
OFFICE OF COAL RESEARCH
and
AMERICAN GAS ASSOCIATION

Report For October 1970
OCR Report No. 73

Project Title Pipeline Gas From Coal – Hydrogenation (IGT Hydrogasification Process

OCR Contract No. 14-01-0001-381 (1) A.G.A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

COAL CHARACTERIZATION

Initial experiments show that residue char can reduce the phenol concentration in the raw-gas quench water to 1% of the original value. The possibility of using char to clean up plant liquid effluents looks promising. We are also measuring H_2S/CO_2 ratios in this quench water.

ENGINEERING ECONOMICS STUDIES

Process economics have been updated to reflect current financial factors and the escalation of investment and labor costs. For raw material costs between 8¢ and 24¢/million Btu, representing lignite to bituminous coal, the gas prices range from 42¢ to 78¢/million Btu.

DEVELOPMENT UNIT STUDIES

Five tests were made in the electrothermal gasifier unit with an oxygen input to observe the effect of oxygen addition on the power requirements of the system. Indications are that the power input can be directly replaced with the carbon-oxygen reaction, forming carbon dioxide. Operation was smooth except for some condensation problems at the bottom of the reactor.

PILOT PLANT CONSTRUCTION

Asphalt paving in the plant was completed. Construction involving items on the IGT check list for the various sections of the plant is continuing. Piping and instrumentation are nearing completion.

Work on the electrothermal gasifier section is aimed at freezing the piping and instrument diagram by the end of this month. Designs of special areas, the hot vent gas line, the power package, and the quench drum are complete.

PILOT PLANT OPERATION

Training of our operating staff continues. Technicians assigned to specific areas are being trained to operate their respective sections. We commissioned the air compressors, low-pressure boiler, and water treatment apparatus. The boilers have been boiled out and the necessary lines pickled. We accepted the analyzer building, the coal unloading area, and the hydrogen plant.

III. Problems

No major problems were encountered this month.

IV. Recommendations

We recommend that the project proceed in the areas defined.

V. Status of Funding

1.	A.G.A. Funding	
A.	1970 Funds Allocated	$ 358,000
B.	Funds Expended This Month (estimated)	$ 25,000
C.	Funds Expended to Date (estimated)	$ 308,000
2.	OCR Funding	
A.	Funds Expended This Month (estimated)	$ 85,000
B.	Funds Expended Since Contract Amendment No. 1 (estimated)	$7,905,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective will be attained within the contract term and the funds allocated.

Approved ______________________
Frank C. Schora, Jr.
Director

Signed ______________________
Bernard S. Lee
Assistant Director

____
Jack Huebler
Vice-President

Appendix. Achievements in October

COAL CHARACTERIZATION

Analyses for phenol and hydrogen cyanide in the condensate have now been accumulated from three hydrogasification runs —

Run No.	Feed Coal	Phenol, mg/ℓ	HCN, mg/ℓ
HT-EG-7	Ireland mine	5000	359
HT-248	Montana subbituminous	4500	4.6
IU4-OH7	Ireland mine	2040	536

We do not know the reason for the low value for hydrogen cyanide on the second sample. Results of the analysis, rerun at the outside laboratory, substantially agreed.

Some experiments were run to determine the level to which phenol in the condensate will be reduced if the condensate is used to slurry the electrogasification residue when the latter is removed from the reactor. Residue char from Run EG-48 and a phenol-water mixture were used. With an initial phenol level of 2600 mg/ℓ and a water-to-char ratio of 2.5 by weight, phenol concentration in the filtrate was reduced to about 1% of its initial level. Additional experiments are planned to determine the effect of treating the condensate more than once with char.

An attempt was made to determine the amounts of carbon dioxide and hydrogen sulfide absorbed, along with ammonia, in the condensate water in the development hydrogasification unit. Equilibrium values do not tell the whole story because the carbon dioxide absorption, or more specifically the reaction to form carbonate from dissolved carbon dioxide, is relatively slow. Two runs made to produce hydrogasification residue from Ireland mine coal were sampled. Samples for carbon dioxide and hydrogen sulfide were run into caustic solution to prevent flashing, and separate samples for the determination of ammonia were subsequently taken. Results indicate that concentrations in the stream are not always constant enough to use this technique. Instead, containers suitable for taking liquid samples under high pressure are being prepared.

The mole ratios of hydrogen sulfide to carbon dioxide obtained are significant.

Run No.	H_2S/CO_2
OH-4	0.55
OH-7	0.43

These ratios are about three times those calculated for equilibrium at the relevant conditions. This confirms the effect of the slow rate of absorption of carbon dioxide.

ENGINEERING ECONOMICS

At OCR's request, we prepared a report on the effect of accounting or financial factors on the economics of synthetic pipeline gas. This study utilizes the A. G. A. accounting procedure to show effects of interest rates, debt fractions, and return on the rate base on gas prices and return on equity. General equations and a nomograph for any combination of operating costs and financial factors are also developed.

Original process economic studies of the HYGAS Process based on bituminous coal and lignite as raw material have been used as a basis for preparing a HYGAS brochure. In the original design for coal feed, purchased electric power was assumed to be available at 3 mills/kWhr. Power was supplied by an onsite MHD system in the original design for lignite feed. Estimates with onsite conventional power plants and purchased power have been used in modifying the original estimates.

Investment and labor costs have been escalated to a 1970 basis and more current financial factors used to compute gas prices. With the above gas plant modifications, gas prices for lignite and bituminous coal plants cover a range of 42¢-78¢/million Btu as the raw materials cost varies from 8¢ to 24¢/million Btu. The details of this work will be given in a subsequent report.

DEVELOPMENT UNIT STUDIES

Electrothermal Gasification

The electrothermal gasifier was equipped with an oxygen feed system for a series of tests to observe the effect of oxygen addition on the power requirements of the system. The oxygen feed system joined the steam and nitrogen inlet lines at the base of the reactor and the mixed gases entered the reactor through a common nozzle.

