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HYDROGASIFIER DEVELOPMENT
COMMERCIAL DESIGN OF SINGLE-STAGE COMMERCIAL SCALE
AND PROCESS DEVELOPMENT SCALE HYDROGASIFIERS

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Work performed under Contract EY-76-C-21-8055

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Prepared for

UNITED STATES DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, West Virginia

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HYDROGASIFIER DEVELOPMENT

Conceptual Design of
Single-Stage
Commercial Scale

and

Process Development Scale
Hydrogasifiers

for

U.S. DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, West Virginia

Contract EY-76-C-21-8055

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HYDROGASIFIER DEVELOPMENT

Conceptual Design of Single-Stage Commercial and Process Development Scale

U.S. Department of Energy

1.0 INTRODUCTION

An evaluation of the process requirements resulting from changing the Hydrane process from a two-stage hydrogenation to a single-stage hydrogasification process was undertaken by the Dravo Corporation for the Morgantown Energy Research Center, U.S. Department of Energy, Morgantown, West Virginia.

Hydrogenation is the reaction of coal with hydrogen to produce gaseous and/or liquid products. Hydrogasification is the gasification of coal by direct reaction with hydrogen to produce gaseous products only.

The present single-stage process scheme has further developed hydrogasification to incorporate rapid heating of fine coal particles (70%, -200 mesh) to the reaction temperature (1600-2000° F). The heating rate has been estimated to be in excess of 1×10^6 ° K per second. The combination of the two foregoing operations, i.e., rapid heating of the particle in an atmosphere of hydrogen, results in devolatilization of the coal particles and rapid reaction of devolatilized hydrocarbons with hydrogen. This process has also been termed "flash hydrolysis."

The advantages which accrue to this process are:

1.1 Increased Throughput

Coal feed rates as high as 33,000 lbs./hr./square foot of gasifier cross-sectional area, have been evaluated in the pilot plant with excellent results. Further experimentation has demonstrated the

1.1 Increased Throughput (continued)

possibility of operating at coal mass flux rates as high as 66,000 lbs./hr./ft.². These rates are several orders of magnitude greater than the 300 to 800 lbs./hr./ft.² for the two-stage Hydrane process.

1.2 High Methane Yield/Single Pass

Methane levels of 15-19% are achievable in the gasifier effluent with corresponding carbon conversions of 40-65%. A prime objective of the program is to achieve high carbon conversion without the coproduction of liquids. This has been accomplished in a limited number of runs.

1.3 Simple Designs

Simplicity of design is achieved in the single-stage gasifier compared to the two-stage gasifier. The single-stage gasifier has the problems of feeding dry coal and the removal of char from the bottom common to other high-pressure gasifiers. Use of rocket engine technology is proposed as the solution to the first problem (coal feed) and use of a coal feed screw is proposed as a solution to the second (metered char removal).

1.4 Definition of Contract Requirements

The change from a two-stage to a single-stage process made it necessary to redesign the reactor. Overall, the following tasks were to be addressed by Dravo:

Task 1.0 Assessment of hydrogasification data from PERC and/or others. Available data pertaining to hydrogasification was to be evaluated by Dravo. Data from the various agencies studying hydrogasification were to be included: Pittsburgh Energy Research Center, Morgantown Energy Research Center, Rocketdyne, and "others."

1.4 Definition of Contract Requirements (continued)

- Task 2.0 Development of a conceptual design for a commercial-scale gasifier; provide a schematic thereof showing:
- (a) Overall dimensions
 - (b) Materials of construction
 - (c) Material thicknesses required
 - (d) Insulation and refractory requirements
 - (e) Access to the gasifier interior
 - (f) Product withdrawal
- Schematics depicting conceptual methods of mixing and feeding the coal to the hydrogasifier and of withdrawing the char from the bottom.
- Task 3.0 Information similar to the above for the conceptual design of a process development unit (PDU).
- Task 4.0 Processing of the product gas to obtain a natural gas substitute. This task was changed by modification M-003 to the contract. The modification expanded the scope to permit comparisons with other alternates. A separate report⁽¹⁾ was issued to cover work performed in completing this task.
- Task 5.0 Areas needing further development:
- Possible effects of coal distributor design requiring study will be discussed. Also to be considered in this task was the desirability of a cold model to aid in design work. The criteria for the design of the plant were to be:
- 1.0 Simplicity
 - 2.0 Operational maintainability
 - 3.0 Reliability
 - 4.0 High volumetric throughput
 - 5.0 High thermal efficiency
- The resolution of these tasks by Dravo is reported herein.

