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SPECIFICATIONS AND DESIGN OF A PRESSURIZED LAMINAR-FLOW ISOTHERMAL REACTOR FOR STUDIES OF COAL REACTIVITY

Technical Report 15

Prepared by

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at

THE PENNSYLVANIA STATE UNIVERSITY

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COAL RESEARCH SECTION
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ABSTRACT

One facet of the larger project entitled 'The Characteristics of American Coals in Relation to Their Conversion to Clean Energy Fuels' is intended to develop and test a series of reactor vessels capable of providing quantitative data on coal performance in reactions important in the gasification of coal, and to generate quantitative data on the pyrolysis behavior and reactivities of representative coal lithotypes and chars derived therefrom.

A most important task element of this facet is the design, construction and testing of a pressurized isothermal reactor capable of operating at temperatures up to 1300°C and at pressures up to 100 atmospheres. Required is an experimental system that will best permit rapid heating, isothermal reaction, rapid quenching of the sample reaction, variation of reaction time, study of pyrolysis or reaction with ambient gases, pressurization, and unambiguous reaction history. Attainment of these characteristics is the objective of the facet element described herein.

The system is designed to feed coal dust at a pre-set rate into a controlled high temperature and pressure reactor, in the presence of hydrogen or other reactive gas, and then separate the solid effluent from the gas.

The coal gasification system is a laboratory scale unit, the central component of which is an internally heated steel pressure vessel. Coal particles are supplied from a feed bin at a uniform, continuous rate to a feed nozzle and fall vertically through a reaction tube. The coal dust in its carrier gas is maintained at "room" temperature until it is delivered from the water-cooled nozzle where

it mixes with a preheated gas stream. Proper design of the mixing orifice and control of flow rates will assure complete mixing, with coal heating rates of 10,000°C/sec or faster. Proper design also provides an inverted velocity profile to assure that the particles remain in the center of the stream instead of impinging on the walls of the reaction tube. A water-cooled probe inserted up the furnace axis collects and rapidly quenches the stream of particles. The solid and gaseous constituents are then separated and collected for analysis. The University is constructing an addition to its High-Pressure Gas Facility in which to house the pressurized isothermal reactor. The building contains a test cell designed to withstand blast forces while venting accidental blasts into an earthen embankment. The reactor is being assembled at this location.

The efficiency of the coal gasification process in yielding gas (volatiles) can be improved by providing the right heating history. Fundamental studies of the effects of heating rates on production in various inert and reactive environments will also indicate the relative suitability of different coals in gasification.

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I. INTRODUCTION

A. Description of the DOE Research Task

This technical report has been prepared in partial fulfillment of a specific Task (Task 25) undertaken within the project entitled "The Characteristics of American Coals in Relation to Their Conversion to Clean Energy Fuels", DOE contract No. EX-76-C-01-2030 and within Facet IV-A: Reactor Development and Operation, of that project.

The objectives of the Program Facet are:

1. to develop and test a series of reactor vessels capable of providing quantitative data on coal performance in reactions important in the gasification of coal.

2. to generate quantitative data on the pyrolysis behavior and reactivities of representative coal lithotypes and chars derived therefrom.

Task 25 is an investigation of the effect of different levels of pressure on the pyrolysis behavior of a series of coal lithotypes, employing several different temperature levels for comparative purposes. The task work statement provides for the contractor (PSU) to

1. design, construct and test a pressurized isothermal reactor capable of operating at temperatures up to 1300°C and at pressures up to 100 atmospheres;

2. utilize this reactor to determine the effect of several levels of pressure on pyrolysis behavior of the series of coal lithotypes, being particularly concerned with volatile matter yields and structural changes in the coal particles at three levels of temperature;

3. investigate the possible use of the pressurized isothermal reactor as a "crucible oven" as a means of repeating, under pressure, a series of dense phase (packed bed) experiments on pyrolysis behavior performed in Task 24. If feasible, and if the previous experiments of Task 24 indicate a real existence of volatile matter capture by coal particles in the bed, the contractor shall repeat those Task 24 experiments at several levels of pressure dictated by the results of work statement 2 above.

This technical report fulfills the requirement of delivering to DOE the design and specification for the pressurized isothermal reactor. The reactor system has been fully assembled at a temporary location at the Combustion Laboratory of The Pennsylvania State University. Air, water and electrical services have been connected. The coal feeder has been tested with several coal particle sizes. It functioned well in providing a uniform delivery of coal nominally sized at larger than 50 microns. However, for smaller particles a uniform feed will require the use of a vibrator or stirrer in the hopper. The delivery characteristics are independent of pressure.

All other components and the entire reactor system are now ready for testing.

B. <u>Pyrolysis of Coal</u>

When coal is heated to sufficiently high temperatures in the presence of an inert medium (e.g. nitrogen, argon or helium) its organic phase is decomposed into two main components: volatile matter and solid residue. The volatile matter is a mixture of low and high molecular weight compounds (e.g., hydrogen, oxides of carbon, methane, and pyrogenic matter; and tars and bitumens, respectively). The solid residue (char or coke) is a matrix of fixed carbon embedded with mineral matter (ash).

The volatile matter content of the parent coal as determined under standard conditions is related to the rank of the coal, and varies in quantity and composition. However, for a single coal the products of coal pyrolysis depend strongly on the experimental conditions. The temperature history, particle size and morphology, and the ambient conditions of the pyrolysis medium are important experimental factors.

A review of research to date on pyrolysis of coal was presented by Nsakala, Walker and Essenhigh in Technical Report 2 on the Characteristics of Chars Produced by Pyrolysis Following Rapid Heating of Pulverized Coal (1), prepared for ERDA under this same contract (No. E(49-18)-2030). To date such work has been restricted to atmospheric pressure pyrolysis in inert gases.

C. Reactions of Coal with Active Gases

Any gasification process (conversion of coal to clean gas) involves heating the coal, and automatically involves sequential or parallel pyrolysis. At the point of interaction of pyrolysis and reaction with ambient gases there may be scope for improving the gasification efficiency. Task 25 of the present project deals specifically with gaining an understanding of the interrelation between pyrolysis and reactions with active gases (O_2, CO_2, H_2O, H_2) in order that gasification processes can be made more efficient. Since commerical gasifiers using hydrogen will operate under pressure, it is also essential that this understanding extend to pyrolysis and reactions at pressure.

The influence of rate of heating on pyrolysis and reactions is quite controversial. The correlation of increased volatile yield with rate of heating is unarguable, but the reasons are somewhat uncertain. Arguments have been presented for the rapid heating being responsible for inhibiting competing reactions, and for the reduction of secondary reactions as affecting increasing volatile yields (2). From such arguments one can conclude that the crucial reactions take place within the first few seconds or milliseconds, and that rapid heating to reaction temperature is desirable to prevent unwanted low temperature reactions in the coal and unwanted secondary reactions in the gas phase or on the surface of other particles. By using rapid heating to inhibit reaction until the coal is at sufficient temperature, the reacting materials will not have become partially cross-linked and less likely to pyrolyse efficiently.

D. Experimental Equipment Design Criteria

The central role of the initial reactions therefore requires an experimental method that will permit

- rapid heating
- isothermal reaction
- rapid quenching of the sample reaction
- variation of reaction time
- study of pyrolysis or reaction with ambient gases
- pressurization
- unambiguous reaction history

Although no one method reported in the literature seems able to satisfy all these requirements, the closest is the method of Badzioch and Hawksley (3). It may be considered to be an elaboration of the Godbert-Greewaold

(1936) furnace for flammability testing of coal dust (and which itself is a development of a previous test devised in France about 1910). In an electrical tube furnace designed to inject a dilute coal stream into the center of a preheated gas stream, the injected stream heats up on mixing at about 10,000 deg c/sec or faster. If the injector is designed so as to provide an inverted velocity profile, then the particles remain in the center of the stream rather than migrating to and adhering to the walls. With dispersion of the particle stream reduced, a water cooled sampling probe inserted up the axis of the furnace collects and rapidly quenches the stream of particles. Proper furnace design assures uniform heating along the length of the tube, and the reaction is restricted essentially to an isothermal region. Reaction (residence) times are varied by positioning the probe.

The requirement of unambiguous reaction history rules out a number of reactors that have been used in the past for various research or development operations. In many flow reactors, there is backmix, as found explicitly by Zahradnik and Grace (4), and the path history of an unknown fraction of the coal is unknown. This is also most probably the case with the reactors used by Coates, Chen, and Pope (5), and by Stickler and Associates (6). In other flow tube reactor experiments, particularly at pressure, ability to vary the reaction time has been limited or non-existent. (The use of thermocouples for gas temperature measurements also vitiates the results).

The heated wire mesh (7) or heated cage (8) has some attraction. One objection is the possibility of interference with the reaction by the wire, particularly if there is possibility of the wire catalyzing some of the gas phase reactions. It is also difficult to obtain rapid quenching. Anthony et al (7) reported that there were, indeed, reactions continuing as the samples cooled down because cooling was not fast enough, and the use of the kinetic results to back-calculate the effect of the reaction on cooling seems to be somewhat circular. It is also difficult or impossible to obtain results at times shorter than about 100 millisec. By comparison, Badziock and Hawksley measured down to 20 millisec. One advantage of the Anthony system, however, would be to study the effect of controlled variable rates of heating. For this purpose, the method would be a good backup to the isothermal furnace.

One disadvantage of the isothermal furnace is the relatively short residence time of up to 300 millisec. Longer times than that permit too great a spread of the particle stream and capture efficiency fall off, except as longer times are obtained by recycling the semi-char products.

The isothermal furnace, therefore, appears to be the only device at present that satisfies nearly all the criteria mentioned above. The method is also capable of further extension, as shown by Kimber and Grey (9), to higher temperatures (and also by Field (10) and by Smith (11) for straight combustion studies). Various tube reactor studies at pressure have not provided the potential for precision measurements that should be possible with the isothermal furnace.

II. REACTOR SYSTEM SPECIFICATIONS

The reactor specifications were drawn up after consultation in November of 1973 with four organizations with previous experience in related or similar systems: Columbia Gas Co., Institute of Gas Technology, U.S. Bureau of Mines at Bruceton, Pa., and Bituminous Coal Research, Monroeville, Pa. A concept study and the preparation of specifications were conducted under contract by Scientific Systems, Incorporated, of State College, Pa.

The reactor specifications were presented to Autoclave Engineers, Inc. by The Pennsylvania State University's Department of Purchasing in an inquiry dated 16 July 1974, Appendix A herein. In response, Autoclave Engineers offered the proposal 44-0892-74F, and revisions included herein as Appendix B. The most notable changes were in the proposed design of the screw feeder to use an Autoclave Engineers, Inc., MagneDrive unit to avoid packings, and in the exclusion of barrier design and specifications. The contract for engineering design and construction of the reactor system was subsequently awarded to Autoclave Engineers, Inc.