Five tests were conducted during the month: Two were terminated before the addition of oxygen, one was partially successful, and two were continued until the char feed was depleted. The unsuccessful runs were terminated due to various mechanical problems.

The feed for the first four tests was a residue from FMC Corporation's Project COED. In the fifth test a mixture of electrothermal gasifier residues which had been previously hydrogasified from a high-volatile bituminous coal was used. Nominal conditions for the tests were —

Run No.	Char Feed Rate (dry), lb/hr	Steam Feed Rate, lb/hr	Oxygen Feed Rate, lb/hr	Oxygen/Carbon Ratio, lb/lb	Bed Temp, °F	Reactor Press., psig	Power Input, kW	Overall Resistance, ohm	Carbon Conversion, %	Steam Conversion, %
EGO-3A	465	88	--	--	1680	995	59.5	0.33	38.8	41.0
EGO-3B	58	88	12.5	0.266	1700	1000	37.0	0.84	45.0	42.3
EGO-4A	43	76	--	--	1920	985	68.6	0.33	78.0	63.0
EGO-4B	64	77	12.0	0.234	1840	970	35.2	1.60	47.2	47.8
EGO-4C	53	77	12.0	0.273	1840	995	48.7	0.99	66.1	54.6

The first test, Run EGO-1, was terminated before steady-state operation was attained when arcing occurred in the bed during the heat-up period. Following the test, the inner electrode was found to have been melted about 6 inches along the tip. This was probably caused by the malfunctioning of the bed-level detectors. The top of the bed was apparently near the electrode tip and the high current density at that point caused it to melt. The bed-level detectors were cleaned and calibrated following the run.

In Run EGO-2, oxygen was let into the reactor at a nominal oxygen/carbon ratio of 0.22 lb/lb for approximately 30 minutes. During this time there was a noticeable increase in the bed temperature in the lower portion of the reactor beginning 1 ft above the gas inlet nozzle. There was no increase in temperature in the top 3 ft of the bed; it remained at 1785 °F. The run was terminated before steady operation could be reached when the temperature at the base of the reactor decreased to below the boiling point of water at 1000 psig. In preparing the unit for the oxygen tests, resistance heaters and insulation which normally cover the reactor bottom and discharge screw housing were removed to avoid potential overheating of the pressure closures in that section. The heat losses in the area, however, were large and caused condensation of steam and packing of the char which prevented its discharge from the reactor. The heaters and insulation were put on following this run.

Two steady-state operating periods were attained during Run EGO-3, one with steam only (EGO-3A) and one with steam plus oxygen (EGO-3B). The steam feed rate during both periods was 88 lb/hr. The char feed rate in Run EGO-3A was 46.5 lb/hr, and 38.8% of the carbon was gasified while 41.0% of the steam was decomposed. The power input was 59.5 kW and the bed temperature was 1680 °F. The oxygen feed rate in Run EGO-3B was 12.5 lb/hr; the char feed rate was 58.0 lb/hr, corresponding to a 0.266 lb/lb oxygen/carbon feed ratio. The carbon gasified was 45.0% and the steam decomposed, 42.3%. The average bed temperature was 1700 °F at a power input of 37.0 kW. The decrease in power input after the addition of oxygen generally corresponds to the heat released by the carbon to carbon dioxide reaction and is also reflected in the higher average bed temperature and increased carbon gasification.

Again the problem of the rapid cooling of the reactor bottom occurred when the fluidizing nitrogen which is used during the heat-up period was shut off after the switchover to steam. A continuous nitrogen purge was necessary during the run to avoid condensation.

There were three steady-state operating periods in Run EGO-4. The first was with steam only, the other two, with a steam and oxygen mixture. The bed temperature of 1920°F was maintained in Run EGO-4A with a power input of 68.6 kW. The carbon gasified was 78.0% and the steam decomposed was 63.0% with feed rates of 43 and 76 lb/hr. The oxygen flow rate was 12.0 lb/hr during the next two periods and the steam feed rate was 77.0 lb/hr. In Run EGO-4B the char feed rate was 64 lb/hr with 47.2% of the carbon gasified and 47.8% of the steam decomposed. The power input was 35.2 kW and the bed temperature was 1840°F. An attempt to establish the conditions of Run EGO-4C more closely to those of Run EGO-4A was made in the third period for better comparison of results between steam only and steam plus oxygen. The char feed rate of Run EGO-4C was 53 lb/hr compared to 45 lb/hr in Run EGO-4A, and the bed temperature was 1840°F. The char conversion was 66.1% and the steam decomposition was 54.6%. The average power input was 48.7 kW.

Run EGO-5 was an attempt to operate at a higher oxygen-to-carbon feed ratio with a feed char of previously lightly gasified high-volatile bituminous char. The run was terminated before steady-state conditions were attained due to excessive solids carry-over into the offgas quench tower and subsequent plugging of the product gas exit line from the reactor.

Following this test the reactor was dismantled for installation of the silicon carbide inner reactor tube. Tests will be conducted to study the electrical characteristics of the Crystar-type silicon carbide for possible use as the liner in the 2-MW electrothermal gasifier.

PILOT PLANT CONSTRUCTION

General

Extras 1 through 29 to the guaranteed maximum price were discussed October 9, 1970, and final determination was reached and agreed upon by both parties subject to approval by OCR.

The reactor model was completed and received. Insulation of the coal mill unit is now in progress. Asphalt paving of the project has been completed.

Engineering

Work continued in electrical instrumentation and piping on recent extra requests and unit acceptance check lists. This should terminate shortly with Procon receives a final request from IGT.

Procurement

Purchasing is still involved with items pertaining to extras and check list items. Its completion will be based upon future engineering requirements.