(1) "Hydrogasification Gas Processing Studies," Dravo Corporation, 2-27-78.

2.0 SUMMARY - RECOMMENDATIONS

Changes needed to convert the two-stage Hydrane hydrogasification process to a single-stage hydrogasification process were assessed by the Dravo Corporation for the Morgantown Energy Technology Center, U.S. Department of Energy, Morgantown, West Virginia.

A free-fall reactor design featuring a cylindrical reaction zone 21 feet in length was chosen as the conceptual design for both the process development unit and the commercial-scale reactor. The inside diameter of the PDU was set at 2' 0" adjustable by the insertion of liners, and the commercial unit, based on Rocketdyne run No. 300-012, was set at 9' 0". The outside diameter of the reaction zone is $4\frac{1}{2}$ feet for the PDU reactor and 11 feet for the commercial-scale reactor. Overall height of the PDU reactor is 44, and is 69 feet for the commercial-scale reactor. Three such commercial-scale reactors would be required in a commercial plant producing 250 MM SCFD pipeline gas.

Both reactors utilize the Rocketdyne "4-on-1" injector assembly to effect contact of the hot hydrogen and the pulverized coal (70%, -200 mesh) feed. The proprietary Rocketdyne injector assembly is depicted as a "black box." It will have the flexibility to study various parameters affecting nozzle design and orientation such as number, configuration, interactions, and reactant flow splitting among nozzles.

Both the PDU and the commercial-scale reactor designs utilize a water injection (quench) to cool the char-gas stream to 1000° F to achieve compatibility with downstream materials of construction, principally in the screw feeder. Discussions with the vendor have resulted in selection of 1000° F as a reasonable estimate of the maximum temperature that could be tolerated without the need for "exotic" materials of construction in the extruder. Preliminary experimentation with a screw feeder using coal at temperatures to 800° F have shown promise of satisfactory service with

2.0 SUMMARY - RECOMMENDATIONS (continued)

standard materials of construction. The water injected would flash and leave with the product gas. Thus, the char handled by the screw feeder will be dry. Preliminary indications are that some moisture may aid operation of the screw feeder due to improved lubrication of the char.

Other designs considered included:

- . Further processing of the hot product gas and char.
- . The inclusion of internal heat transfer surface to recuperate sensible heat from the gas and the char.
- . Quenching with sufficient water to create a char-water slurry in the gasifier.

The system chosen (i.e., a "humidification" to lower the gas and char temperatures to make it compatible with available materials of construction) does not espouse innovative design. This is a deliberate choice made to lessen the degree of risk in the development of the "materials processing" end of the hydrogasifier. The design is simple, reliable and is available with today's state-of-the-art.

The alternates were rejected for the following reasons:

- . Further processing of the hot product gas and char is limited by available materials of construction. Operating conditions of 2000° F and 1500 psig necessitate design conditions including a margin of safety. This raises the design conditions to the 2200° F, 1650 psig ranges. These conditions effectively eliminate this option.
- . The inclusion of internal heat transfer surface to recuperate sensible heat from the gas and char is also limited by the arguments given for the first alternate above. The possibility of stress cracking in the materials subjected to this temperature coupled with its inaccessibility does not conform to a simple,

2.0 SUMMARY - RECOMMENDATIONS (continued)

practical design. The combination of high risk design (because of materials limitation), probable large internal space requirements, and mechanical complexity caused this design to be rejected

- Quenching with water to create a char-water slurry was rejected because of the thermal penalty incurred and because of the inordinate quantity of contamination (H_2S , CO_2 , etc.) generated.

Both reactors are of the "hot wall" design and rely on continuous infrared scanning to detect the development/growth of "hot spots." Sufficient insulation is provided to maintain the inside wall of the steel shell at $\sim 450^\circ F$. Heat losses have been calculated to be less than 1% for both reactors. Refractory and insulation requirements specified to achieve these low losses are:

	<u>Thickness (inches)</u>		<u>Heat Loss BTU/hr/ft²</u>
	<u>Refractory</u>	<u>Bubble Alumina</u>	
PDU	3	12	1,323
Commercial-scale	4½	7½	1,530

Continuous sheet insulation 1/8" thick is used between the steel shell and the bubble alumina for both reactors, and another like sheet is used between the refractory and the bubble alumina in the commercial reactor. All materials are Carborundum Company materials.