During the design and construction of the reactor unit, itself, the extreme dangers of hydrogen reaction work were brought out clearly, resulting in an assessment of the system and its intended location by the University risk insurers. To permit full operation of the system with highly reactive gases, safety modifications were offered as AE proposal 44-3110-76F, included herein as Appendix C, and contracted. A special high pressure gas facility has been constructed at an appropriate site (Appendix D).

III. REACTOR SYSTEM DESCRIPTION AND OPERATION

A. General Description

The system is designed to feed coal dust at a preset rate into a controlled high temperature and pressure reactor, in the presence of hydrogen or other reactive gas, and then separate the solid effluent from the gas.

The coal gasification system is a laboratory scale unit, the central component of which is an internally heated steel pressure vessel. Coal particles are supplied from a feed bin at a uniform, continuous rate to a feed nozzle and fall vertically through a reaction tube. The coal dust in its carrier gas is maintained at "room" temperature until it is delivered from the water-cooled nozzle where it mixes with a preheated gas stream. Proper design of the mixing orifice and control of flow rates will assure complete mixing, with coal heating rates of 10,000°C/sec or faster. Proper design also provides an inverted velocity profile to assure that the particles remain in the center of the stream instead of impinging on the walls of the reaction tube. A water-cooled probe inserted up the furnace axis collects and rapidly quenches the stream of particles. The solid and gaseous constituents are then separated and collected for analysis.

Serving the reaction vessel are a number of separate components: a hydrogen compressor; an emersion heater and compressor oil temperature controller to permit outdoor location of the compressor rack; an argon supply rack; a valve rack providing a gas supply control station; a coal feeder assembly, separator vessel and filter vessel all mounted on the reactor vessel supporting frame; and a main control console with a semi-graphic display of critical points and status lights.

To completely specify the system, a description of the components and then an overall operation description will be presented.

B. System Components

1. Hydrogen Compressor

A Corblin hydrogen compressor will compress hydrogen from an external source into hydrogen accumulator vessels. Hydrogen will enter the compressor assembly at a bulkhead. If the pressure at this point is greater than the pressure in the accumulator vessels the gas will bypass the compressor and flow into the accumulator vessels until pressure is equalized. When the compressor is operating it will start when a low limit pressure switch closes and stop when a high limit pressure switch closes.

The compressor assembly is supplied with interstage and discharge heat exchangers and water cooled heads. A flow switch is mounted in the cooling circuit to stop the compressor in the event of a low or no flow condition. Both stages of the compressor are equipped with triple diaphragms and leak detection circuits. In the event of diaphragm leakage power to the compressor will automatically be shut off. All electronic controls and alarms are located in the control panel.

2. Compressor Heater Rack

To permit outside installation of the compressor an emersion heater and thermostat for the oil has been assembled. The thermostat controls the heater based on the prevailing outside temperature so that a proper oil operating temperature is maintained.

3. Argon Supply Rack

A small rack has been provided for connection of argon cylinders to the system.

4. Valve Rack

A valve rack provides the control station needed to regulate the flow of hydrogen and argon gas to the reactor assembly. Hydrogen enters the rack through a bulkhead and passes through a regulator used to adjust the inlet hydrogen pressure to the reactor assembly. A surge check valve in the line will check and stop flow if a major leak or break occurs anywhere in the system that draws more than 10 SCFM. An air operated shutoff valve controlled from the control panel is used to start hydrogen flow to the reactor assembly. Hydrogen flows to the reactor assembly by way of two lines. One line (primary hydrogen) passes through a manual valve, a flow meter, a metering valve, and through a bulkhead of the semi-venturi in the coal feed assembly. The other line (secondary hydrogen) leads to a shutoff valve, a flow meter, a metering valve, and through a bulkhead, on its way to the hydrogen preheat section of the reactor vessel.

Argon is used in the system to balance the pressure between the furnace section of the reactor vessel and the reaction zone, and to purge the system before operation. The argon pressure will follow the hydrogen pressure by means of a differential pressure controller and inlet and exhaust control valves. Argon pressure in the furnace will be automatically controlled to stay 0-20 PSI higher than the hydrogen pressure in the reaction zone.

During the purge cycle argon enters the hydrogen and argon lines through air operated valves, and pressurizes the system to approximately 100 PSI. The procedure is repeated for a total of 3 cycles for complete purging of air from the system. Pressure regulators have been supplied on all air operated valves to supply the correct operation pressure.

5. Coal Feeder Assembly

The coal feeder assembly consists of the feed bin, screw feeder, and semi-venturi. Coal dust is placed into the feed bin (approx. 500 CC capacity) and metered out by the screw feeder into the venturi assembly. The screw feeder operates by rotating a tube about a fixed helical spring. Coal will pass into the feed tube through slots and be forced through the tube by action against the stationary spring. As the coal gets to the downstream end of the feed tube it will fall through slots and into the semi-venturi. The feed tube is rotated by a magnetic drive assembly. This decouples the feeder and drive and eliminates problems of leakage through a rotating seal. The MagneDrive will be driven by an air motor at variable speed to provide a coal feed rate of one to five cc per minute.

6. Reactor Vessel

The reactor vessel contains the feed nozzle, catch tube, furnace, reaction tube, and thermocouples needed for control and monitoring of internal temperatures.

Primary hydrogen and coal dust enter the vessel through the feed nozzle and secondary hydrogen enters through the secondary hydrogen inlet tube in the bottom cover. The secondary hydrogen is preheated in the preheat coil to approximately the operating temperature and discharged into the annular space between the inside of the furnace tube and the outside of the reaction tube. From here it flows to the top of the vessel and through the flow straightener into the reaction zone where it meets the primary flow. The gas and coal dust flow down through the reaction tube and leave the vessel through the catch tube.

The feed nozzle, catch tube, vessel cover, and vessel body are water cooled and are each provided with the low flow switches and over temperature switches which will cut power to the furnace and set off an alarm if closed.

The temperature of the reaction tube will be sensed by eight type "R" thermocouples mounted in grooves in the side of the tube. The temperature of each will be recorded by the temperature recorder located on the control panel. The temperature of each of the four furnace zones will be recorded and controlled through one active and one spare type "R" thermocouple (eight total) positioned in the center of the corresponding zone. Temperature in the reaction zone should be controllable to within 10°C. of the set point and the maximum temperature will be 1200°C. All thermocouples connected through the bottom cover have the furnace electrodes.

All five furnace electrodes are water cooled and the cooling circuit is designed to be monitored by a flow switch which will stop power to the furnace in case of a low flow condition.

Residence time of coal dust in the reaction zone will be adjusted by varying the distance between the top of the feed nozzle and the tip of the catch tube. This distance will be varied by the use of four catch tubes, each four inches different in length. Each tube is adjustable through four inches to five a variable residence length of between four and twenty inches.

7. Separator Vessel

The separator vessel is designed to separate most of the solid effluent from the gas stream. Discharge gas and solids from the reactor enter the side of the separator vessel. The gas will leave after passing through a 20 micron screen located at the top of the vessel. Solid and liquid particles will fall to the bottom for retention.

8. Filter Vessel

The filter vessel is designed to filter out any particle of less than twenty micron size that passes through the separator vessel.

9. Reactor General Assembly

The reactor general assembly consists of the coal feed assembly, reactor vessel assembly, separator vessel, filter vessel, valves and switches needed for water cooling, valves and fittings needed for pressure control of the hydrogen gas, and the totalizing hydrogen flow meter.

The supporting framework for the above equipment is in four sections bolted together for ease in handling and servicing. The bottom section (4' x 4' x 7' high) acts as the main support structure. The reactor vessel and feeder sections have been mounted on top of this section and the carriage assembly, which houses the separator and filter vessels and reactor catch tube, is supported on the side. The carriage assembly is mounted on guide bearings and rests on a hydraulic jack for the purpose of raising and lowering the catch tube. A hydraulic hand pump is mounted on the side of the base support section for operating the jack. A panel housing valves, gauges, and the flow meter also is part of this section.

10. Control Panel

The control panel houses all electronic and pneumatic equipment necessary for operation of the system. The panel was built as one unit divided internally into two sections. The left hand side (facing front) housed the temperature recorder and programmer, pressure controller, temperature controllers, alarm section, differential pressure controllers, screw feed motor control and switches. The right side contains the high power equipment needed to operate the reactor furnace. The control panel must be located outside the room housing the reactor and compressor assemblies. It contains no hydrogen and argon carrying lines.

C. System Operation

1. Pressure Control

Hydrogen and argon pressures in the system are controlled from the control panel. Hydrogen gas pressure in the system is controlled by the pressure controller through a pressure control valve. The set point can be adjusted manually on the pressure controller. Control is proportional pneumatic utilizing 3-15 PSI control signals. A high limit set point will close the hydrogen supply valve, open a dump valve, and sound the alarm if exceeded.

Argon pressure will automatically follow the hydrogen pressure by means of a differential pressure controller. The controller compares the pressure in the hydrogen portion of the system to that of the argon part and operates two control valves. This controller is also proportional pneumatic and is set up to maintain argon pressure 0-21 PSI higher than hydrogen pressure. The controller has been equipped with high and low deviation limit settings. If the high limit is exceeded the alarm will sound and the argon supply valve will be closed until the high limit deviation has been corrected. A light will remain on indicating the condition until it is manually reset. A similar result will occur if the low limit is exceeded, but the hydrogen supply valve, will be closed. Gauges are also available for pressuring monitoring.

2. Temperature Control

The reactor furnace temperature is designed to be controlled by four temperature controllers and one temperature programmer. The programmer will be used to heat up and cooling and can be used to automatically control an entire run by supplying an externally programmed set point to the controllers. The controllers may also be used independently of the programmer by manually controlling the set point. The controllers will operate in the proportional current and automatic reset modes and will be connected to silicon controlled rectifiers for final power control to the furnace element.

Temperature at the 16 thermocouple locations will be recorded on a multiple point recorder which is equipped with a point selection feature allowing any number of the 16 points to be recorded. The recorder is also equipped with a high limit set point which will sound an alarm, stop furnace power, and close the hydrogen supply valve if exceeded.

3. <u>Other Control Features</u>

See Section B.1 for compressor control features and Section B.5 for cooling controls located on the reactor vessel.

All air operated valves are switch controlled from the control panel through air solenoid valves. The air motor used to drive the coal feeder is controlled by a pressure regulator and monitored by a tachometer on the control panel.

4. <u>General Safety Features</u>

All pressure containing parts for hydrogen and argon are designed for a maximum allowable working pressure of 2200 PSI. The maximum recommended operating pressure of the system is 1500 PSI.

An automatic hydrogen overflow shut-off loop consists of a thermal-flow meter with an appropriate power supply flow indicator and alarm relays used in conjunction with an air operated valve and associated solenoid valves. The primary hydrogen will be automatically shut down when an overflow condition arises. This condition will be visually and audibly indicated on the control panel. The loop can also be manually activated.

A portable gas leak detector has been furnished for ease in locating any leaks in the system.