Construction

Activities of the field are still piping, instrumentation, electrical insulation, painting, and cleanup. Inclement weather has been a problem,and production is slowed considerably on days when it occurs. Work is being concentrated in the utility, compressor, and coal handling areas at the moment. Upon receipt of the remainder of the acceptance check list items and requested extras, a final completion date will be determined.

Schedule

As of this moment and time of the year, the manpower, and work expected, Procon projects final completion will extend into the latter part of November.

PILOT PLANT OPERATION

Electrothermal Gasifier Unit

Revision 3 of the piping and instrumentation diagram was issued October 2, 1970,for the start-up operation and Revision 0 for the final operation on October 5, 1970. It is planned to freeze the piping and instrumentation diagrams by the end of October. Updated revisions of the plot plan, utility piping and instrumentation, process flow diagrams, and line index will also be issued at this date. Basic engineering design data sheets are being updated.

A formal purchase order was placed with Struthers Wells for the electrothermal gasifier reactor (8.06-01) on October 12, 1970, and for the cyclones (8.06-43/44) with Buell Engineering on October 2, 1970. Authorization for placement of a purchase order for the electrothermal gasifier vent gas scrubber (8.06-02) with General Welding has been received from IGT and is in process. All this equipment has been modified, and updated quotes will be forthcoming for the issue of revised purchase orders. Quotes are being tabulated for submittal on the steam separator (8.406-41). Because of a major modification caused by the design and fabrication criteria finally adopted for the electrothermal gasifier power feed system to which the quench drum (8.06-42) is connected, the requisition of the drum is being revised and will be reissued for quotes this week. Procon received, with pertinent comments, IGT's specification for the transformer-rectifier unit for the electrothermal gasifier power feed system and is completing a requisition for issue this week.

The layout of the electrothermal gasifier structure has been completed, with all levels of required platforming. The structural and foundation design is being reviewed for modification as required. Foundation design for the vent gas scrubber (8.06-02) has been started. Work on the high-alloy material bulk take-off has started, as some of this material can become critical due to its long delivery time. The recent decision to reincorporate the water jacket enveloping the outer pipe, as well as requiring that part of the high-pressure superheated steam be put into the process gas line to bypass the electrothermal gasifier reactor, has introduced new design problems which are being studied for feasible solutions.

The requisition for special control valves has been issued for quotes. Vendor contacts have proceeded for a design for the control valves on the high-temperature, high-pressure service in the char drop legs and for the bottom of the electrothermal gasifier reactor.

IGT-MPR--11/70

INSTITUTE OF GAS TECHNOLOGY · IIT CENTER · CHICAGO 60616

Project Status Report
For
OFFICE OF COAL RESEARCH
and
AMERICAN GAS ASSOCIATION

Report For November 1970
OCR Report No. 74

Project Title Pipeline Gas From Coal – Hydrogenation (IGT Hydrogasification Process)

OCR Contract No. 14-01-0001-381 (1)   A.G.A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

COAL CHARACTERIZATION

Additional tests with electrothermal gasifier residue char show that the char may be useful for removing phenol from plant liquid effluents. Phenol concentrations in the simulated plant waste liquid were reduced by a factor of 1000 or more. Through a two-stage countercurrent contact, we should be able to reduce the phenol concentration to less that 5 ppb.

DEVELOPMENT UNIT STUDIES

A new low-resistance silicon carbide (Crystar) tube was tested in the electrothermal gasifier. It showed very rapid heat-up and acceptably low resistance; however, thermal expansion stresses caused the tube to crack, leading to arcing, which damaged it. Another tube was installed and will be tested shortly.

PILOT PLANT CONSTRUCTION

Construction centers mainly on rework around the hydrogasifier structure. We expect final completion of the plant before the end of this year.

The piping and instrumentation diagrams for the electrothermal gasifier unit were frozen for the establishment of a guaranteed maximum price. All long-delivery items are on order, except for the transformer-rectifier package quotations, which will be reviewed.

PILOT PLANT OPERATION

Training of our operating staff continues. We are now fully staffed, except for two or three technicians needed to handle coal. The low-pressure boiler, put on-stream on November 16, 1970, is in operation round-the-clock. The steam generated provides tracing steam to keep the plant from freezing. The coal unloading facility was thoroughly tested upon receipt of 700 tons of Montana lignite. IGT accepted the coal preparation section.

III. Problems

No major problems were encountered this month.

IV. Recommendations

We recommend that the project proceed in the areas defined.

V. Status of Funding

1. A.G.A. Funding

A. 1970 Funds Allocated	$	358,000
B. Funds Expended This Month	$	25,000
C. Funds Expended to Date	$	333,000

2. OCR Funding

A. Funds Expended This Month (estimated)	$	214,000
B. Funds Expended Since Contract Amendment No. 1 (estimated)	$	8,110,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective will be attained within the contract term and the funds allocated.

Approved ______________________
Frank C. Schora, Jr.
Director

Signed ______________________
Bernard S. Lee
Assistant Director

____
Jack Huebler
Vice-President

Appendix. Achievements in November

COAL CHARACTERIZATION

We further investigated the filtering and adsorption properties of the residue from electrogasification. The objective here was to remove the phenol from the condensate, obtained from the hydrogasifier effluent gas, by using the condensate to slurry the char from the electrogasification process. Residues from Runs EG-34, EG-35, EG-37, and EG-46 were composited to provide a large sample from the processing of bituminous coal. Carbon conversions in the electrogasification runs ranged from 33 to 42%.

Water retention in the filter cake after filtration through a Buchner funnel was about 0.9lb/lb of char. This is substantially higher than the 0.65 lb/lb retention shown by the sample from Run EG-48 previously investigated. The results also show greater phenol adsorption.

Sample	Init Phenol Concn,ppm	Phenol Adsorbed, mg/g of char	Residual Phenol Concn,ppm
EG-48 Residue	2590	7.6	17
Composite	4900	12.3	4.9, 6.8
Composite	52	0.13	0.014

The phenol concentration of 5000 ppm is about the maximum found in condensates from the experimental hydrogasification unit. The ratio of water to char in the tests, 2.5 by weight, exceeds the amount necessary to slurry the char.