The upper operating limits for the two are:

	<u>Temperature (° F)</u>	<u>Pressure (psig)</u>
PDU	2400	2000
Commercial-scale	2000	1800

2.0 SUMMARY - RECOMMENDATIONS (continued)

Experimental flexibility is provided by the conditions chosen for the PDU. Experiments performed in the pilot plant indicate the need for such flexibility. The trend in hydrogasification has been such that increasingly higher temperatures and pressures are under investigation. For example, early trials at 500 psig quickly gave way to tests at 1000 psig, and these, in turn, were followed by tests at 1500 psig. Other investigations have shown interesting results at even higher pressures. Rocketdyne's work also progressed to pressures of 1500 psig and temperatures approaching 2000° F. The capability of the PDU to operate at conditions significantly higher than those projected for the commercial-scale reactor will enhance its value as a predictive tool.

Product gas removal is provided by two gas off-takes from the char settling chamber. The gas is caused to reverse its flow pattern from downflow to upflow before exiting the reactor.

Char removal from the gas is expected to be greater than 90% by combining the reversal of the gas flow pattern with a velocity low enough to settle out char particles greater than 16 microns.

Char removal from both reactors will be by use of a screw feeder having a "solid pack" at the discharge end to form a gas seal. Use of a small differential pressure between the hydrogasification and the char receiver downstream will minimize the power requirements for the feed screw drive.

Processing of the gas to obtain a pipeline gas substitute was reported in "Hydrogasification Gas Processing Studies," Modification M-003 to the existing contract, Dravo Corporation, February 1978. Three methods were studied: use of a moving bed of carbon (hypersorption), Cryogenics, and oil absorption. The hypersorption process (moving carbon bed) was chosen

2.0 SUMMARY - RECOMMENDATIONS (continued)

because it recovered nearly pure individual components at near system pressures with economics comparable to the Cryogenic system. Oil absorption was too expensive due to gas recompression costs, liquid loss and pumping (absorbent) costs.

Recommendation

A conceptual plant design study wherein the economics of the Rocketdyne hydrogasification process can be evaluated is needed. Should the economics of the system prove to be competitive with other processes, then an integrated PDU should be designed and built for further experimentation. The process chemistry having been proven, it remains to accentuate process design and hardware development.

3.0 RESOLUTION OF CONTRACT TASKS

The rationale supporting the resolution of the contract tasks is reported in this section.

3.1 Task 1.0 - Assessment of Data

The intent of this task was to obtain an assessment of the technical data available from various government-sponsored/conducted hydro-gasification research projects. The available data was surveyed and it was deemed to be insufficient in scope upon which to base a reactor design. Meanwhile, additional data generated by Rocketdyne's liquefaction and gasification programs exhibited unusually promising performance. The result of this assessment was the choice of the Rocketdyne single-stage, free-fall reactor as the preferred system. The rationale for this choice is given in Section 3.2 below.

3.2 Task 2.0 - Conceptual Design - Commercial-Scale Reactor

Develop a conceptual design of a commercial-scale hydrogasification reactor and provide a schematic thereof.

3.2.1 Design Basis - Commercial-Scale Reactor

The commercial-scale reactor design shown in Figure 3.2-1 was based on Rocketdyne run No. 300-12 by agreement with DOE. This run was selected as the design basis because only gaseous products were made. The reaction conditions used in Run 300-12 were:

Coal type	Kentucky #9 hvAb
Coal mass flow rate	4,116 lbs./hr./ft. ² hydrogasifier cross section
Hydrogen: coal mass ratio	0.489
Oxygen: hydrogen mass ratio	0.787
Average pressure (psig)	1,496
Reactor gas outlet temperature	1,908° F

3.2.1 Design Basis - Commercial-Scale Reactor (continued)

Hydrogen preburner wall temperature	1,970° F
Gas residence time	
Maximum (from mixed reactants temperature)	3,710 milliseconds
Minimum (from hydrogasifier outlet temperature)	3,120 milliseconds

The general criteria for the design of the reactor were established by the DOE:

- 1.0 Design simplicity
- 2.0 Operational maintainability
- 3.0 Reliability
- 4.0 High volumetric throughput
- 5.0 High thermal efficiency

Three hydrogasifiers each fed 3,200 tons/day coal would be required for a commercial plant producing 250 million SCF pipeline gas/day, equivalent to 250 billion BTU's/day.