All wiring and electronic control components are in accordance with the national electric code where applicable.

D. Test Program for Reactor System

The following program is an outline for the testing of equipment by AE.

1. Testing at Autoclave Engineers (all gas testing done with helium).

a. Hydrostatic testing and gas testing at maximum allowable working pressure (2200 PSI) of the following components:

Feed Bin

MagneDrive Assembly

Reactor Vessel

Separator Vessel

Filter Vessel

Valves

b. The feed assembly was tested to verify the coal feed rate obtained with a previously constructed model.

c. The compressor was pressure tested (2200 PSI for the 2nd stage and 240 PSI for 1st stage) and gas flow tested to verify that the design conditions are met.

d. Electrical continuity of furnace assembly was checked.

e. System Testing

The control system was given a complete electrical continuity and functional test.

The gas system (piping assembly) was given a helium pressure test to 200 PSI for 1/2 hour and a functional test to verify proper operational sequencing of valves and performance of instrumentation.

The reactor furnace assembly and gas pressure control system were functionally tested to verify the differential pressure controls. The system was made up with small pressure vessels connected to the helium and hydrogen lines in place of the reactor vessel.

2. Testing To Be Done At The Installation Site

a. Gas test system as a complete unit to 220 PSI with helium gas, and hold for 5 hours. The maximum allowable pressure drop due to leakage will be 5 PSI.

b. Check furnace for electrical continuity.

c. Pre-oxidize furnace element by heating in air (at the rate of 100°F/Hr.) at atmospheric pressure to 1920°F. and hold for 8 hours.

d. Check control system for electrical continuity.

e. Check gas system and control system for correct operation and valve sequencing. This will include testing the differential pressure control network.

f. A complete hot test to the system using helium will include:

Preset all flow and pressure control instruments.

Start cooling flow to furnace electodes, nozzle, catch tube and pressure vessel.

Heat furnace at the rate of 200°F/Hr/ to 2200°F.

Open PCV-3 to start gas flow.

Start coal feeder.

Run for 1/2 hour.

Shut down furnace coal feeder and gas flow.

Depressurize system.

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Appendix A

Reactor Specifications: Penn State Inquiry to Autoclave Engineers, Inc.

LEGEND FOR ENGINEERING FLOW DIAGRAM

C	H_2 Diaphragm Compressor
CV-1	By-Pass Check Valve
CV-2	Reverse Flow Safety Check Valve
CV-3,4	N_2 Flow Check Valve
ECV	Excess Flow Check Valve
FA	Flame Arrester
FI-1	H_2 Primary Flow Flowmeter
FI-2	H_2 Secondary Flowmeter
FI-3	H_2 Totalizing Flowmeter
FI-4	N_2 Flowmeter
FS-1,2	Water Low Flow Switch
GP-1,2,3	Gage Protector
HE-1,2,3,4	Heating Elements
LF	Line Filter
MV-1	H_2 Primary Flow Metering Valve
MV-2	H_2 Secondary Flow Metering Valve
MV-3	Gas Chromatograph Metering Valve
MV-4,5	Water Flow Metering Valve
NV-6	N_2 Flow Metering Valve
PA	Pressure Alarm
PCR	Pressure Controller/Recorder
PCV	Pressure Control Valve
PI-1	H_2 Supply Pressure Gage
PI-2	H_2 Accumulator Pressure Gage
PI-3	H_2 Input Pressure Gage
PI-4	Bin Pressure Gage
PI-5	Drain Pot Pressure Gage
PR	Power Safety Shut-off Relay
PRV-1	Compressor Input Press, Reg. With Integral Gages
PRV-2	H_2 Input Pressure Regulator
PRV-3	N_2 Pressure Regulator with Integral Gages
PRV-4,5	Air Pressure Regulator with Integral Gages
PS-1	H_2 Suction Lower Pressure Switch
PS-2	H_2 Output Upper Pressure Switch

LEGEND FOR ENGINEERING FLOW DIAGRAM (cont.)

PS-3	Bin Upper Pressure Limit Switch
PS-4	Reactor Upper Pressure Limit Switch
PWC 1 to 4	Power Controller, SCR Type (Heating Element)
SFC	Screw Feed Control
SFM	Screw Feed Motor
SV-1	H_2 Input Shut-off Valve
SV-2	Air Operated H_2 Safety Shut-off
SV-3,4,5	Shut-off Valve, Ball Type
SV-6,7	Shut-off Valve
SV-8,9	Shut-off Valve, Water Flow
SV-10	Shut-off Valve, Solenoid Operated, N_2 Flow
SV-11	Shut-off Valve, N_2 Flow
SV-12,13	Air Line 3-Way Valve, Solenoid Operated
T	N_2 Purge Timer
TA	Temperature Alarm
TC-1 to 4	Temperature Controller (Heating Element)
TI	Temperature Indicator, Reactor Head
TL-1	Upper Temperature Limit Switch (Heating Elements)
TL-2,3	Upper Temperature Limit Switch, Water
TP-1 to 12	Temperature Probe, Reactor Head
TR	Temperature Recorder, Multi-Point

Objectives

The coal gasification system described herein, is a laboratory scale unit to determine the characteristics of coal particle residues after exposure to high heating rates and temperatures for brief periods in a high pressure hydrogen atmosphere. Particles supplied by the feed bin are fed at a uniform, continuous rate to the feed nozzle and fall vertically through the reactor bore. A hydrogen flow rate, at a velocity greater than the terminal velocity of the particles, carries the particles into the catch tube. The primary and secondary hydrogen flows are adjusted to equal velocities. The particles are rapidly heated upon exiting the feed tube, and are rapidly cooled upon entering the catch tube. Solids and liquid residues are collected by the catch pot and drain pot respectively, and effluent gas passes to a gas burn-off and gas chromatograph (user supplied) for analysis. A more detailed description of system function is given under system description.

System Description (Figure 1)

Tank gas from the H_2 supply manifold passes through the check valve CV-1 until pressure between the supply and accumulator system is equalized. Thereafter, the supply gas pressure passes through the booster compressor C until maximum pressure established by PS-2 is achieved (or lower suction pressure lower limit established by PS-1 is reached).

With SV-1 open, pressure is reduced to approximately desired system pressure by PRV-2 and is held by SV-2 from entering the system.

Prior to operation with H_2 the system is purged with N_2 via PRV-3, SV-10, MV-6, FI-4, and SV-11 for an adjustable pre-determined time set on timer T. An interlock (not illustrated) prevents H_2 flow through SV-2 until the timed period is completed. The N_2 flow enters the furnace

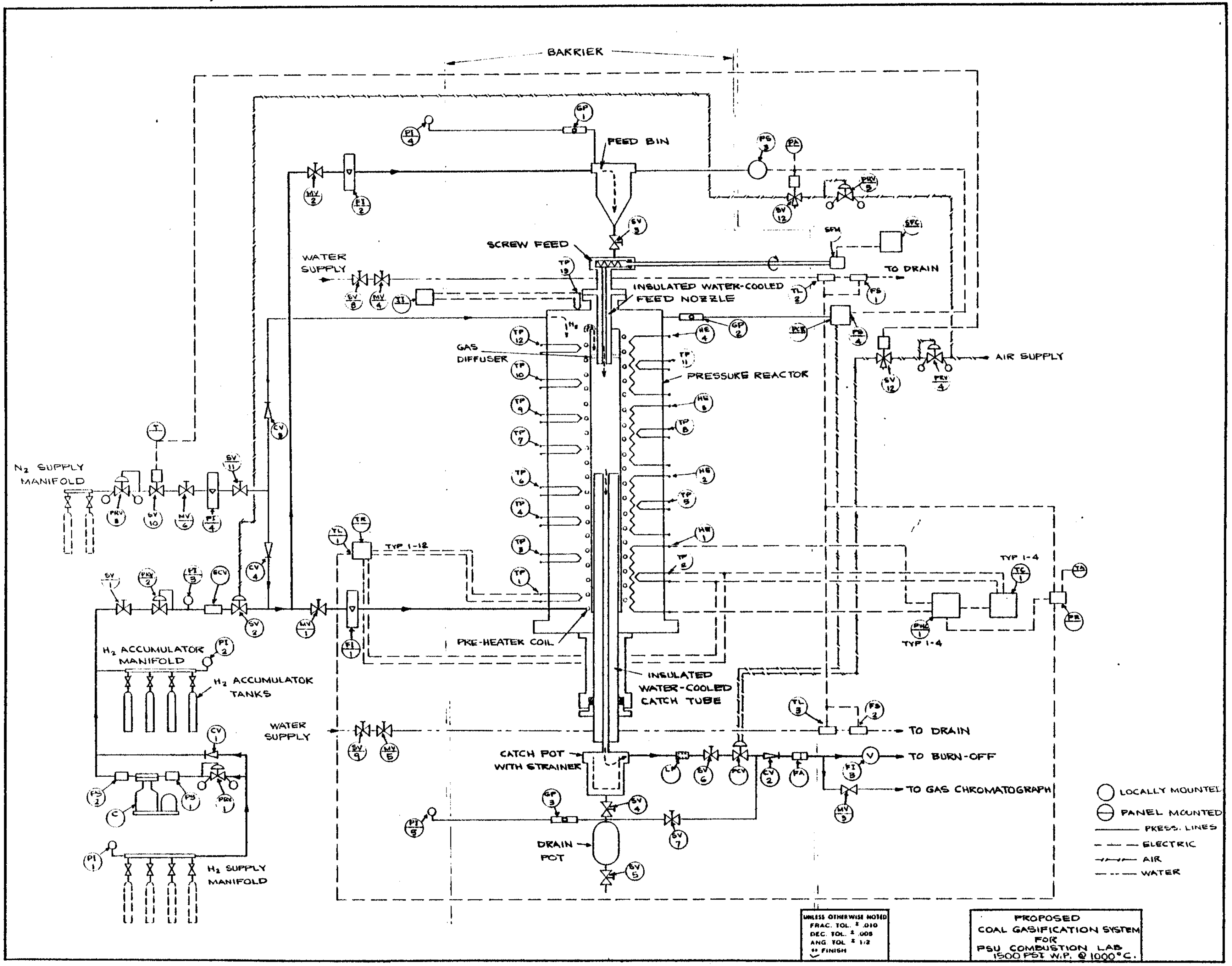

Figure 1. PROPOSED COAL GASIFICATION SYSTEM

insulation area as well as the primary and secondary H_2 flow lines. The timer, via SV-12 maintains the outlet flow valve PCV open during the purge cycle. The N_2 flow exists by the system exhaust line and the oxygen content may be monitored by the gas analyzer. The H_2 flow must be initiated manually after the N_2 purge time has occurred.