In conclusion, it appears that the adsorptive capacity of the residue char varies, presumably with conversion. It will be possible to remove phenol from the condensate; however, it may be necessary to recycle the filtered condensate to slurrying with another lot of char in order to reduce the phenol concentrations below 5 ppb.

DEVELOPMENT UNIT STUDIES

Electrothermal Gasification

Installation of the 5.0-inch-ID silicon carbide (Crystar) tube, supplied by Norton Co., as the outer electrode of a concentric configuration was completed this month. The inner electrode consisted of a solid type-316 stainless steel rod, divided into two sections of different diameters. The immersed electrode section was a rod 30 inches long and 1 inch in diameter. The 1-inch-diameter rod was chosen to provide the present concentric electrode configuration with a current path similar to those of the concentric arrangements previously tested. The upper section consisted of a 1.5-inch-diameter rod, 50.5 inches long and electrically insulated from the outer electrode by a 43-inch-long, Vycor glass tube. Other design changes have been previously reported in the August 1970, IU-4-1 Project Status Report. A cutaway view of the reactor configuration and design modifications is shown in Figure 1.

One test, Run EG-67, was conducted in the pilot plant unit at 1000 psig using FMC COED char as the feed material. The purpose of Run EG-67, the first made with the Crystar-type silicon carbide tube, was to obtain electrical characterics data under operating conditions for this new type of electrode. The overall resistance of the system was 100-200 ohms at the start of the heat-up period. Heat-up to the steam injection temperature of 1300°F was smooth and rapid, with an average power input of 20 kW for this period.

Table 1 shows a comparison of the overall resistance of the system for Run EG-67 and the previous successful test, Run EG-66, at different bed temperature levels during heat-up. No problems were encountered during the transition from nitrogen to steam as the fluidizing gas. An average bed temperature of 1700°F was maintained for 50 minutes at a power level of 20-30 kW; the average overall resistance was 0.66 ohm. We were unable to attain steady state because the feed system continuously jammed. Shortly after the feed screw jammed at a bed level temperature of 1700°F, arcing occurred across the bed, with one thermocouple indicating 2100°F.

