GASIFICATION IN PULVERIZED COAL FLAMES

Third Quarterly Progress Report

January - March 1976

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ABSTRACT

This project is concerned with the production of power and synthesis gases from pulverized coal via suspension gasification. A literature review of high temperature probes has been completed and a survey concerning confined jet gasification is continuing. Final designs for the vortex gasifier and gas sampling probe are nearing completion. Coal handling facilities are being constructed and test cell design is continuing. Most of the test cell equipment has been ordered and the mass spectrometer has been received.

I. OBJECTIVE AND SCOPE OF WORK

The objective of this program is to investigate the feasibility of using currently available pulverized coal burners to produce power or synthesis gas from coal. Two configurations will be considered: (1) the annular confined jet with secondary swirl, and (2) the vortex tube with tangential entry. The first burner is characterized by a single axial injector of high primary velocity; secondary swirl is used to control mixing and residence times. The second burner is modeled after the cyclone combustor; large residence times and slagging operation should lead to high carbon efficiencies.

In both burners, coal combustion with air and/or air-oxygen mixtures supports the endothermic gasification reactions. The burners are designed such that axially injected, preheated steam is surrounded by swirling air, thus promoting efficient gasification. Pulverized coal is carried by primary steam in the confined jet system, and by secondary air in the vortex gasifier.

Species concentrations and temperature are measured both within and downstream of the gasifier chambers. These profiles are used to assess the influence of process variables such as pressure, solid/gas feed rates, swirl intensity, inlet temperature and geometrical injection pattern on both the rate and extent of coal conversion. Simple models governing entrained flow systems will be developed to further interpret the experimental data.

II. SUMMARY OF PROGRESS

Most of the test cell equipment has been ordered with the only major outstanding items being the air heaters and steam superheater. A revised flow diagram has been developed. The coal handling facility is ready for partial use. Only screening and pulverizing are now possible. Size grading, crushing, and weighing operations will be available shortly.

Vortex gasifier design has reached the materials selection stage but design of a containment vessel for 300 psig (20 atm) continues

to be a problem. Design of the jet gasifier has not begun but the literature search is underway.

The mass spectrometer has been received and tested, and a sampling probe has been developed. The sampling system has been designed incorporating the proposed probe and the necessary filtration to insure a clean representative sample for the mass spectrometer inlet.

III. TECHNICAL PROGRESS

The vortex gasifier is presently in the final refinement stage; acquisition of materials and construction will begin soon. All material for the coal handling facility has been received and the facility is operational on a limited basis. Most of the material for the test cell is on hand or has been ordered. Full time construction work on the cell will begin in May. The mass spectrometer has been received and operationally tested. Gas sampling system and probe design is nearly complete with construction of the probe to begin shortly.

Vortex Gasifier Design

Recent progress on gasifier design has centered around reactor sizing. The principle design constraints are a length/diameter ratio of 1.5 and a coal feed range of 4 to 40 lbm coal per hour. The 1.5 length/diameter ratio, recommended in the literature, is aerodynamically optimum. The coal feed range reflects our desire to operate the gasifier on a bench scale level; however, the Vibra-Screw feeder is able to operate at higher or lower feed rates via changes in the feed screw and tube assembly.

Within these two constraints, we wish to optimize the surface and volumetric heat release rates, particle residence time, and the ratio of chamber diameter to sampling probe diameter. With the chamber length/diameter ratio and coal feed rate held fixed, choice of chamber diameter specifies the surface and volumetric heat release rates. A 6 inch diameter chamber will allow an operating range having surface and volumetric

heat releases within an order of magnitude of both full scale and experimental gasifiers. The gas residence time of this chamber will be rather short compared to other gasifiers; however, it is the particulate residence time, not gas residence time, which is significant. Particulate residence time will be lengthened considerably by swirling the flow. By maximizing the ratio of chamber diameter to sampling probe diameter, flow disturbance can be minimized. We have designed a 1/4 inch diameter probe to meet our requirements.

Use of a rammable plastic refractory as a chamber wall material seems favorable. Its high temperature integrity and resistance to slag are attractive. A cylindrical resistance heating element will probably be used to minimize wall heat losses. A 1 foot diameter heater, the largest stocked by Electro-Applications, Inc., would enclose both the refractory wall (with the recommended minimum wall thickness of 3 inches) and a 6 inch diameter reaction chamber.

Pressure containment at 10-20 atmospheres is influenced by opposed effects: (1) material strength at the high temperatures characteristic of small containment diameters and (2) pressure vessel weight at larger diameters. Heat transfer calculations indicate an outside wall temperature of 600°K for a 24 inch diameter pressure vessel during combustion. For these conditions, the pressure vessel can be fabricated from ordinary carbon steel. Smaller diameter vessels will require expensive alloy materials.

Various calculations have been made for reaction chambers with diameters ranging from 5 to 8 inches. The 6 inch diameter chamber appears attractive from both operating and design aspects.

Coal Handling Facility

All equipment for the coal handling facility has been received. Single phase (120 vac) and three phase (240 vac) power have been wired into the cell to operate the coal processing equipment. Compressed air is also available. A six foot square hood has been placed over the

processing area and connected to the vent fan to insure adequate removal of any dust that may be generated. Pulverizing and screening coal is now possible; work continues to incorporate the crushing, size grading and weighing operations.