Primary and secondary H_2 flows are adjusted with MV-1 and MV-2 and read on FI-1 and FI-2. The primary flow passes through a pre-heater coil adjacent to the heating elements and then into the top of the approx. 1 in. diameter x 24 in. high reactor bore, passing through a diffusing element. The secondary H_2 flow passes through the feed bin, SV-3, the screw feeder and the feed nozzle. The primary and secondary flow rates are adjusted to provide approximately isokinetic laminar flow between the feed nozzle and the catch tube so that the coal particles fall vertically from the screw feeder through the feed nozzle into the catch tube orifice.

The H_2 exits the catch pot through a strainer and through LF, SV-6, PCV, CV-2, FA and to FI-3 and MV-3. The control valve PCV is regulated by the pressure controller recorder PCR to maintain the pre-set pressure in the pressure reactor.

The coal particles are caught in the catch pot strainer and liquids drain into the drain pot. Liquid samples may be drawn off by appropriate use of the adjacent valves to isolate and depressurize the container.

Water supplies pass through valves SV-9, MV-5 and SV-8, MV-4 through the catch tube and feed nozzles respectively and exit through temperature and flow sensors TL-3, FS-2 and TL-2, FS-1 which will automatically cut off power to the heating elements via PR if an unsafe condition exists, sounding the alarm TA. The multipoint recorder TR records temperatures at the thermocouple positions TP-1 thru 12 and can also activate PR and TA if an overtemperature condition exists.

Temperature is controlled by Temperature controllers TC-1 through TC-4 (only one illustrated) in a continuously variable fashion by means of the SCR power controllers PWC-1 through 4. Reactor vessel shell maximum temperature is indicated on T2.

The feed bin pressure gage PI-4 monitors pressure and a sensor PS-3 senses unsafe pressure conditions shutting-off H_2 flow through SV-2 by means SV-12 solenoid valve, and sounding over-pressure alarm PA. Similarly pressure recorder-controller PCR senses over-pressure conditions in the reaction vessel with resultant shut-off of H_2 supply and sounding of the alarm.

Coal particle feed rate is controlled by the pitch/size of the feed screw and by the variable speed motor SFM and control SCF.

No arc-producing apparatus and no electrical connectors except of a fixed nature are located within the barrier surrounding the reaction system proper.

Where feasible, manual valves SV-3, 4, 5, 6, and 7 in the system proper will have extensions with handles located outside the barrier.

A heat exchanger may be required between the catch pot and LF to maintain gas exit temperatures to a level compatible with the exhaust line components.

H_2 Flow Rate and Pressure:

The expected total H_2 flow rate will be 3 SCFM (180 SCFH) for the intended 30 minute duration of a run. H_2 at lower pressures and flow rates will be maintained during heat-up, idling and cool-down of the furnace.

The maximum H_2 working pressure will be 1500 PSI.

N_2 Purge Flow Rate:

The N_2 purge flow will be at least 2 SCFM (120 SCFH).

Feed Bin:

The feed bin shall be constructed of #304 or 316 stainless steel and have an internal capacity in excess of 500 cc. The working pressure will be 1500 PSI. The design conditions will be 2200 PSI at 500°F and design shall conform to Section VIII, Div. 1 of the ASME Pressure Vessel Code.

The cover shall be easily and quickly opened and closed for sample loading and shall not contain connections of any kind.

The shape of the feed bin will allow continuous gravity-feed of the coal sample material to the screw-feed device.

Removeable sealed connections shall be provided on the feed bin for secondary H_2 flow, pressure gauge PI-4 and pressure switch PS-3. These entrances will be designed as to preclude clogging by the coal sample material.

Screw Feed:

The screw feed will carry sample material received from the feed bin to the entrance of the feed nozzle in a uniform and continuous manner, and shall have a variable feed rate of 1 cc to 5 cc per minute for coal of approximately 50 micron particle size and a density of about 1 gm/cc.

The feed screw will be driven through a suitably packed gland by an external variable speed drive.

Construction of the screw feed proper, will be of #304 or 316 stainless steel or equal. Operating pressure 1500 PSI. Design conditions 2200 PSI at 600°F.

Feed Nozzle:

The feed nozzle shall permit material supplied by the feed screw to fall freely down the vertical axis of the reactor. The minimum i.d. of the nozzle will be 1/8 in.

Water cooling in the nozzle shall extend to within 1/4 in. of the nozzle tip and shall efficiently cool the material passing through the bore.

The exterior of the nozzle will be insulated with high efficiency material to minimize heat transfer from the surrounding primary gas flow.

The maximum diameter of the nozzle assembly within the reaction chamber will be 3/4 in.

The nozzle tip will be of suitable geometry to minimize turbulence of the gas flow, so that laminar flow will exist past the tip.

The nozzle will extend approximately 2 in. into the reaction chamber and will be suitably sealed to and removeable from the feed screw assembly and the pressure reactor proper for cleaning.

Operating pressure is 1500 PSI. Design pressure will be 2200 PSI at 500°F without water flow. The water passage shall be designed for 150 PSI at 500°F at zero reactor pressure. Construction shall be of #304 or #316 stainless steel with all permanent joints MIG or TIG welded.

Pressure Reactor Assembly:

1. Reactor Vessel. The vessel will be labricated of #304 or #316 stainless steel and design shall conform with Section VIII, Div. 1 of the ASME Pressure Vessel Code. Working pressure will be 1500 PSI. Design conditions are 2200 PSI at 500°F. Permanent joints will be MIG or TIG welded.

The outside of the vessel shell (excluding flanges) shall not be less than 6 in. or more than 9 in. diameter.

The top of the vessel will provide a sealed mounting connection for the feed nozzle and a connection for N_2 purge.

A connection for the pressure controller/recorder PCR will be provided so as to preclude clogging by insulation or other material.

The removeable sealed bottom of the vessel will allow installation of the furnace assembly, and removal for maintenance. The primary gas flow connection, the monitoring and control thermocouples and the heating element feedthrus shall, preferably, enter through the bottom of the vessel. A sealed mounting connection will be provided for the catch tube assembly.

2. Reaction Chamber. The reaction chamber shall be 24 in. high by 1 in. i.d. and consist of a tube of #316 stainless steel or better and of sufficient wall thickness to be self-supporting and avoid significant distortion at operating temperatures.

The tube shall support a porous disk of #316 stainless steel or better at a level above the tip of the feed nozzle to promote uniform gas flow.

Positive connection of the preheater tube will be made at the top of the coil.

3. Furnace Assembly. Heating elements shall provide four separately powered zones suitably distributed to allow establishment of constant temperature zones within the reaction chamber, between the feed nozzle and catch tube at all catch tube positions and at reaction chamber temperatures of 500°C to 1000°C. The heating element and insulation materials shall be suitable for operation in H_2 and N_2 under pressure and

at atmospheric pressure in air. Sufficient reserve power capacity to ensure reasonable heat-up time and element operational life will be provided.

Furnace insulation shall be primarily of low k factor, low heat storage capacity material and will include refractory structural components and convective shields as required.

The reactor vessel shall not exceed design temperature at any point with the reaction chamber operating at maximum operating temperature and pressure (1000°C and 1500 PSI) and an H_2 flow rate of approximately 180 SCFH.

4. Preheater Coil. A helically wound tube in proximity with the heating elements will allow the temperature of the primary H_2 gas flow to be raised to approximate working temperature prior to entering the reaction chamber.

Catch Tube:

The catch tube will collect material which falls vertically from the feed nozzle. The tip of the catch tube shall be of suitable geometry to guide material and the entraining gas flow into the bore of the assembly. The minimum i.d. of the catch tube will be 1/4 in.

Water cooling shall extend to within 5/16 in. of the tip and shall provide efficient cooling of the material passing through the bore. The exterior of the catch tube (interior to the vessel) shall be insulated with high efficiency material to minimize heat transfer from the surrounding reaction chamber.

The maximum o.d. of the catch tube (in the reaction chamber) will be less than the 1 in. working bore consistant with adjustability requirements.

The nozzle will be continuously adjustable for a distance of at least 4 in. by means of a suitably sealed gland. Total adjustment range of from 4 in. to 20 in. between feed nozzle tip and catch tube tip will be provided by interchangeable sealed spacer flanges which will be interposed between the reaction vessel bottom and the catch tube gland assembly.

Interchange of spacer flanges should be possible in a one hour period or less and should not require disassembly or demounting of the pressure reactor proper and will be possible within the normal mounting constraints of the system.

Design shall provide guidance for maintaining the catch tube centralized in the reaction chambers.

Operating pressure will be 1500 PSI. Design conditions will be 2200 PSI at 500°F without water flow. The water passage will be designed for 150 PSI at 500°F at zero reactor pressure. Construction shall be of #304 or #316 stainless steel with all permanent joints MIG or TIG welded.

Catch Pot:

The catch pot assembly will be constructed of #316 stainless steel and shall contain a removeable strainer. Capacity of the strainer will be 500 cc. The strainer will be suitably sealed in the catch pot to preclude bypass flow of coal particles.

The bottom of the strainer and of the catch pot will facilitate drainage of fluids into the drain pot.

The cover and strainer will be quickly and easily removeable for access to the contents. The catch pot will be suitably sealed to and removeable from, the catch tube, exhaust line and drain pot for cleaning.

Working pressure will be 1500 PSI. Design conditions will be 2200 PSI and 600°F.

Drain Pot:

The drain pot will be a cylinder of at least 200 cc capcity of #304 or #316 stainless steel or equal. The internal contours of the cylinder shall promote maximum drainage of the contained fluids when SV-5 is opened. The drain pot shall be demountable from the system for cleaning.

Working pressure is 1500 PSI. Design conditions are 2200 PSI at 500°F.

Control Module:

The control module will be separate from the safety barrier and shall be suitable to contain all necessary controls and devices not otherwise provided for at the manifolds, compressor, or within the safety barrier. Components shall be easily accessible for maintenance. Electrical components shall be protected so as to prevent accidental shock hazard. The top will be vented to prevent the possible accumulation of explosive gas.

The control panel shall mount all components shown with a horizontal line in the identifying circle in the flow diagram. All panel mounted controls and indicators will be identified with appropriate labels and arranged in a logical, functional order. A suitable flow diagram connecting the components in a clear manner will indicate their interrelationship. Where feasible, all controls and indicators will be located not lower than 2-1/2 feet or more than 6 feet from floor level.

Safety Barrier:

The safety barrier will contain components as indicated on the flow diagram and others as deemed desirable and feasible. No arc-producing devices and no electrical connections except of a fixed nature will be located within the barrier. All electrical connections will be provided with locking devices to prevent accidental loosening. The barrier will consist of a front, top and two sides. The open side of the barrier will be placed within two feet of an outside wall at the installation site. The barrier will have necessary framing and reinforcement and must be constructed in sections which will pass through a 3 ft by 6-1/2 ft entrance to the assembly area.

The top of the barrier will slope upward to the open side to prevent accumulation of explosive gas.

The barrier must be sufficiently large to contain the indicated components and allow access and clearance for maintenance and disassembly of components.

Provision shall be made for securely mounting the barrier to the floor.