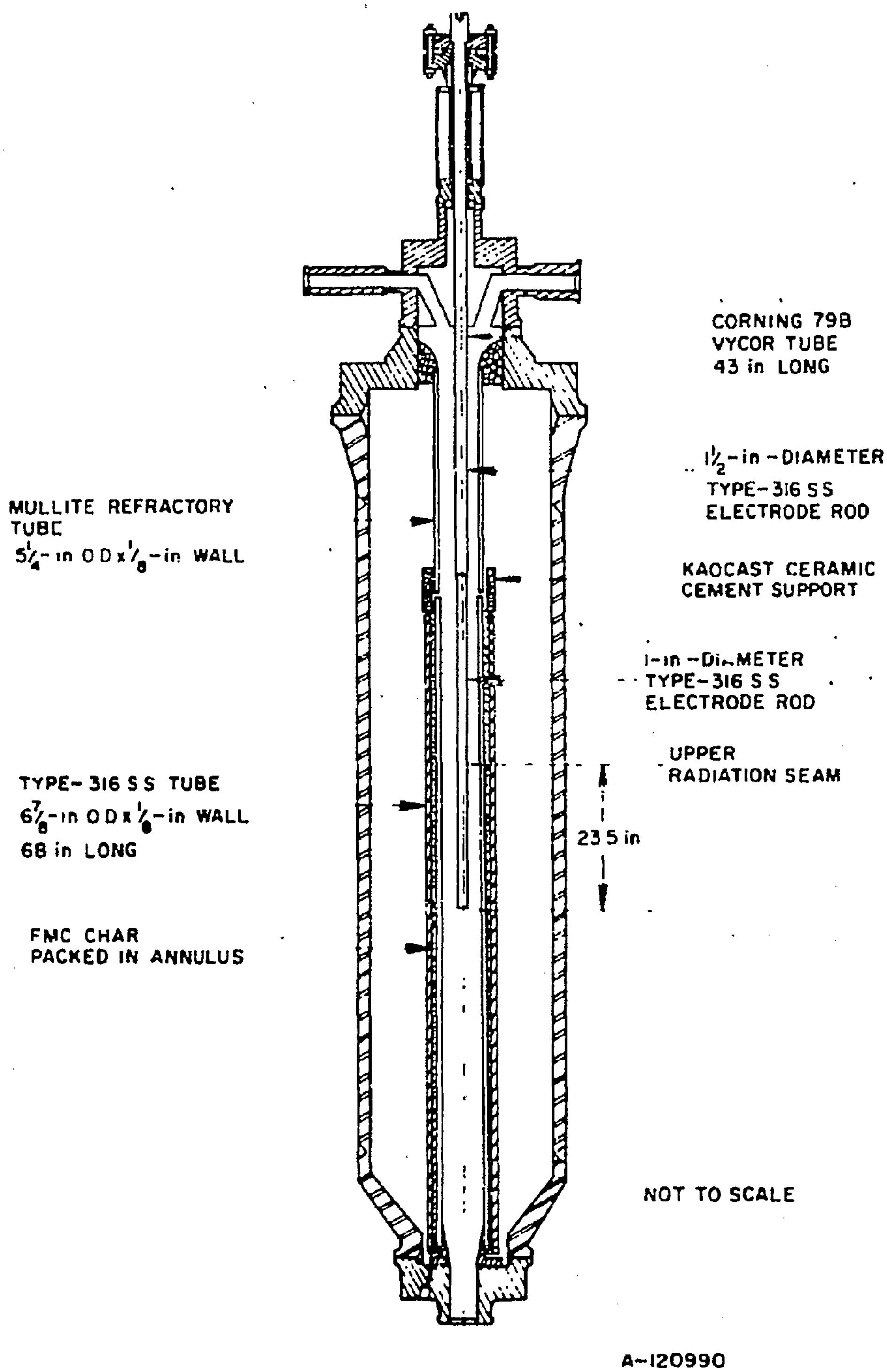

Figure 1. CUTAWAY VIEW OF REACTOR FOR RUN EG-67

Table 1. OVERALL RESISTANCE OF CRYSTAR AND CRYSTALLON-TYPE SILICON CARBIDE AT DIFFERENT BED TEMPERATURE LEVELS

Temperature, °F	Run EG-67 (Crystar)	Run EG-66 (Crystallon)
	R,ohm	
500	20	20
600	2.5	20
850	0.77	6
1000	0.80	2.0
1300	0.51	1.8
1600	0.73	1.6

The overall resistance of the system increased to approximately 3 ohms; however, the pressure drop across the reactor indicated the existence of a full bed. A char plug, formed above the exposed area of the inner electrode, may have been the cause. Arcing across the bed continued, and the run was terminated as a temperature of 2200°F was indicated at the top of the silicon carbide tube. Inspection of the reactor showed severe cracking of the mullite refractory tube, as well as of the silicon carbide tube. The top of the Type-316 stainless steel shell was melted. Other melted spots along the steel shell were observed. The inner electrode appeared to be in good condition, except for some melted spots at the junction of the 1-inch to 1.5-inch-diameter sections.

The possibility of cracking by thermal expansion exists. The junction between the mullite ceramic tube and the Crystar silicon carbide tube was held in place by a form made of Kaocast refractory cement. The cement form rested on top of the stainless steel shell and was attached to both the mullite and the silicon carbide tubes. Expansion of the stainless steel shell produced a shearing force on the silicon carbide tube due to the low coefficient of expansion of the Kaocast refractory cement. The silicon carbide was cracked at the same height as the stainless steel shell, indicating the existence of stresses at that point. As previously mentioned, a char plug formed at the top of the reactor. As an attempt was made to discharge the solids, the plug was lowered to the junction of the 1 to 1.5-inch-diameter sections of the inner electrode, and a path of low resistance was established, giving rise to the arcing observed. The interaction of the electrical arcing and the stress forces increased the severity of the cracking; char filtered through the cracks until an electrical contact was made between the Type-316 stainless steel shell and the inner electrode leading to the damage.

A new Crystar-type silicon carbide tube is being installed, and care has been taken to avoid direct contact between surfaces in a way that thermal stresses became significant. Also, the junction of the 1 to 1.5-inch-diameter sections of the inner electrode has been shifted to a position well-above the bed level to avoid any arcing that may occur across the electrodes. Completion of the new setup is expected shortly.

PILOT PLANT CONSTRUCTION – HYGAS PLANT

General

Home office extras 30 through 50 were submitted to IGT for review. An evaluation meeting was scheduled for December 2, 1970; a field extra review is scheduled for December 3, 1970. The coal handling area has been turned over to IGT. Vendor servicemen are checking out the coal mill area prior to turning it over to IGT.

Engineering

Minor changes are still to be made in instrumentation, electrical work, and piping.

Purchasing

Home office purchasing is complete.

Construction

The main item of construction is the reactor structure: Change of the PDT locations from below to above the taps is approximately 40% complete.

Painting, insulation, and check list changes in other areas are being completed prior to IGT's acceptance. Final control panel checkout is very close to being completed.

Able Construction Co. is installing weather stripping on all doors in the control and switchgear room to obtain the required positive pressure.

Schedule

For this time of year and with the manpower and work expected, final completion is scheduled for January 1, 1971.

PILOT PLANT OPERATION

Electrothermal Gasifier Unit

After piping and instrumentation review meetings in the early part of November, the following documents are the frozen revisions for the purpose of establishing the guaranteed maximum price:

P & I Diagram (Start-up Operation)	1863-8.00-2J	Rev 4
P & I Diagram (Final Operation)	1863-8.00-4F	Rev 1
Plot Plan	1863-10.01-1J	Rev 1
Process Flow Diagram	1863-8.00-1J	Rev 2
Utility P & I Diagram	1863-8.00-3G	Rev 2
Line Index & Pipe Specifications	1863-8.11-1	Rev 2
One-Line Electric Diagram	1863-10.12-1G	Rev 0

The basic engineering design data sheets were updated and revisions issued reflecting comments received and discussions with IGT. Piping specifications to be used on this job, as well as line-sizing criteria for the nitrogen purge lines and the impulse lines for the differential pressure and the flow transmitters, were discussed with IGT.

Purchase orders have been placed on all items authorized by IGT and bid tabulations with vendor recommendations were submitted on others when complete information was available. Technical evaluations and bid tabulations are under way at present on the major instrument requisitions, as well as on the steam separator and the quench drum. The transformer-rectifier unit specifications have been issued for quotes; these are expected at the end of the present week. Extensive vendor contact was made for this item, and technical evaluation and vendor selection will be expedited to enable the timely purchase of this long-delivery unit.

Incoloy piping bulk material requisitions were completed for issue this week, reflecting the updated design changes and modifications. These are critical, long-delivery items that require special preferential handling. It was not possible to firm them up and issue them earlier because of the design changes introduced with the addition of the steam ring in the electrothermal gasifier vent gas line, the modification of the char dust cooler, and other late modifications such as raising the elevation of the char lift cyclone, thus lengthening feed and exit lines to it. The piping plan drawing is in progress, and critical stainless steel lines are being checked for stress.