In addition to the gas, each gasifier would produce 88,580 lbs./hr. char that would be sent to the hydrogen plant to provide the hydrogen necessary for the reaction.

3.2.2 Reactor Overall Dimensions

The drawing shows a single-stage, free-fall reactor with a nine-foot inside diameter and a reaction zone 21 feet long. Below the reaction zone is a quench zone six feet in diameter and 15.5 feet long. The quench zone is equipped with spray nozzles for quenching the gas-char mix to 800-1000° F. The quench zone is reduced in diameter to take advantage of the more favorable liquid-vapor mass ratios resulting in a shorter quench section.

3.2.2 Reactor Overall Dimension

Separation of the char and gas is accomplished in the expanded "settling chamber" which comprises the bottom of the hydrogasifier. This chamber is designed to remove all char particles larger than 16 microns. This approximates a removal efficiency of greater than 90%.

Ten minutes inventory of char is provided in the settling chamber, five minutes active and five minutes surge.

3.2.3 Materials of Construction and Metal Thickness Required

The reactor is of the "hot wall" design similar to that used in fluid catalytic crackers in the petroleum industry. The inside wall of the steel shell is designed to operate at about 450° F, thereby preventing the condensation of moisture between the shell and the insulation. The deleterious effects of moisture on the insulation will, therefore, be avoided.

Shell materials of construction are 6-3/4-inch Type 516 carbon steel with a Type 347 stainless steel overlay 1/4 inch thick. The stainless overlay will protect the reactor shell from corrosion in the presence of hydrogen sulfide and from problems related to the high hydrogen content of the gas stream (hydrogen embrittlement).

3.2.4 Insulation and Refractory Requirements

The heat loss from the reactor is held to $< 1\%$ by an insulating layer of bubble alumina 12 inches thick. The insulation is protected by an inner layer of refractory brick, four inches thick. A Hastelloy X sleeve protects the brick work from moisture in the quench zone. The sleeve also extends into the settling chamber to provide for flow reversal to aid in the char-gas separation.

A layer of fibrous insulation is placed between the inner shell of the reactor and the outer face of the insulation. This material will

3.2.4 Insulation and Refractory Requirements (continued)

create a compressible barrier that provides for differential expansion of the various materials. The material maintains some "springback" and helps maintain a seal against bypassing of gases around the insulation upon repeated heatup and cooldown.

3.2.5 Access

Access to the reactor is provided for by a manway in the reaction zone of the reactor. This is sufficient for inspection and minor repairs. Major repairs would be possible by removal of the injection assembly and/or top head.

3.2.6 Method of Product Withdrawal

Product gas is withdrawn from the upper part of the char settling chamber via two pipes 180° apart. This is shown in Figure 3.2-1 "Conceptual Design Commercial-Scale Reactor." The product gas is conducted to the char settling chamber by the quench sleeve, undergoes reversal of direction at the end of the sleeve and effectively is separated from the char. Char particles greater than 16 microns are removed in the quench chamber (~90%) and the gas then is conducted to further processing.

3.2.7 Mixing and Feeding the Reactants to the Reactor

The problem of mixing and feeding the reactants to the reactor has been effectively solved by use of the Rocketdyne 4 on 1 injector. The injector is a mechanical device that feeds a dense phase stream of coal and causes the hot hydrogen to impinge on the coal stream. The gasification reactions are thereby initiated.

Discussions with Rocketdyne concerning the problem of flow splitting resulted in agreement by Dravo to depict the injector assembly as a

3.2.7 Mixing and Feeding the Reactants to the Reactor (continued)

"black box." This was done because of the proprietary nature of the technology of flow splitting of the solids (coal), hydrogen and oxygen within the "black box."

3.2.8 Withdrawal of Product Char

Product char withdrawal from the reactor is depicted on the reactor schematic, Figure 3.2-1. Shown is a screw feeder that makes use of a packed end section to form a gas seal from compacted char. By maintaining a small pressure differential between the hydro-gasifier and the char receiver after the screw, only enough pressure to form the seal and to remove the char need be put on the char. This will help minimize wear on the feeder internals and conserve energy.