Reactor Supporting Frame:

A rigid framework located within the safety barrier will support and secure the reaction vessel and associated attached components.

Adjustment shall be provided to level the reactor and to provide support for the adjustable catch tube and attached components.

The frame will have provision for secure attachment to the floor.

Temperature Calibrating Device:

In order to establish operating parameters of the heating system for various conditions of operation (temperatures, preysures, flow rates and zone lengths) a device will be provided which will permit probing of the reaction chamber at operating conditions through the feed nozzle bore without coal flow.

The adjustable thermocouple probe must extend to the maximum zone length (to lowest position of catch tube).

H_2 Diaphragm Compressor - C:

Two stage, 0.9 SCFM capacity at 2200 PSI output pressure with suction low limit and outlet upper limit pressure switches (PS-1, PS-2) for automatic operation. A manual start/stop switch and all electrics will be provided for operation on 220VAC, 60 cycle, single phase.

Suitable for hydrogen service. Corblin Model AOCL-250 or equal.

H_2 Supply:

H_2 from the supply tanks will be scavanged to low pressures by the compressor and stored at approx. 2200 PSI maximum in the H_2 accumulator tanks to provide sufficient head for the desired working pressures and flow rates.

H_2 Accumulator Tanks:

H_2 accumulator tanks will be four standard (Matheson 1A or equal) H_2 gas cylinders with shut-off valves and CGA #350 outlets.

H_2 Supply Manifold:

A four station, 2500 PSIG, single row type manifold, brass, with station valves and check valves and CGA #350 connections.

H_2 Accumulator Manifold:

A four station, 2500 PSIG, single row type manifold, brass, with station valves and CGA #350 connections.

N_2 Supply Manifold:

A two station, 2500 PSIG, single row type manifold, brass, with station valves and check valves and CGA #580 connections.

N_2 Flow Meters - FI-1 and FI-2:

The primary and secondary flow meters will be of the high pressure visible float type with 2 percent scale accuracies and a working pressure of 2500 PSI or greater. Materials of construction and design will be compatible with H_2 and N_2 at ambient temperature.

The primary flow meter will have a maximum flow capability of 250 to 350 SCFH of H_2.

The secondary flow meter will have a maximum flow capability approximately equal to the ratios of the secondary to primary flow areas (feed nozzle exit orifice area divided by the reaction chamber cross-sectional area) times the maximum primary flow meter flow rate. (e.g. - a .2 in. diameter nozzle orifice area would be 1/25 the 1 in. reactor i.d. and would be sized to 1/25 the flow capacity of the primary flow meter).

N_2 Purge Timer - T:

N_2 purge of the system will be manually initiated and run for an adjustable period of time of 0 - 2 hours as set on a suitable timer.

H_2 operation will be manually and separately initiated. A visual signal will indicate the end of the timed N_2 purge.

Pressure Gauges - PI-1 thru PI-5:

Pressure gauges, other than those integrally mounted on regulators and other equipment, identified as PI-1 through PI-5 will have a range of 0-3000 PSI, an accuracy of 1/2 percent or better F.S. and have corosion resistant elements and a minimum 4-1/2 in. nominal dial face. Elements should have a burst pressure in excess of 9000 PSI.

Flame Arrester - FA:

A flame arrester shall be placed in the gas exhaust line to prevent a flame front from travelling toward the H_2 filled components during a non-flow condition.

Pressure Control and Recording - PCR:

H_2 gas from the accumulator manifold is reduced to approximate working pressure by regulator PRV-2. Flow rates are established by MV-1 and MV-2 in conjunction with PRV-2. Pressure in the reactor is sensed by the pressure controller-recorder PCR and deviations from the set point cause a corrective air signal to adjust the air-operated proportioning control valve PCV to maintain the set pressure within 1% or 10 PSI, whichever is greater, between 500 and 1500 PSI working pressure.

Temperature Control:

Four solid state proportioning temperature/power control systems provide individual zone control by means of the connected zone thermocouples. Power to the heating elements is provided in a continuously variable manner to ensure smooth temperature regulation. An upper temperature limit set-point will provide sensing of unsafe conditions.

Range will be 0-1200°C, type K.

Temperature Recording - TR:

A multipoint temperature recorder with 12 in. (nominal) strip chart records temperatures as sensed by the eight monitoring thermocouples and the four control thermocouples. An adjustable upper temperature limit switch will provide sensing of unsafe temperature conditions.

A thermocouple break protection feature, which may be by-passed if desired, will be provided.

A point selection feature will allow points to be selectively printed for clarity. Chart speeds, printing rate and printing colors will be chosen to promote recognition of plotted points.

Range will be 0-1200°C, Type K.

Thermocouples - TP1 - TP12:

Monitoring thermocouples and control thermocouples used in the reaction vessel will be inconel sheathed, type K. Twelve thermocouples will be provided. Eight will be equally spaced along the 24 in. length of the reaction chamber (monitoring thermocouples) and four will be located as required for control of the heating elements (zone thermocouples). The monitoring thermocouples will not be located within the reaction chamber, but will be located in close proximity and if feasible, be in contact with, the reaction chamber.

Water Cooling:

Water cooling of the feed nozzle will prevent significant increase in coal temperature prior to entering the heating zone. Water cooling of the catch tube will rapidly quench the coal particles preventing further decomposition and cool the effluent gas to temperatures compatible with the exhaust line components.

Cooling water exit temperatures should not exceed 180°F with a maximum inlet pressure of 40 PSI at maximum reactor operating temperature, pressure and H_2 flow rate (1000°C 1500 PSI and 180 SCFM).

Tubing Size/Connections/Material:

Tubing for gas flow will be 1/4 in. o.d. or larger, stainless steel (#304 or #316) and connections to components will be of the CPI (Swagelok, Gyrolok, etc.) type. Where suitable, components will be selected with compatible stainless steel fittings and adaptation to other fitting sizes and types will be kept to a minimum. Tubing and connecting fittings will be rated for at least 2500 PSI W.P. at expected temperature. Air lines and water lines will be copper of suitable capacity with brass compression fittings.

Safety Alarm Systems:

1. Sensors in the water cooling drain lines will detect low water flow rates and excessive water temperature and will shut-off heating element power through PR and actuate audible and visible alarms.

2. Over-temperature conditions detected by the temperature recorder or temperature controllers will shut off heating element power through PR and actuate audible and visible alarms.

3. Over-pressure conditions detected by the upper pressure limits in PCR and PS-3 will shut-off gas flow via SV-2 and actuate audible and visible alarms.

4. The above safety functions may actuate a common solid-state audible alarm, but separate visible alarms will indicate the specific unsafe condition so that appropriate corrective action may be quickly taken by the operator.

5. Other safety features as deemed adviseable will be incorporated by the supplier.

Leak Detector:

A portable, battery-operated gas leak detector which is intrinsically safe in explosive atmospheres will be provided for use with the system. Bacharach model SA-65A or equal.

Volumetric Flow Meter:

A totalizing flow meter (FI-3) will be provided to measure the effluent gas volume. The meter shall have a flow capacity of at least 250 SCFH, will have an accuracy of 1 percent or better and will be suitable for H_2 service.

Components not Described:

Components shown on the flow diagram and not further described in detail and other components not shown but required for a functional system will be chosen and furnished by the supplier to make a complete unit needing only tank gas, electric, air and water supplied for operation.

Components chosen will be appropriate for the operating conditions and will be rated in excess of working conditions.

Components handling exhaust materials from the reactor will be of stainless steel or equivalent material and stainless steel will be preferably used where possible for all high pressure components.

Electrical components will operate on 110 or 220 VAC, 60 cycle single phase A.C.

Installation:

The supplier will provide installation and assembly of the system at the site and demonstrate the ability of the system to perform correctly at maximum operating conditions.

Appendix B

Autoclave Engineers, Inc.

Proposal 44-0892-74F with Revisions

The following Coal Gasification System has been proposed in response to the inquiry set out in Appendix A. First is a general description and breakdown of the proposed system. A more detailed explanation is contained in the attached specification sheets. Attached is a preliminary drawing, Figure 1, illustrating the proposal.

A. Pressure Conditions

1. Maximum allowable working pressure for the system and its components will be 2200 psi at 500°F except the screw feeder and catch pot which will be 2200 psi at 600°F.

2. The reaction chamber will operate at 1500 psi at 1000°C in a hydrogen atmosphere.

B. Equipment

1. The design of all pressure containing components will be in accordance with Section VIII, Division I of the ASME Pressure Vessel Code. The reactor vessel design will be submitted to the Pennsylvania Department of Labor and Industry for permission to stamp the vessel with a "Pennsylvania Special" number. All other vessels are below 6" ID and 3000 psi and, therefore, are exempt from Pennsylvania's requirements.

2. The major equipment will be furnished in three (3) modules. Each module will be piped and wired ready for installation. The three (3) modules are:

(a) The Control panel assembly including instruments, valves, tubing and wiring. No hydrogen containing components will be on the control panel.

(b) The reactor and pressure vessel frame assembly including local gages, valves, fittings and tubing.

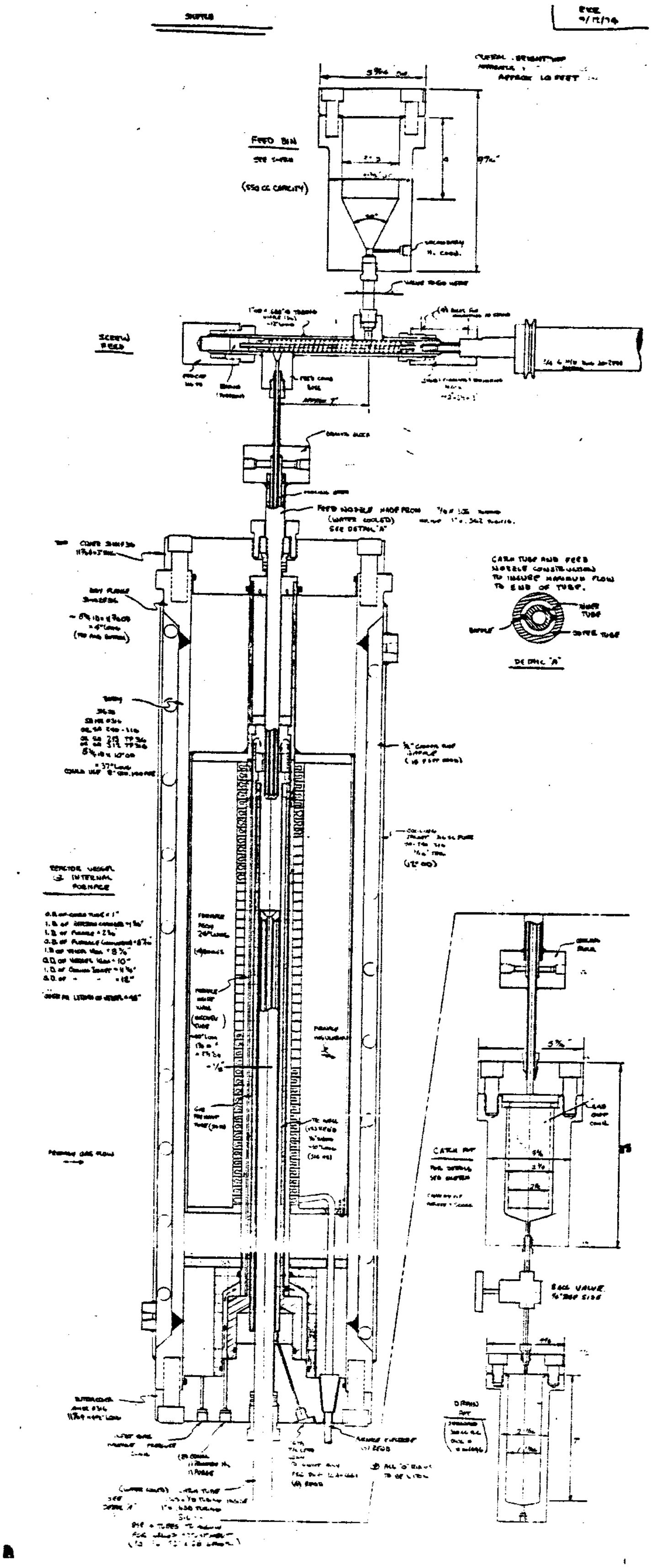

Figure 1. PRELIMINARY DRAWING OF PRESSURIZED COAL GASIFICATION SYSTEM

(c) The compressor assembly including local gages, valves, fittings, tubing and wiring.