Requisitions for the electrothermal gasifier reactor structural steel support, the reactor foundation, and the foundation for the steel structure around the reactor have been issued. The steel structure around the reactor has been designed and the drawings and requisitions are being finalized. This includes the platforming for the 123-foot,9-inch level on the electrothermal gasifier reactor structure, requested by IGT, and the other minor modifications required and agreed upon. The foundation for the electrothermal gasifier vent gas scrubber has been designed, and the drawings and requisitions are being finalized for issue. The reactor refractory requisition is out for quotes, excluding its electrical conduction portion, which is still pending final definition by IGT.

Attempts at getting a supplier interested in developing a cone-type control valve for operation at the bottom of the electrothermal gasifier reactor proved unsuccessful so far, due to the extreme design conditions. Several vendors contacted declined, and we are now waiting to hear from Crane-Flomatics Division on this application.

The electrothermal gasifier reactor (8.06-01) will be stamped ASME Section I, instead of Section VIII, as originally specified; the hydrogasifier (3.06-01) was stamped in the same fashion. Struthers Wells will update its quote to meet this requirement, plus incorporate other changes which have been made. Delay in getting design and pricing information from Grayloc retarded the updating of the required quotes, both in this case and for the cyclones ordered from Buell, although no setback on delivery date has resulted. Grayloc was contacted to expedite the required information.

Redrawing of the semigraphic layout on Panel C to incorporate the electrothermal gasifier unit has been started. Work will be completed around the first week in December, and, after review, SCAM will be contacted for a quote on the resetting and reconnection work required for this panel.

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IGT EDUCATION RESEARCH

INSTITUTE OF GAS TECHNOLOGY · IIT CENTER · CHICAGO 60616

Project Status Report
For
OFFICE OF COAL RESEARCH
and
AMERICAN GAS ASSOCIATION

Report For Fourth Quarter, 1970
OCR Report No. 75

Project Title Pipeline Gas From Coal – Hydrogenation (IGT Hydrogasification Process)

OCR Contract No. 14-01-0001-381(1) A. G. A. Project No. IU-4-1

I. Project Objective

The overall objective of this project is a process for producing pipeline gas from coal that is economically attractive for supplementing natural gas supplies. The present objective is the design, construction, and operation of a large integrated pilot plant to obtain scale-up data and operating experience. Developmental research, engineering studies, and economic evaluations are in progress to help attain this objective.

II. Achievements

COAL CHARACTERIZATION

Initial results from studying the distribution of minor coal constituents in the HYGAS Process show that all the nitrogen removed from the coal appears as ammonia. The yield of ammonia in Run HT-248 with Montana subbituminous coal as feed was 14.5 lb NH_3/ton of dry coal, corresponding to 64.9% of the nitrogen in the coal. Since over 75% of the ammonia appears in the recycle quench water, if a cooling tower is used, most of the ammonia is released to the atmosphere. We are studying means for recovering the ammonia and avoiding atmospheric pollution.

Phenol and cyanide were also found in the above effluents. Tests with electrothermal gasifier residue char show that the char may be useful for removing phenol from plant liquid effluents. Phenol concentrations in the simulated plant waste liquid were reduced by a factor of 1000 or more. Through two-stage countercurrent contact, we should be able to reduce the phenol concentration to less than 5 ppb.

Vapor-liquid equilibrium constants for a mixture simulating raw hydrogasifier effluent were determined to aid in the design of its quench system.

To date microtumbler tests indicate that the attrition resistance of gasified residue does not change and, in fact, may increase slightly with conversion. It is possible that the expected decrease in strength, caused by the removal of material by gasification, throughout the particle is compensated for by the increased strength caused by coking or graphitization of the particle.

HIGH-PRESSURE METHANATION

Results from a series of runs at low flow rates and low pressures agreed well with results at high pressures. An improved correlation was obtained for the methanation rate expression, which was extended to cover regions with large excesses of hydrogen and methane.

$$r = \frac{k_1 p_{CO} \, p_{H_2}^{0.5}}{1 + k_2 p_{H_2} + k_3 p_{CH_4}}$$

Data at low conversions and near equilibrium are being collected to test this correlation: Initial data indicate that it requires modification for conditions near equilibrium. The temperature-dependence studies of the reaction rate at 740° and 850°F show that the rate expression is still valid up to 850°F.

The laboratory unit to measure the sulfur tolerance of methanation catalysts for use in the pilot plant was completed, and shakedown of the unit is in progress. The two pilot plant process gas chromatographs were tied-in with this unit to check out the analyzers and try them with gases similar to those that will be encountered in the pilot plant.

Ethylene hydrogenation was briefly studied to see if this type of process can be adapted for starting up the pilot plant hydrogasifier. We tested both Ni-Mo and ammonia synthesis catalysts. Ethylene can be hydrogenated to ethane at room temperature over the more active Ni-Mo catalyst; without a catalyst the reaction does not occur below 800°F. Hydrogenation occurring at 1100°F was accompanied by the formation of carbon and tar.

ENGINEERING ECONOMICS STUDIES

A computer program was developed to estimate the cost of vessels as a function of their dimensions and configurations. The effects of financial factors on the return on equity for gas utility financing were calculated, and the results presented in graphical form.

The economics of lock hopper and slurry systems for feeding pretreated char to the hydrogasifier were compared using recent data. The results indicate that the lock hopper system could show a gas price advantage of 3¢/million Btu if a reasonable life of the control valves can be expected. These valves must seal against 500-psi differential pressure and must handle solids flowing through them. Further probing is planned.

The use of partial or total air cooling for a pipeline gas plant was examined in detail. For a 500 billion Btu/day lignite-based plant total air cooling or air cooling to 140°F, followed by water cooling to 100°F, shows that the plant makeup water requirement can be reduced by 82-88% over a totally water-cooled plant. The capital investment for an air-cooled plant is less than for a water-cooled plant; substantial savings in power consumption should also result. The work was done in cooperation with Hudson Products Corporation, a major supplier of air coolers.