The feeder is equipped with devolatilization and liquid drain ports to allow venting of occluded gases from the char and to dispose of water, respectively.

Such systems under DOE sponsorship have been under investigation for feeding coal to pressurized systems with promising results. Other systems considered included lockhoppers, total quench of the gas stream followed by slurring of the char, and staged pressure letdown schemes.

Lockhoppers were rejected because of anticipated valve wear problems, cumbersome pressurizing and depressurizing cycles required, and probable upsets to the system during the cycles (pressure bumps).

Total quenching would incur too large an energy penalty, require a water-solids separation scheme, and deliver the solids (char) at an undesirably low pressure.

3.2.8 Withdrawal of Product Char (continued)

The screw feeder provides for a continuous smooth operation and delivers the char at pressure and a reasonably high ($\sim 1000^{\circ}$ F) temperature to minimize energy losses.

3.2.9 Hydrogasifier Instrumentation

Enough instrumentation for process control but without excess is included in the hydrogasifier design. The number of flanges that need to be cut into the shell is thereby minimized. Thus, smooth contours are retained in the hydrogasifier interior.

Continuous indication of the reaction zone outlet temperature, the gas outlet temperature and the char outlet temperature are part of the design. Only the reaction zone outlet temperature thermocouples are inside the reactor; the gas outlet temperature and the char outlet temperature are located on the outlet nozzles from the hydrogasifier. The gasification outlet zone thermocouples will be paired one at the refractory face and one at the alumina refractory interface at each of six circumferential positions around the hydrogasifier. Water-cooled sampling tubes (2) will be located 180° apart on the same level as the thermocouples.

Control of the char level will be accomplished by a nuclear-type gage. The signal from the sensors would be used to control the speed of the char removal screw. This would maintain the char level between preselected levels.

3.2.10 Other Designs Considered

Other designs considered for the commercial-scale reactor and reasons for their rejection were:

3.2.10.1 Pittsburgh Energy Research Center Single-Stage Reactor

This process utilizes a downward, entrained flow reactor. Coal distribution is achieved by feeding coal, in the dilute phase, into the central tube of the coal feeder surrounded by the feed hydrogen.

This process was not selected for the following reasons:

Lower projected capacity - The capacity figures quoted for this reactor were in the range of 300-800 lbs. coal/hr./ft.² of reactor cross section. This does not compare favorably with the 5000-33,000 lbs./hr./ft.² mentioned for the Rocketdyne scheme. This would result in a commercial plant with 15 reactors, each 15 feet in diameter, compared to three reactors about nine feet in diameter using the Rocketdyne reactor.

Limited to non-caking coals - There has not been adequate demonstration of the utility of this process with non-caking coals. This would limit this process to the non-caking or mildly caking coals.

3.2.10.2 Cities Service Research & Development Process for Coproduction of Gases and Liquids

This process was studied in two variations: free-fall reactor and an entrained flow reaction coil. It was developed with the objective of coproducing liquids and gases. This objective did not meet the criterion of zero liquids production required in the hydro-gasification study. Therefore, the process was dismissed as a candidate for this study.

3.2.10.3 Hydrane Two-Stage Reaction

The Hydrane two-stage process was the forerunner of the present single-stage process. It was replaced by the Rocketdyne type single-stage designs because it had:

limited throughput (300-800 lbs./hr./ft.²), and

3.2.10.3 Hydrane Two-Stage Reaction (continued)

- lower conversion to methane per pass.

3.2.10.4 Upward-Flow Entrained Flow Reactor

This concept included entrainment of the feed coal in the hydrogen with the total reacting stream flowing upward, exiting the reactor at the top.

This scheme was rejected because of lack of experimental backup. Unknowns included feed system, char-gas separation, and char withdrawal. It appeared that the systems necessary for char-gas separation would depend on a number of "char diplegs" each with its own problems of maintaining seal, erosion, etc. This would tend to make the system fall outside the requirements of simplicity, operational maintainability, and reliability.

3.3 Task 3.0 - PDU Design

3.3.1 Task Objective

The development of the conceptual design for a PDU-scale reactor was the objective of this task. Information similar to that developed for the conceptual commercial-scale reactor was to be generated, including a schematic depicting the concept. The required schematic is shown in Figure 3.3-1, "Conceptual Design 4 TPH PDU."