Temporary storage barrels for coal and char have been obtained and one drum each of West Virginia coal and coke are presently on hand. Indiana coal is available from the Purdue Power Plant.

Test Cell

As noted in Table I, most of the major equipment for the test cell has been ordered or is available from existing stock. A revised flow diagram has been developed as shown in Figure 1. The new diagram incorporates more detail than the previous diagram and includes the nitrogen purge and ignition systems. Work is underway to complete an electrical diagram and to arrange for installing three phase power in the cell. Three phase power will be required to operate the boiler, steam heater, both air heaters, and the reactor heaters.

The only major outstanding items for the reactor support system are the air and steam heaters. The steam and primary air heaters will be constructed here using "clamshell" heaters over tubing. We expect to purchase a circulation heater for secondary air with final heating of the air accomplished by a combination of regenerative type heating and additional electrical heating with "clamshell" type heaters.

Half inch stainless steel tubing will be used for the steam and secondary air lines (up to the heater) and quarter inch stainless steel will be used for the primary air up to the feeder. One inch stainless steel pipe will be used for secondary air downstream of the heater, and 3/8" tubing will be used for coal transport.

Full time construction work will begin in May. Most equipment should be on hand by that time, and we hope to complete the air, nitrogen, and ignition systems by the end of August. This would include wiring and instrumentation.

TABLE I
EQUIPMENT STATUS

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
AIR SUPPLY SYSTEM, GENERAL			
ASV - High pressure air shut-off valve, located outside cell	Valve in place		On hand
Air filter	Balston 95S	\$ 78.00	Received
AR-1 - Air regulator	Regulator in place		On hand
SV-M - Safety valve	400 psig set press safety valve (Kunkle fig. 264)	\$ 104.63	Ordered
P6 - Pressure gage	1500 psig gage		On hand
AIR SUPPLY SYSTEM, PRIMARY AIR			
PA1 - Manual shut-off	600 psig globe valve		On hand
PAC - Control valve	Remotely loaded air control valve		On hand
PAE - Remote shut-off valve	ASCO solenoid valve, 8228A65 (1/4" pipe fittings)	\$ 61.50	Ordered
PAFM - Flowmeter	Thermal Instruments Co. Model 60	\$1300.00	Ordered
Air heater	Heat P.A. to 300°F		Bids requested

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
PA-2 - Manual shut-off	1/4" high temperature valve		On hand
CV2 - Check valve	Autoclave 1/4" AE speedbite SW Cat. No. SWB 8800	\$ 38.00	Ordered
Feeder	Vibra-Screw live bin feeder	\$2600.00	Received
AIR SUPPLY SYSTEM, SECONDARY AIR			
CV1 - Check valve	Positive shut-off, spring loaded check valve		On hand
SA1 - Manual shut-off	10,000 psig valve		On hand
SAC - Control valve	Remotely loaded air control valve		On hand
SAE - Remote shut-off	Magnetrol solenoid valve 1/2" (E33A62)	\$ 107.00	Received
SAFM - Flowmeter	Thermal Instrument Co. Model 60	\$1300.00	Ordered
Air heater	Heater capable of 1200°F at 400 lbm/hr & 800° at 550 lbm/hr		Bids requested
AIR SUPPLY SYSTEM, CONTROL AIR SUPPLY			
CA1 - Shut-off valve	1/8" valve		On hand
CAR-1 - Control air regulator for steam system pneumatic valves	150 psi outlet pressure regu- lator		On hand

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
CAL-1 - Control air loader for primary air control valve	350 psig outlet/400 psig inlet small volume regulator		On hand
CAL-2 - Control air loader for secondary air control valve	Same as CAL-1		On hand
CAL-3 - Loader for SE-1	Regulator in place		On hand
CAL-4 - Loader for SE-2			
P1 - Pressure gage	400 psig gage		On hand
P2 - Pressure gage	400 psig gage		On hand
P3 - Pressure gage	100 psig gage		On hand
P4 - Pressure gage	100 psig gage		On hand
CAT - Control air trip valve	Four way solenoid valve		On hand
P-5 - Pressure gage for supply to steam valve regulators	150 psig gage		On hand

STEAM SUPPLY SYSTEM

Boiler	Coates Electric Boiler (Neal Engr.)	\$3210.00	Ordered
SE-1 - Shut-off/control valve	Autoclave Engr. 6V71B8-OL with air to open operator	\$ 150.00	Ordered
SE-1T - Electric emergency trip for SE-1	Asco 3 way solenoid valve, NC operation (Cat. No. 8320A132)	\$ 25.00	Ordered