The above scheme was revised to include conventional steam-turbine power generation instead of MHD generation. The gas price increases from 33¢ to 40¢/million Btu when the steam cycle is used. We examined air and water cooling with each mode of power generation. Air cooling shows about a 1¢/million Btu cost advantage in the gas price over water cooling at a 3.5% makeup water rate and an even greater advantage at higher makeup rates.

Process economics have been updated to reflect current financial factors and the escalation of investment and labor costs. For raw material costs between 8¢ and 24¢/million Btu, representing lignite to bituminous coal, the gas prices range from 42¢ to 78¢/million Btu. A report updating the HYGAS Process with electrothermal gasification is nearly complete. Current financial factors are incorporated.

DEVELOPMENT UNIT STUDIES

Results of free-fall thermal treatment of lignite at 1300 °F, using nitrogen as a sweep gas, showed 14% carbon gasification. The degree of gasification at 280 psi, comparable to another run at 1000 psi, indicates that devolatilization is the only reaction occurring.

Hydrogasification of lignite at 500 psi with hydrogen and steam showed 41% carbon gasification, indicating no significant loss of reactivity from the 1000-psi operation. Results of lignite gasification at 500 psi with synthesis gas-steam and hydrogen-steam mixtures show that about 5% more carbon (36 vs. 41%) was gasified with the hydrogen-steam mixture. Either gas mixture is adequate for the HYGAS Process in terms of obtaining the required gasification.

The study of Montana subbituminous coal showed that a 1000-psi pressure is definitely preferred over 500 psi with either the hydrogen-steam or synthesis gas-steam mixtures. Operation was smooth at 1000 psi, but erratic at 500 psi. Lower methane and higher carbon oxides yields were also obtained at 500 psi. The study of New Mexico subbituminous coal showed that the coal was similar in behavior and reactivity to the Montana and Colorado subbituminous coals tested earlier. With 13 coals tested to date in the 4-inch hydrogasifier, further study of other coals will be postponed.

Designs are being completed to examine the flow patterns and pressure balance in a model of the upper section of the HYGAS hydrogasifier. The model will permit preliminary study of any future modifications.

The nozzles from Spraying Systems Corp. appear to show no wear when dispersing coal-water slurries. Photographs were taken that should permit measurement of the spray distribution.

After a number of successful runs at 1900 °F and 1000 psi using IGT's hydrogasified char, silicon carbide was tried as the central electrode and as the reactor tube. The material withstands hot spots well, but shows a high initial electrical resistance. Upon heating, the resistance gradually drops to an acceptable range. A new low-resistance silicon carbide (Crystar) tube was tested in the electrothermal gasifier. It showed very rapid heat-up and acceptably low resistance; however, thermal expansion stresses caused the tube to crack, leading to arcing, which damaged it. Another tube was installed and tested, but it also cracked despite precautions taken to eliminate the thermal stresses. A third tube, Crystar impregnated with silicon metal, is on order and will be tested. We are also setting up a bench test to check the effect of high-pressure, superheated steam on silicon carbide.

A run aimed at defining the electrical characteristics of the bed yielded much data. High- and low-frequency current and voltage fluctuations, along with transient response of the bed to step-changes in power input, should provide the necessary data for designing the power package of the 2-MW electrothermal gasifier unit. Work to date indicates that the 2-MW electrothermal gasifier will have a direct-current power supply and a concentric electrode configuration.

A magnetic flip coil was installed in the electrothermal gasifier unit to suppress arcing and reduce current fluctuations. Two tests showed that the frequency of the current flicker was noticeably reduced, while its amplitude remained unchanged. Although some additional tests with the coil may be made later, no flip coil will be used in the 2-MW unit. The fabrication and installation of the coil can be difficult; the coil requires significant power that only reduces the frequency of current flicker but not its amplitude.

Five tests were made in the electrothermal gasifier unit with an oxygen input to observe the effect of oxygen addition on the power requirements of the system. Indications are that the power input can be directly replaced with the carbon-oxygen reaction, forming carbon dioxide. Operation was smooth except for some condensation problems at the bottom of the reactor.

NEW PROCESS STUDIES

A fuel cell engineering study to supply power to the electrothermal gasifier was completed, including details of power plant configuration and cost calculations. A bus bar cost of 4.5 and 5.4 mills/kWhr is estimated for fuel cell power densities of 300 and 150 watts/sq ft. Capital investment is estimated at $99 and $123/kW for cell power densities of 300 and 150 watts/sq ft.

Instead of generating additional power from the hot fuel cell waste gases, as in the above study, we considered using the waste gases for 1) raising high-pressure steam or 2) supplying heat to the producer gas generator. Scheme 1 is more attractive than scheme 2, but is not economically as attractive as the original study in which the waste gases generated additional power.

PILOT PLANT CONSTRUCTION

The HYGAS pilot plant construction is complete except for minor miscellaneous field changes. Procon is out of the field, at its own request, except for one man who supervises the completion of insulation work. Morrison Construction Company, a local contractor under subcontract to IGT, is finishing the items left undone by Procon. The cost of the work will be paid out of the funds retained by IGT on its subcontract with Procon. All work is expected to be completed by January 1971, except for insulation work, which may not be completed until February.

Together with Procon we began the design and construction of a 2-MW electrothermal gasifier system for the HYGAS pilot plant. The reactor will be built aboveground instead of in a pit, where solids transfer might be easier, because the cost of underground construction is prohibitive. For safety purposes, the reactor will have a water jacket similar to the hydrogasifier's. The gasifier vessel has been placed on order with Struthers-Wells Corporation, and delivery is expected in June 1971. The transformer-rectifier package is also on order, due for delivery in July 1971 from Westinghouse. The piping and instrumentation diagrams for the electrothermal gasifier unit were frozen for the establishment of a guaranteed maximum price, due to be submitted in January 1971. Piping spool sheets are being prepared, and quotations for piping and electrical subcontracts are in progress.