The PDU has a reaction zone about 21 feet long (same as the commercial-scale reactor) and is encased in a steel shell. Steel is Type 516 with a 1/4-inch overlay of Type 347 stainless steel. The quench zone is 15 feet long encased in a steel shell 3 inches thick, with a 1/4-inch stainless steel overlay. Other features are described on the drawing.

3.3.2 PDU Design Basis

The PDU was conceived as an intermediate scale-up step that would generate data from which a commercial-scale reactor could be designed. The PDU schematic, Figure 3.3-1, shows that its design very closely resembles that of the commercial-scale reactor. However, the operating limits of the PDU reactor are extended to permit investigation over a broader range than that of the commercial-scale reactor. These limits are a permissible reaction zone temperature of 2400° F and an operating pressure of 2000 psig. By appropriate adjustment of the coal rate and the hydrogen rate, gas residence times of 5000 milliseconds can be achieved.

Adjustment of the mass flow rate can be varied from about 2500 lbs./hr./ft.² to about 40,000 lbs./hr./ft.² of reactor area by the insertion of liners into the reaction zone. Table 3.3-1, "Operability Limits," summarizes the range of experimental conditions possible in the PDU.

Table 3.3-1

Operability Limits - PDU
4 TPH Coal Feed Rate
0.489 H₂: Coal Mass Ratio

Maximum pressure	2000 psig
Maximum temperature	2400° F (at reaction zone outlet)
Gas residence times	Maximum: 5,000 milliseconds Minimum: 1,500 milliseconds

Investigations into the effect of possible interactions between coal injection nozzles will be possible. This can be accomplished by changing the injector assembly in the reactor head.

3.3.3 Generation of Scale-Up Data

Providing scale-up data for scale-up to the commercial-scale is the chief function of the PDU. The physical data necessary to establish the needed empirical correlations and backup for theoretical models of the reaction will be obtainable from the PDU.

Temperature readings at four-foot intervals will be available from six pairs of thermocouples at each level. One of the thermocouples will extend to the "hot face" of the refractory lining, the other to the interface between the refractory and the insulation. The service life of the thermocouple at the "hot face" is expected to be short, but continued operation should be possible from its companion thermocouple, protected as it will be by the refractory.

Temperatures of the gas outlet and the char outlet will also be available.

Sampling of the gas at each level will be possible by use of a water-cooled sampling tube at each temperature level.

The foregoing combination of temperature, pressure and sampling data should provide the scale-up information required.

3.3.4 Other Differences, PDU and Commercial-Scale Design

In addition to the differences in allowable operating conditions, monitoring capabilities in temperature and pressure, sampling capability and throughput, there is a difference in the quench zone design between the two reactors. Whereas the commercial-scale reactor will have a sleeve made of Hastelloy X protecting the quench zone, the PDU's "sleeve" will be an extension of the inner refractory lining. This design feature was necessary because of the temperature limitation of Hastelloy X, lower than the required 2400° F operating temperature of the PDU.

3.3.4 Other Differences, PDU and Commercial-Scale Design (continued)

Insulation requirements for the PDU are slightly greater than for the commercial-scale. Whereas the commercial-scale reactor used four inches of firebrick backed up by 12 inches of bubble alumina, the PDU used brick work 4 inches thick and 9 inches of bubble alumina. Both reactors limit heat loss to less than 1% and an inside shell temperature of 450° F. Both rely on infrared scanning to detect hot spots.

3.4 Task 4.0 - Processing the Product Gas to Obtain Natural Gas Substitute

The requirements of this task were reported by Dravo in a report "Hydrogasification Gas Processing Studies" reported by Dravo in February 1978.

Cryogenics, absorption in an absorption oil, and separation by adsorption using a moving bed of carbon were compared. The moving bed of carbon (hypersorption) was the process selected previously because it produced nearly pure streams of each of the desired constituents at system pressure. There was no significant difference in the economics of the two systems (Cryogenic vs. hypersorption).

3.5 Task 5.0 - Areas Needing Further Development

Design features of the reactor feed coal distributor were to be highlighted in this section of the report. Other problems noted were also to be included.