C. Construction Materials

1. All pressure containing parts will be of 316 SS. The interior shell of the furnace will be of Inconel. All support equipment including the compressor frame, reactor frame, valve rack and instrument panel will be of welded steel construction. All components subject to atmospheric corrosion will be painted.

D. System Description

1. For description purposes, we will use the component nomenclature as shown on your specification diagram.

2. Tank gas from the Hydrogen supply manifold will pass through the check valve, CV-1, until the pressure between the supply and accumulator system is equalized. Thereafter, the supply gas pressure will pass through the booster compressore "C" until maximum pressure is established by pressure switch, PS-2, or the low suction pressure limit is established by pressure switch, PS-1.

With SV-1 open, pressure is reduced to approximately the desired system pressure by PRV-2 and is held by SV-2 from entering the system. Prior to operation with hydrogen the system is purged with nitrogen via PRV-3, SV-10, MV-6, FI-4, and SV-11 for an adjustable predetermined time set on timer "T". A hydrogen interlock will prevent flow through valve, SV-2, until the time period is completed. The nitrogen flow enters the furnace insulation area, as well as the primary and secondary hydrogen flow lines. The timer, via SV-12, keeps the outlet flow valve PCV open during the purge cycle. The nitrogen flow exits by the system exhaust line and any oxygen content will be monitored by the gas analyzer.

The hydrogen flow must be initiated manually after the nitrogen purge.

Primary and secondary hydrogen flows are adjusted with MV-1 and MV-2, and read on flow indicators FI-1 and FI-2. The primary hydrogen flow passes up through the annular space between the furnace inside wall and the preheat tube, then into the top of the 1" ID x 24" IL reaction chamber, and then through the diffusing element. The secondary hydrogen flow passes through the feed bin, SV-3, the screw feeder and the feed nozzle. The primary and secondary flow rates can be adjusted so the coal particles will flow vertically from the screw feeder through the feed nozzle and into the catch tube.

The hydrogen exits the catch pot through a strainer and through the line filter, LF, and valves SV-6, PVC, CV-2, the flame arrester, FA, and the totalizing flow indicator, FI-3, and MV-3.

The control valve PCV is regulated by the pressure controller recorder PCR to maintain the present pressure in the reactor vessel. Basically, the reactor is designed with two (2) isolated pressure zones, one (1) for the reaction chamber, the other for containing an inert gas to prevent hydrogen embrittlement of the furnace windings. A more detailed explanation of the pressure balance system is detailed in the product specification sheet covering the reactor and furnace assembly. The coal particles are caught in the catch pot strainer, and liquid drains into the drain pot. Liquid samples may be drawn off by appropriate use of the adjacent valves, SV9, MV-5, SV-8, MV-4 and through the catch tube and feed nozzles respectively. The water will then wxit through the temperature flow sensors TL-3, FS-2, TL-2, and FS-1. Any unsafe condition will sound alarm "TA". The multipoint recorder "RT" records and also can activate the power safety relay "PR" and temperature alarm "TA", if an over temperature condition exists. Temperature is controlled by temperature controllers TC-1 through TC-4 with continuously variable 3CR power controllers PWC-1 through PWC-4. The reactor vessel maximum temperature is indicated on temperature indicator T2.

The feed bin pressure gauge T1-4 monitors pressure, and pressure switch PS-3 will sense unsafe pressure conditions and shut off the hydrogen flow through vavle SV-2 by means of solenoid valve SV-12, sounding over pressure alarm "PA". Similarly pressure recorder controller PCR senses over pressure conditions in the reaction vessel which shuts off the hydrogen supply and sounds the alarm.

Coal particle feed rate is controlled by the pitch of the feed screw, the variable speed air motor designated SFM, and the variable speed control unit SFC.

No arc producing apparatus and only solid electrical connectors will be located on the reactor vessel module.

Where feasible, manual valves SV-3, SV-4, SV-5, SV-6, and SV-7 will be equipped with extension handles. A heat exchanger in the form of a coil is located at the top inside of the catch pot to maintain the proper gas exit temperature.

The total hydrogen flow rate will be 3 SCFM. Hydrogen at lower pressures and flow rates may be maintained during heat up, idling and cooling down of the furnace.

The nitrogen purge flow will be at least 2 SCFM.

E. Safety Considerations

1. Autoclave proposes the reactor frame module be installed in Pennsylvania State University's existing concrete cell with appropriate ceiling modifications made by Pennsylvania State University, to accommodate the equipment.

Further, we recommend an exhaust ventilation fan be installed to move at least 300 CFM of air through the cell.

If room still exists, the hydrogen storage cylinders and the compressor module also could be installed in the cell. If sufficient space does not exist, however, these components still should be installed in a well ventilated location.

PRODUCT SPECIFICATION SHEET
FORMING PART OF PROPOSAL #44-0892-74F

1. FEED BIN

One (1) special pressure vessel with an internally machined bottom cone as shown on the presentation drawing and the following specifications:

Capacity:		550 cc
Inside Diameter:		3"
Outside Diameter:	Low Chamber:	4-3/8"
At Flange:		5-9/16"
Inside Length:		6-1/2" (Total)
Outside Length:		9-9/16"
Design Pressure:		2,200 psi at 500°F

MATERIALS

Body:	SA-182-F316
Cover:	SA-182-F316
Closure Parts:	Cap Screws SA-193-B16
Closure Gasket:	316 Stainless Steel

DESIGN

The vessel design will conform to Section VIII, Division I of the ASME Pressure Vessel Code.

The pressure vessel body will be single wall designed to operate elastically at test pressure. Careful attention will be paid assuring generous radii and avoiding stress concentrations.

CLOSURE

The vessel closure will include a fully confined metal gasket and hex socket head cap screws assembled through the cover and threaded into the body flange.

CONNECTIONS -- Body Connections

Flange Area:	1/4" cone connection for the gauge protector and pressure switch.
Body Side Connection:	One (1) 1/4" cone for the secondary hydrogen input.
Bottom Connection:	One (1) 9/16" cone outlet to the screw feeder.

2. SCREW FEED

The screw feed assembly will carry sample material from the feed bin to the feed nozzle, and will have a variable feed rate of 1 CC to 5 CC per minute for approximately 50 micron particle size and a density of about 1 gram per cubic centimeter. The screw feed will be driven by an Autoclave Engineers MagneDrive unit providing a packless seal. A variable speed air motor will power the entire screw feed assembly.

Construction of the screw feed assembly will be as illustrated in Figure 1, and conform to the following specifications:

Inside Diameter:	.688"
Outside Diameter:	1" for the Body 2-1/4" at the Covers
Inside Length:	13"
Outside Length:	Less MagneDrive Unit - 15-1/2"
Total Outside Length:	28-1/4"
Design Pressure:	2200 PSI at 500°F.

MATERIALS

Body:	316 SS
End Cap:	316 SS
Couplings:	316 SS
MagneDrive Bearings:	Purebon
Screw Feed Bearings:	Purebon

The internal screw will be 300 series stainless steel. The screw feed body will be single wall construction designed to operate elastically at the test pressure.

CONNECTIONS

One (1) SF-562-CX 9/16" cone for coal/hydrogen inlet.

One (1) SW-250 connection for coal/hydrogen outlet to the reactor.

3. FEED NOZZLE

The feed nozzle is illustrated in Figure 1. The inside diameter of the nozzle will be .305", the OD at the sheath will be 3/4". Maximum outside diameter at the reactor cover will be 1". Total immersion length in the reactor will be 11". Total overall length will be 23". Water cooling will be via two (2) 1/2" copper tube connections in the nozzle and will extend to within 1/4" of the nozzle tip. The nozzle tip will be designed to minimize gas turbulance.

The nozzle will extend approximately 2" into the reaction chamber and will be designed for easy removal for cleaning.

The feed nozzle assembly will be constructed of 316 SS with a design pressure of 2,200 psi at 500°F. The water passage will be designed for 150 psi at 500°F at zero reactor pressure.

4. THE PRESSURE REACTOR ASSEMBLY

The special reactor assembly is illustrated in Figure 1.

VESSEL SPECIFICATIONS

Inside Diameter:	8-3/4"
Outside Diameter:	10" for the Body Shell 12-1/4" at the Flange Cover area.
Inside Length:	42"
Outside Length:	48"
Design Pressure:	2,200 psi at 500°F.

Reaction Chamber Dimensions

Inside Length:	24"
Inside Diameter:	1" (Inside the tangent points of the thermocouple wells.)

MATERIALS

Body:	SA-182-F316
Top Cover:	SA-182-F316
Bottom Cover:	SA-182-F316
Cap Screws:	SA-193-B16
Seals:	Viton "O"-Rings
Reaction Chamber Tube:	316 SS
Porous Disk:	316 SS
Cooling Jacket:	SA-240-316SS
Insulation Retainer:	Transite
Castable Insulation:	Aluminum Oxide

VESSEL DESIGN

The pressure vessel body will be of single wall construction designed to operate elastically at the test pressure. Careful attention will be paid to assure avoiding stress concentrations.

VESSEL CLOSURE

Both closures will consist of fully confined Viton "O"-Ring seals and utilize hex socket head cap screws assembled through the cover and threaded into the body flange.

CONNECTIONS

Top Cover

(one 1) feed nozzle connection.