PILOT PLANT OPERATION

We are now fully staffed, except for two or three technicians needed to handle coal. The low-pressure boiler, put on-stream on November 16, 1970, is in operation round-the-clock. The steam generated provides tracing steam to keep the plant from freezing. The coal unloading facility was thoroughly tested upon receipt of 700 tons of Montana lignite. Also on the site are 700 tons of Illinois No. 6 seam bituminous coal.

Due to the incomplete insulation in the plant, we experienced two freeze-ups in various steam tracing sections. We scheduled the operation and performance test of the hydrogen plant for the first week of January, after which the coal preparation and pretreatment sections will be shaken down and operated.

III. Problems

No major problems were encountered this period.

IV. Recommendations

We recommend that the project proceed in the areas defined.

V. Status of Funding

1. A.G.A. Funding

A.	1970 Funds Allocated	$ 358,000
B.	Funds Expended This Month	$ 25,000
C.	Funds Expended to Date	$ 358,000

2. OCR Funding

A.	Funds Expended This Month (estimated)	$ 225,000
B.	Funds Expended Since Contract Amendment No. 1 (estimated)	$8,330,000

As a result of personally reviewing the pertinent data and information reasonably available, it is our opinion that the project's objective has been attained within the contract term and the funds allocated.

Approved ______________
Frank C. Schora, Jr.
Director

Signed ______________
Bernard S. Lee
Assistant Director

____
Jack Huebler,
Vice-President

Appendix. Achievements in December

COAL CHARACTERIZATION

Vapor-liquid equilibrium constants for a mixture of carbon dioxide, carbon monoxide, hydrogen, methane, and benzene were determined at 100°F and 1180 psia. Results, with estimated limits of accuracy, were as follows:

Component	Composition, mol %		Equilibrium Constant	
	Vapor	Liquid		
CO_2	20.9	13.7	1.53	±0.02
CO	25.8	2.5	10	±5
H_2	26.8	4.8	5.6	±0.2
CH_4	25.3	7.1	3.6	±0.1
C_6H_6	1.2	71.9	0.017	+0.005, −0.002

The uncertainty in the results for carbon monoxide is large because air leaked into the vaporized liquid sample. The determination will be repeated when the apparatus becomes available.

ENGINEERING ECONOMICS

The report on escalated costs for the HYGAS Process using electrothermal gasification is nearly complete. Drawings and tables are in final form, and the text is 80% complete. The report compares current economics of pipeline gas from coal and lignite based on the original designs. It shows the economic effects of changes in investment, cost of coal, operating labor, maintenance, electric power, and financial factors. Differences between the original reports and the new numbers are analyzed.

ELECTROTHERMAL GASIFICATION

A new 5.0-inch-ID tube of Crystar-type silicon carbide was installed in the pilot unit, and one test was conducted. It was installed to allow free movement along its length for thermal expansion. Run EG-68 was conducted under the same conditions as Run EG-67 at 1000 psig, using FMC char as the feed. The overall resistance of the system was similar to that of Run EG-67, decreasing from 20 ohms at the start of heat-up to about

0.5 ohm at 1400 °F. The unit operated very smoothly during the heat-up — no upsets or mechanical problems were encountered. However, after several hours of operation a sudden increase in the temperature of the tube wall occurred about 12 inches from the top. Evidence of an arcing condition became apparent on the ammeter, and the test was terminated.

Inspection of the silicon carbide tube following the test showed that it was cracked in several places. One was a circumferential break corresponding to the area of temperature rise observed during the run; there were numerous others in the bottom section of the tube (Figure 1).

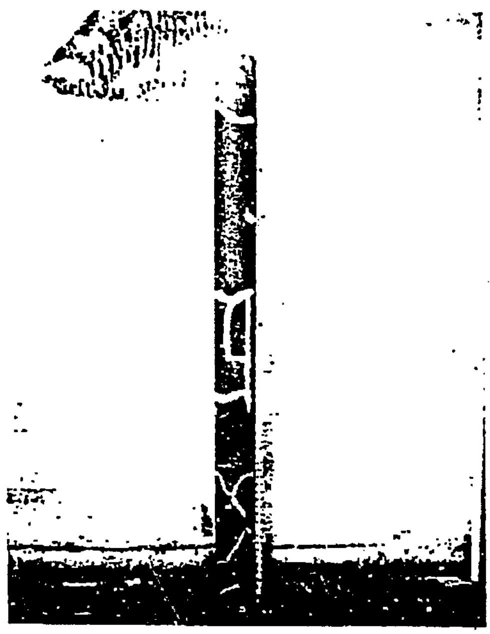

Figure 1. CRYSTAR-TYPE SILICON CARBIDE TUBE FOLLOWING RUN EG-68

The cause of the cracking is not yet clear. It cannot be attributed to any operational problems, nor to any apparent thermal stresses, since the temperature gradient in the area of the cracks was very small. Discussions are being held with the supplier, Norton Co., in an effort to determine the cause of the cracking.

Another type of silicon carbide has been recommended for testing in the pilot unit. It is a silicon-metal-impregnated, Crystar-type which exhibits much lower resistivity characteristics than those tested thus far. A 5-inch ID X 1/4-inch wall tube has been ordered and will be installed upon receipt. Recently we looked into the effects of steam and reducing gases on silicon carbide. Steam appears to react with silicon carbide at the operating conditions of the electrothermal gasifier to form various silicon and carbon oxides. However, most data available were obtained from tests conducted in either high-pressure saturated steam or low-pressure superheated steam, but not in high-pressure superheated steam. Since some reports indicate appreciable oxidation of the silicon carbide in a steam atmosphere, we are designing a small test reactor which will be able to more closely simulate the operating conditions of the electrothermal system and will conduct several tests on samples of the silicon-metal-impregnated Crystar-type silicon carbide. Results of the tests should provide data which would be useful in determining whether silicon carbide could be used as a liner in the 2-MW reactor.

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