3.5.1 Coal Distribution

This problem was a carryover from the Hydrane studies preceding development of the 4-on-1 injector. These problems can be considered to have been resolved by the development of the 4-1-injector. Other problems are introduced through use of the injectors:

3.5.1 Coal Distribution (continued)

- (1) Nozzle interaction - The effects of nozzle interaction should be investigated. Present data is based on a single injector discharging into the reaction zone. It will be possible to investigate this phenomenon in the PDU.
- (2) Flow Splitting of Reaction Ingredients - Use of multiple nozzles will require that each of the reactant streams be proportional to each nozzle. Rocketdyne has stated that the "black box" design of the injector assembly provides for flow splitting.
- (3) Turndown/Metering of the Coal Feed - Means of controlling the feed rate of pulverized coal to each injector have not been addressed due to the nature of the pilot plant. It may be possible to shut off the feed to any number of injectors in a multiple injector assembly and achieve, thereby, stepwise degree of flow control. However, reproducible, variable rate of flow of coal to an individual injector has not been achieved except over a broad range by pressure differential. Establishing flow control will also elucidate the operating limits of an injector (as regards rate) and is a necessary step in scale-up of the injector.

3.5.2 Desirability of a Reactor Cold Model

The utility of cold model will be very great in initial design studies of the nozzle assembly configuration. This is particularly true when multiple nozzles are attempted as they will help define the type of dispersion achieved and how best to optimize such a dispersion. On the other hand, the bottom design of the reactor (that is, char removal) will also be enhanced by a cold model. This is especially true in the solids-gas disengaging section where lack of internal cyclones may require study in order to effect the best possible solids removal from the exit gas stream. That this is important is

3.5.2 Desirability of a Reactor Cold Model (continued)

indicated by a recent Rocketdyne report which showed that the solids entrained in the gas in their pilot plant was sufficient to erode the seat from the back pressure control valve. These remarks also apply to the spray system. Here the optional arrangement of the sprays, to get the best contact with the descending char-gas stream, will be needed. Use of a cold model will help define the best configuration.

3.5.3 Chemical and Mechanical Properties of the Char

3.5.3.1 Char

The physical and mechanical characteristics of the char at 800-1000° F as well as at the upper operating limit for the PDU (2400° F) are unknown. Knowledge of the physical properties of the char at the elevated temperatures expected to be encountered will be necessary to aid in the design, as stated. The projected 1000° F design assumes that the char retains its brittle, friable characteristics at this temperature. The occurrence of a plastic-like zone at 1000° F is unlikely; however, this should be verified by investigation.

The existence of such a plastic condition for the char at these temperatures would necessitate chilling the char to a lower temperature, with accompanying thermal penalties, and would also show the need for a pulverizer at the extruder discharge tube to reduce particle size to useable dimensions, should agglomeration upon compaction at these temperatures occur. Two hundred to 300 lbs. of char, each type, would be sufficient for these tests.

3.5.3.2 Gas Holdup

Gas holdup of the char will need to be evaluated. This is necessary in order to properly design the devolatilization capability of the feed screw. Gases occluded in the char will need to be devolatilized and the feed screw design will be aided by knowledge of the gas quantities involved.

3.5.3.3 Char Water Holdup and Drainage Characteristics

It is probable that there will be times when the quench sprays will be turned "ON" and that liquid water will be present in the bottom of the hydrogasifier. The design of the feed screw will be such that drainage of liquid water will be possible through the back end of the feed screw. Dravo's discussions with Ingersoll-Rand indicate that this will be possible; therefore, the conceptual design indicates a drain for the removal of liquid water from the back end of the feed screw for use during startup.

3.5.3.4 Heat of Reaction

The heat of the hydrogasification reaction continues to be a mystery. At present, the best available information indicates that the reaction is exothermic. At a meeting in Washington a heat of reaction of 750 BTU/lb. of coal converted was arbitrarily chosen. It is possible that with the improved instrumentation on the PDU a better definition of the heat of reaction will be available. Mathematical analyses of the gasification scheme are hindered by lack of this knowledge. Mechanical design (insulation requirements and shell thicknesses) can be calculated with greater accuracy than at present, if the heat content of the vessel is better understood.

ITEM NO.