Bottom Cover

One (1) 1/4" inert gas connection
One (1) 1/4" primary hydrogen connection.
Four (4) 3/8" thermocouple lead connections.
Five (5) tapered cone furnace electrode feed throughs.
One (1) 1" catch tube connection.
One (1) pressure monitoring connection - 1/4".

COOLING JACKET

Rating:	150 psi at 500°F at zero reactor pressure.
Inside Diameter:	11-3/4"
Outside Diameter:	12"
Inside Length:	40"

JACKET MATERIALS

The shell will be 316 Stainless Steel, and will be equipped with a copper coiled internal baffle.

JACKET CONNECTIONS

The cooling jacket will have inlet and outlet 3/4" copper tube.

INTERNAL ACCESSORIES

Thermowells

Twelve (12) 316 SS, 14/" x .180 by approximately 30" long thermocouple wells will be installed on a 1-5/16" bolt circle within the preheat tube.

Thermocouples

Twelve (12) Type "K" thermocouples made to length will be installed in the above thermowells.

EXTERNAL ACCESSORIES

One (1) special calibration thermocouple well (for insertion in the top of the reactor vessel in place of the feed nozzle) to be used to calibrate the reaction chamber thermocouples. Total length - 36". Immersion length - 32". The maximum outside diameter will be 3/4" at the connection; the sheath inside diameter will be 3/16". The sheath will be Inconel.

The removable bottom cover of the reactor vessel will permit removal of the furnace assembly for maintenance.

Please note, all connections into the reactor vessel assembly will be through this bottom cover with the exception of the feed nozzle. The 1" x 24" reaction chamber will consist of the 316 SS tube of sufficient size to be self supporting and avoid distortion at operating temperatures. The tube shall also support a porous disc of 316 SS at a level above the tip of the feed nozzle to promote uniform gas flow.

The reactor vessel will be separated into two pressure chambers, the reaction chamber and the furnace chamber. The reaction chamber pressure will be controlled by the pressure control valve and pressure controller as specified. The furnace chamber will be pressurized with nitrogen to within 7-1/2 psi. of the reaction chamber. Pressure balance will be maintained by the use of a differential pressure controller permitting the furnace chamber pressure to follow the reaction chamber pressure.

PRESSURE REACTOR FURNACE ASSEMBLY

The reactor vessel furnace assembly will be completely sealed from the reaction chamber by "O" rings. This isolation is necessary to protect the furnace elements from the coal dust and high temperature hydrogen atmosphere.

The furnace will consist of four separate zones with a total of 10 kilowatts at 220 volts, single phase, 60 cycles. The furnace will be designed for 1,000°C. operation at 1,500 psi. in a nitrogen atmosphere. The inside diameter of the furnace at the element is 2-1/2". The inside wall of the furnace will be constructed of Inconel with the following dimensions:

Inside Diameter:	2-1/16:
Outside Diameter:	2-1/2"
Overall Length:	40"

The top insulation is approximately 8-1/2" thick and consists of powdered alumina. The insulation surrounding the feed nozzle will be castable ceramic held in place by a transite retainer. The bottom insulation will consist of approximately 9" of powdered alumina held in place by transite retainer plates. The combination of internal insulation and external cooling jacket will permit the reactor vessel to operate within the design pressure and temperature limits.

5. CATCH TUBE ASSEMBLY

The catch tube assembly will collect solid material at the bottom of the reaction chamber. The inside diameter will be .305", and the outside diameter will be approximately 1". Water cooling will be via two 1/2" copper tube connections as illustrated in Figure 1.

Four (4) separate catch tubes of 38", 36", 32" and 28" lengths will be supplied and in combination with a scissors type lab jack will permit the nozzle to be continuously adjustable for a distance of at least 16". The total adjustable length will range from 4" to 20" between the feed nozzle tip and the catch tube tip. Interchange of the catch tubes will be possible within one hour and will not require disassembly or dismounting of the pressure reactor. The design also will position the catch tube centrally in the reaction chamber. The catch tube will be designed to operate at 2,200 psi. at 500°F. The water passage will be designed for 150 psi. at 500°F. at zero reaction pressure. Construction of the catch tube will be 316 SS.

6. CATCH POT

One (1) catch pot as illustrated in Figure 1.

VESSEL SPECIFICATIONS

Capacity:	Approximately 600 CC
Inside Diameter:	2-3/4"
Outside Diameter:	4-3/8"
Inside Length:	6-1/2"
Outside Length:	11-11/16"
Design Pressure:	2,200 psi. at 600°F

MATERIALS

Body:	SA-182-F316
Cover:	SA-182-F316
Closure Parts:	Bolts to be SA-193-B16
Closure Gasket:	316 SS

DESIGN

The pressure vessel body will be of single wall construction designed to operate elastically at the test pressure. Careful attention will be paid to assure avoiding stress concentrations.

CLOSURE

The pressure vessel closure will consist of a fully confined solid metallic gasket utilizing hex socket head cap screws assembled through the cover and threaded into the body flange.

CONNECTIONS

Cover

One (1) SW-375, 3/8" catch tube connection
Two (2) cooling coil connections.

Body

Flange Area: One (1) SW-250, 1/4" gas out/burn off connection.
Body Bottom: One (1) SF-250-CX, drain connection.

INTERNAL ACCESSORIES

One (1) basket type strainer, 316 SS to have a 500 CC capacity.
One (1) cooling coil of 316 SS tubing, which will act as a heat exchanger and will be installed below the inside face of the cover to maintain proper gas exit temperatures.

7. DRAIN POT

The drain pot is illustrated in Figure 1.

VESSEL SPECIFICATIONS

Capacity:	300 CC
Inside Diameter:	1-13/16"
Outside Diameter:	2-9/16" for the Body 4-1/8" at the Flange
Inside Length:	7"
Outside Length:	9-1/4"
Design Pressure:	2,200 psi. at 500°F.

MATERIALS

Body:	SA-182-F316
Cover:	SA-182-F316
Closure Parts:	Bolts to be SA-193-B16
Closure Gasket:	316 SS

DESIGN

The pressure vessel will be of single wall construction designed to operate elastically at the test pressure. Careful attention has been paid to assure avoiding stress concentrations. The inside will be contour to promote maximum drainage when valve SV5 is opened. The drain pot will be demountable for cleaning.

CLOSURE

The pressure vessel closure will consist of a fully confined solid metal gasket utilizing hex socket head cap screws assembled through the cover and threaded into the body flange.

CONNECTIONS

Cover

One (1) SF-250-CX, 1/4" cone liquid inlet connection.
One (1) SF-250-CX, 1/4" cone connection to the gauge protector and valve SV7.

Body

One (1) SW-375, 3/8" connection on the center lines for draining via valve SV-5.

8. THE CONTROL PANEL MODULE

The control panel module will contain all the necessary controls and devices not otherwise provided locally at the manifolds, compressors, or within the reactor frame. All components will be easily accessible for maintenance. Electrical components will be protected to prevent accidental shock. The top of the unit will be vented. No hydrogen containing parts will be mounted in the control panel. The control panel module shall mount all components shown with a horizontal line in the identifying circle on the flow diagram supplied with your inquiry except those pressurized with hydrogen. All panel mounted controls as indicated will be identified with appropriate labels and arranged in a logical, functional order. A suitable graphic flow diagram will be provided to present a clear interrelationship of the components. All controls and indicators will be located not lower than 2-1/2 Ft. or more than 6 Ft. from floor level. The general dimensions of the control panel module will be 6 Ft. high, 7 Ft. wide by 3 Ft. deep. The control panel module will arrive at the job site piped, wired and tested ready for interconnection. The inside will be painted white, the outside will be painted light grey.

9. REACTOR SUPPORT FRAME ASSEMBLY

One (1) special reactor frame assembly as illustrated in Figure 2 will be furnished to the following specifications:

Overall Length:	Vertically 10 Ft.
Overall Width:	4 Ft.
Overall Depth:	4 Ft.

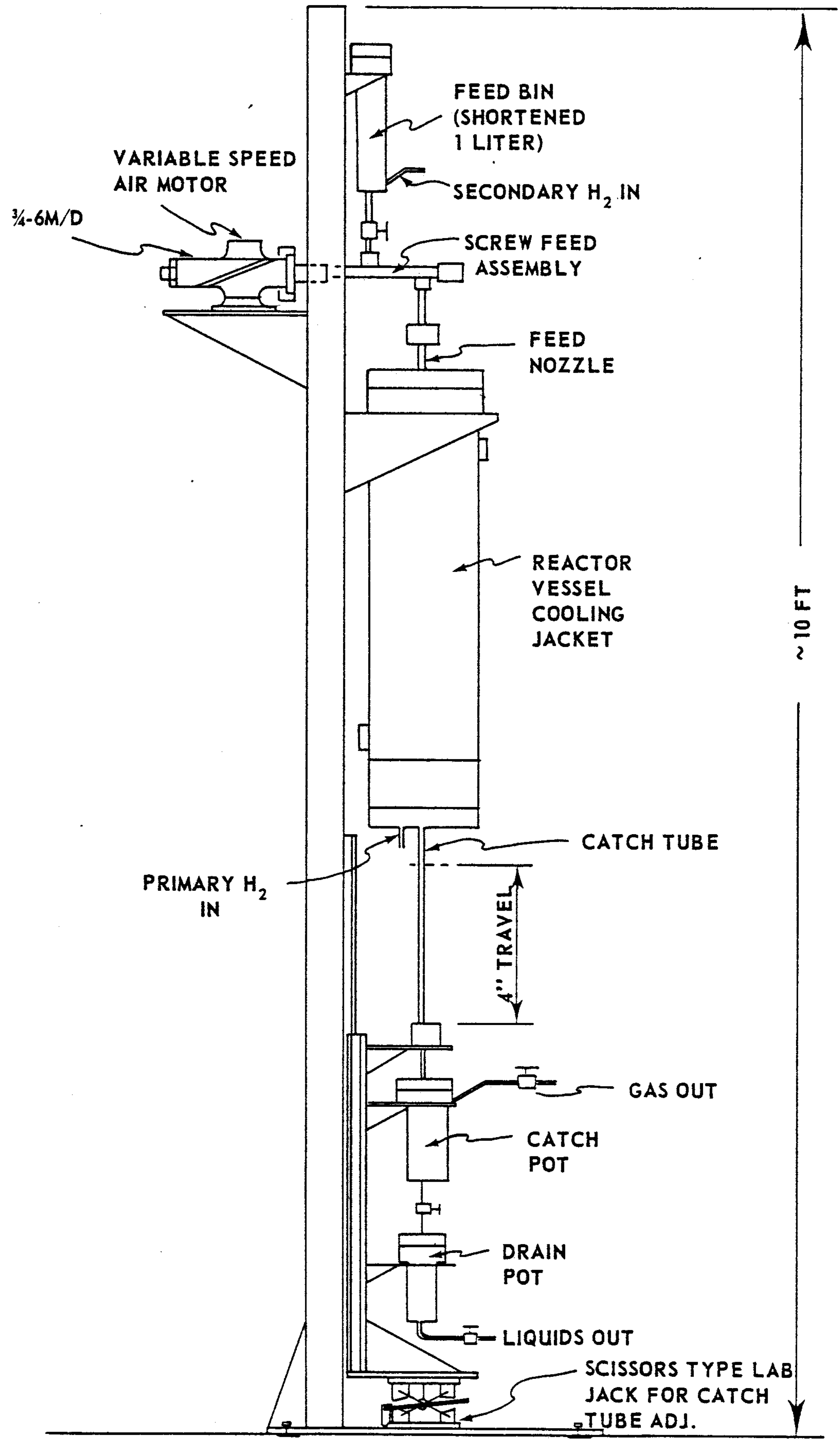

Figure 2. REACTOR SUPPORT FRAME ASSEMBLY

METHOD OF CONSTRUCTION

The reactor frame will be constructed of welded steel and furnished with a 4' x 4' base plate. It will support all the equipment shown on the attached drawing plus all the local valves, fittings, and tubing. The reactor base plate will be adjustable for leveling. The reactor frame assembly will incorporate a moveable sled to be used with the four replaceable catch tubes when the length of the catch tubes must be adjusted in the reaction chamber of the reactor vessel. The catch tube, catch pot, drain pot, and associated valves and fittings will be mounted on the sled which can then be raised via a scissors type laboratory jack. Also, mounted on this unit will be all other control components not otherwise contained in the control panel module or mounted locally as part of the compressor assembly. All control valves will be air operated.

10. THE HYDROGEN DIAPHRAGM COMPRESSOR

Autoclave Engineers will provide one (1) Corblin diaphragm compressor model AOCL-250 to the following specifications:

The compressor will be of two-stage design with a 0.9 SCFM capacity at 2,200 psi. output pressure and atmospheric suction pressure. Suction low limit and outlet upper limit pressure switches PS1 and PS2 will provide automatic operation. A manual stop/start switch and electrical components will be provided for operation at 220 volt AC. 60 cycles, single-phase service. Mounted locally on the compressor will be check valves, CV-1, and the pressure regulating valve PRV-1. The hydrogen supply tanks will be scavanged to low pressure by the Corblin compressor and stored at approximately 2,200 psi. maximum in the hydrogen accumulator tanks. This will provide sufficient head for the desired working pressures and flow rates. Autoclave Engineers will have to respectfully decline to include as part of this proposal the nitrogen supply tanks, the hydrogen accumulator tanks and the hydrogen supply tanks and their associated manifolds. These are lease items from Matheson Gas and other suppliers.

11. INSTRUMENTATION

The primary and secondary flow meters will be high pressure float, type flow meter with 2% scale accuracy and a working pressure of 2,500 psi. The materials of construction will be compatible with hydrogen and nitrogen at ambient temperature. The primary flow meter will have a maximum flow capability of 250-300 SCFH of hydrogen. The secondary flow meter will have maximum flow capacity approximately equal to the ratio of the secondary to primary flow areas times the maximum primary flow meter flow rate.

Autoclave Engineers will provide an Eagle Signal Model BR-499-A600 nitrogen purge timer. Nitrogen purge of the system will be manually initiated and run for an adjustable period of time from 0-2 hours as set on the timer. Hydrogen operation will be manually and separately initiated. A visual signal will indicate the end of the timed nitrogen purge cycle.

PRESSURE GAUGES PI-1 THRU PI-5

Autoclave Engineers will furnish five (5) 0-3,000 psi., 4-1/2" dial pressure gauges which have an accuracy or 1/2% of full scale with corrosion resistant internal elements and a blow out back. The dial will be graduated for 20 psi. per division.

FLAME ARRESTER

A flame arrester will be provided and installed in the gas exhaust line.

PRESSURE CONTROL AND RECORDING

The pressure recorder controller PCR will be a Foxboro Model 40R-A4. directly connected to the pressure line with 316 SS helical element. The range of this instrument will be 0-2,500 psi. with a Type 70 electric contacts for over pressure alarm signal. The output to the controller will be a 3-15 psi. pneumatic signal. This unit will be used in relation with the inert gas pressurizing of the furnace section during the purge cycle. The pressure recorder controller will monitor the pressure in the reactor and deviations from the set-point will cause a corrected air signal to adjust the air-operated proportioning control valve PCV to maintain the set pressure to within 1% or 10 psi., whichever, is greater between 500 and 1,500 psi. working pressure.

TEMPERATURE CONTROLLER

Four (4) solid state SCR proportioning temperature power control systems will provide individual zone control in the furnace by means of the connected zone thermocouples. Power to the heating elements is provided in a continuous variable manner to insure smooth temperature regulations. An upper temperature limit set point will provide sensing for unsafe conditions. The range will be 0-1,200°C., the thermocouples used with the above system will be Type "K".

TEMPERATURE RECORDER - TR

The temperature recorder will be a Leeds Northrup Speedomax W multi-point recorder. Scale range will be 0-1.200°C., and the calibration of the instrument will be Type "K". The unit will be equipped with a thermocouple break protection circuit in the upscale direction. The Leeds and Northrup flexlect B option permits any point to be printed separately and is included in the instrument. The total points capable of being recorded will be twelve (12). A high limit switch is also included as part of this recorder.

THERMOCOUPLES TP-1 THROUGH TP-12

The monitoring and control thermocouples used in the reaction vessel will be sheathed in either or Inconel or Stainless Steel depending on their function. The calibration for the thermocouples will be Type "K". All twelve (12) thermocouples will be equally spaced along the 24" inside length of the reaction chamber. This will include the eight (8) monitoring and four (4) control thermocouples.

12. COOLING WATER

Cooling water exit temperature will not exceed 180°F., with a maximum inlet pressure of 40 psi., at rated reactor operating temperature.

13. TUBING SIZE/CONNECTIONS/MATERIAL

Tubing for the gas flow will be 1/4" OD or larger 316 SS. Pressure connections to the system components will utilize Autoclave Engineers cone fitting for hydrogen gas or speed bite fittings for nitrogen gas. Adaption to other fittings will be kept to a minimum. The tubing and connection fittings will be rated for at least 2,500 psi. working pressure at the expected operating temperature. Air and water lines will be copper tubing of suitable capacity with brass compression fittings.

14. SAFETY ALARM SYSTEM

A. Sensors in the water cooling drain lines will detect low water flow rates and excess water temperature. Automatic shut off to the heating element through the safety power relay PR will occur during an unsafe situation actuating audible and visual alarms.

B. Over temperature conditions detected by the temperature recorder or temperature controllers will automatically shut off the heating element also through the power safety control relay PR and actuate audible and visual alarms. Over pressure conditions detected by the upper pressure limit switches, upper pressure limits in the pressure recorder controller and pressure switch PS3 will automatically shut off the gas flow via valve SV-2 and actuate audible and visual alarms.

Any of the above unsafe conditions will actuate a common solid state audible alarm, but separate indicators identify the specific unsafe conditions so appropriate corrective action quickly may be taken by the operator.

15. LEAK DETECTOR

Autoclave Engineers will furnish a portable Bacharach model SA-65A gas leak detector which will be safe in an explosive atmosphere.

16. VOLUMETRIC FLOW METER

A totalizing flow meter FI-3 will be provided to measure the effluent gas volume. The meter shall have a flow capacity of at least 250 SCFH and will have any accuracty of 1% or better. The unit will be suitable for hydrogen service.

17. POWER REQUIREMENTS

All electrical components within the system will operate on 110 or 220 volts, 60 cycle, single-phase AC service. Total power required is 15 Kw. maximum.

18. SAFETY BARRIER

The safety barrier surrounding the reactor frame portion of this proposal will be supplied by the customer. Autoclave Engineers recommends that the existing concrete facility be modified to accept the high pressure portion of this system. The reason being economy. The relationship of the physical plant with respect to the physical dimensions of the proposed equipment make it ncessary for Autoclave Engineers to respectfully decline to quote on the safety barrier at this time. Autoclave will, however, be pleased to act on a consultant basis when the specifications for the safety barrier have been generated. The capacity of the barrier chamber exhaust fan should be at least 300 CFM. All control switching inside the barrier will be designed intrinsically safe, 2 volts maximum at .1 ma.

Appendix C

Hydrogen Safety Modifications: Autoclave Engineers, Inc.

Proposal 44-3110-76F

The hydrogen safety modifications are described below.

(1) Automatic hydrogen overflow shut-off loop.

Consists of a thermal-flow meter with appropriate power supply, flow indicator and alarm relays in conjunction with one (1) Model SC-60720M air operated valve and associated solenoid valves. The primary hydrogen supply will be automatically shut down when an overflow condition arises. This condition will be visually and audibly indicated on the control panel. The loop can also be manually activated.

(2) Compression modification to permit outside installation will require the addition of an emersion heater and thermostat for the oil. The thermostat will control the heater based on the prevailing outside temperature such that proper oil operating temperatures are maintained.

(3) To permit the valve rack to be installed outside will necessitate the existing type 416 stainless steel collars and glands used on tubing connections to be replaced with those of type 316 stainless steel. Additionally, we will install heater tape and a thermostat for regulators and flow meters to assure they properly function at extreme low outside temperatures.

Appendix D

Specification and Design of High Pressure Gas Facility Addition to House Reactor System

The Pennsylvania State University has approved the construction of an addition to its present High Pressure Gas Facility in which to house the pressurized isothermal reactor. It is being constructed along with an addition to serve the needs of the Department of Mechanical Engineering in its research on solid propellents. Each structure will be built on concrete slab, and will house test cells designed to withstand blast forces while venting accidental blasts into an earthen embarkment.

The test cell housing the reactor assembly will be heavily reinforced cast concrete. Eighteen-inch thick walls will extend to a clear height of twenty feet to accommodate the assembly. The entire height of the external wall will be constructed of three-inch thick styrofoam designed to blow off under a differential pressure of less than one psi, providing for the reduction of reflected shock waves and explosive gas concentrations, and their adverse effects in the event of a following vapor phase explosion. Otherwise, the test cell will be tightly sealed to prevent hydrogen leakage into other internal spaces. The blow-out wall will be protected against weather and release due to wind by a roll-type garage door operated remotely from the console location. Electrical service to the test cell will be restricted to explosive-atmosphere-safe lighting and control devices, intrinsically safe low voltage devices and sensors, and to an -epoxy packed power supply to the reactor heating windings.

Service involving dissassembly of the reactor will be enabled by a chain hoist which will travel on a carriage rail. The carriage rail itself will travel on a pair of crain rails, providing access to all corners of the cell.

A covered mechanical area provides for storage of argon and hydrogen source and accumulator bottles, a valve rack and a compressor and heater rack. This area will be protected from the elements by metal louvers which will permit free air exchange. Special equipment features will permit operation at below-freezing temperatures.

The remaining structure will be constructed of eight-inch concrete block to house a work area, the control console and analytical facilities.