No. REQ'D

REFERENCES

DESIGN CONDITIONS

VESSEL 1800PSIG @ 2800

MAX. METAL TEMP. 650

OPERATING CONDITIONS

VESSEL 1500PSIG @ 2000

MAX. METAL TEMP. 650

MATERIALS

SHELL, HDS. ASTM A 516 GR. 70 WITH 1/4"

THICK TYPE 347 STAINLESS STEEL WELD OVERLAY

BOLTING

GASKETS

SUPPORTS

CORROSION ALLOWANCE (OVERLAY)

THICKNESS (SLE ELEVATION)

SHELL TOP HD. BOTT. HD.

JACKET JACKET HD. COIL

CONSTRUCTION FUSION WELDED

CODE ASME SECTION VIII DIVISION I

STRESS RELIEF AS REQ'D. RADIOGRAPH FULL

TESTING PER CODE REQUIREMENTS

INSPECTION PER CODE REQUIREMENTS

STAMPING

NAME PLATE

PAINT

OPERATING CAPACITY

GAL. % FILL

FULL CAPACITY

GAL. S.G. OF PROD.

ESTIMATED WEIGHT

EMPTY

LB. FULL OF H₂O

OPERATING

LB. FULL OF PROD.

INSULATION SUPPORTS ARE NOT REQUIRED

G	2	12"			PRODUCT GAS REMOVAL
F	2	2"			SAMPLING TUBES - SEE NOTE
E	6	2"			6 PAIRS - SEE NOTE
D	1	20"			MANWAY
C	4	2"			SPRAY SYSTEM
B	1	2"			VENT
A	1	1 1/2"			DRUM

MARK	REQ'D	SIZE	RATING	FACING	REMARKS
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Dravo

CORPORATION

Blaw-Knox Chemical Plants Division • Pittsburgh, Pennsylvania

DESIGNED	PROC.	ENG.	DATE	TITLE
ACM/JSL			9-10-78	CONCEPTUAL
DRAWN	LAM		9-10-78	COMMERCIAL SCALE
CHKD.				HYDROGASIFIER
APPR.				FOR
APPR.				DOE - METC
APPR.				DWG. NO.
APPR.				FIGURE 3.2-1
				CPD 7029 - SK100 - 3

ITEM No. _____ No. REQ'D. _____
REFERENCES _____

DESIGN CONDITIONS
VESSEL 2400 PSIG @ 2600 °F.
MAX. METAL TEMP. 650 °F.
OPERATING CONDITIONS
VESSEL 2000 PSIG @ 2400 °F.
MAX. METAL TEMP. 650 °F.

MATERIALS
SHELL, HDS. ASIM A 516 GR. 70 WITH 1/4" THICK TYPE 307 STAINLESS STEEL WELD OVERLAY
BOLTING _____
GASKETS _____
SUPPORTS _____

CORROSION ALLOWANCE (OVERLAY)
THICKNESS (SEE ELEVATION)
SHELL TOP HD. _____ BOTT. HD. _____
JACKET JACKET HD. _____ COIL _____

CONSTRUCTION FUSION WELDED
CODE ASME SECTION VIII DIVISION 1
STRESS RELIEF AS REQ'D. RADIOGRAPH FULL
TESTING PER CODE REQUIREMENTS
INSPECTION PER CODE REQUIREMENTS
STAMPING _____
NAME PLATE _____
PAINT _____

OPERATING CAPACITY _____ GAL. % FILL
FULL CAPACITY _____ GAL. S.G. OF PROD.
ESTIMATED WEIGHT
EMPTY _____ LB. FULL OF H₂O _____ LB.
OPERATING _____ LB. FULL OF PROD. _____ LB.

INSULATION SUPPORTS ARE NOT REQUIRED

MARK	REQ'D	SIZE	RATING	PAVING	REMARKS
G	1	20"			MANWAY
F	2	2"			PRODUCT GAS REMOVAL
E	6	2"			SAMPLING TUBES - SEE NOTE
D	36	2"			36 PAIRS - SEE NOTE
C	4	2"			SPRAY SYSTEM
B	1	2"			VENT
A	1	142"			DOWN

REV.	MADE	CHKD.	DATE

Dravo CORPORATION
Blaw-Knox Chemical Plants Division • Pittsburgh, Pennsylvania

DESIGNED ACM/JSL 9-10-78
DRAWN LAM 9-12-78
CHKD. _____
APPR. _____
APPR. _____
TITLE CONCEPTUAL DESIGN
4TPH FDU
FOR DOE - METC
DWG. NO. FIGURE 3.3-1
CPD 7029-SK100-4
REV. _____