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
SE-2 - Shut-off/control valve	Autoclave Engr. 6V1B8HT-OL with high temp. packing and air to open operator	\$ 260.00	Ordered
SE-2T - Electric emergency trip for SE-2	Asco 3 way solenoid valve, NC operation (Cat. No. 8320A132)	\$ 25.00	Ordered
SD-1 - Steam remote operated drain valve	Autoclave Engineers. 6V71B4 CL with air to close operator	\$ 110.00	Ordered
SD-1P - Pilot valve for SD-1	Asco 3 way solenoid valve, NC operation (Cat. No. 8320A132)	\$ 25.00	Ordered
SD-2P - Pilot valve for SD-2		\$ 25.00	Ordered
SD-2 - Remote operated steam drain valve	Autoclave Engr. 6V71B8 HT CL with air to close operator and high temp. packing	\$ 200.00	Ordered
Steam superheater	Heater to heat steam from saturation to 1000°F (540°C)		Bids requested
S-1 - Gasifier selection valve	1/4" high temperature valve		On hand
S-2 - Gasifier selection valve	Same as S-1		On hand
CV-3 - Check valve	Autoclave Engr. 1/2" AE Speed-bite SW Cat. No. SWB8800	\$ 42.00	Ordered
SFM - Flowmeter	Thermal Instrument Co. Model 60	\$1400.00	Ordered
WATER FEED SYSTEM			
Feedwater tank	Large tank in existing stock; will need 600 psig hydrostatic test		On hand

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
WF-1 - Manual shut-off valve	600 psig 1/4" or 1/8" valve		On hand
WFF - Fill valve	1/2" 600 psig valve		On hand
WFD - Drain valve	600 psig 1/4" or 1/8" valve		On hand
WF-2 - Feedwater manual shut-off	600 psig 1/4" valve		On hand
WV - Vent valve	600 psig 1/4" valve		On hand
NITROGEN SYSTEM			
NR-1 - Nitrogen regulator for purge system	3000/500 psig regulator		On hand
N-2 - Purging solenoid valve	2 way high pressure solenoid valve		
N-4 - Purging solenoid valve	2 way high pressure solenoid valve		
NR-3 - Boiler nitrogen cap regulator	500/5 psig regulator		On hand
BN-1 - Boiler nitrogen cap shutoff	600 psig @ 500°F 1/4" or 1/8" valve		On hand
P7 - Purge N ₂ pressure	400 psig gage		
P8 - Boiler N ₂ cap pressure	30 psig gage		On hand

<u>Location and Use</u>	<u>Description of Equipment</u>	<u>Cost</u>	<u>Comments</u>
MISCELLANEOUS			
Steam blowdown tank (BD tank)	4" (approx) diameter tank for separation of water from steam before vent; construct from scrap		Materials on hand
IGNITION SYSTEM			
IGR-1 - Ignition gas regulator	Manually set regulator (3000 psig inlet, 300 psig outlet)		
IGE - Ignition gas remote shut-off valve	1/4" tubing solenoid valve with 1/16" orifice		On hand
IAE - Ignition air remote shut-off valve	Same as IGE		On hand
IAR-2 - Ignition air regulator	Manually set regulator (400 psig inlet, 300 psig outlet)		On hand
IA-1 - Ignition air shut-off valve	600 psig valve for 1/4" tubing		On hand
P9 - Ignition gas pressure	400 psig gage		
P10 - Ignition air pressure	400 psig gage

Figure 1. Test Cell Schematic

Gas Sampling System

Our gasification program is characterized by a unique feature; we will attempt to measure gas-phase composition and temperature not only at the exhaust, but also within each gasifier. Due to the presence of particulates, these measurements will not be straightforward. However, the measurements can be made by an appropriately designed mass spectrometer-probe system.

1. Mass Spectrometer

The complete UTI Q-30C quadrupole mass spectrometer system has been delivered. A UTI (UTHE Technology International) representative inspected the system and found it to be in working order. The representative demonstrated the use and maintenance of the Q-30C, and clarified the written instructions. UTI will send another representative within six months to give advice on calibration and adaptation of the mass spectrometer for specific use in coal gasification experiments.

2. Sample Inlet System

A preliminary design of the sample inlet system is shown in Figure 2a. The sample gas is pulled through the probe into the water-cooled stainless steel section where the chemical reactions are quenched (Chedaille and Braud, 1972). A cyclone and filter serve to remove particulates from the sample gas, as particles may damage the mass spectrometer. A Universal Oil Products 1/2 inch cyclone and a Balston 95A filter will be used, which together are capable of removing all particles greater than 0.6 microns in diameter and most of the smaller particles. The vacuum pump will pull the sample to the mass spectrometer and can also be used to regulate the sample gas flowrate and pressure at the mass spectrometer inlet. Wherever possible, the inlet lines will be teflon tubing in order to reduce water adsorption, catalytic reactions, and adherence of tars and solids (Fuchs et al., 1974). Heated inlet lines will be used to control the temperature of the gas entering the mass spectrometer and to avoid water condensation.

Figure 2a. Sample Inlet Schematic

Figure 2b. Probe Schematic

3. Probe

A preliminary design for a sonic pyrometer type probe is near completion. This design attempts to achieve simultaneous temperature and concentration measurements, with consideration for high operating temperatures, particulate intake reduction, and ease of calibration (Figure 2b).

The sonic pyrometer consists of a bare thermocouple centered in a nozzle at a point where the gas is at sonic velocity. Our particular nozzle design will allow some gas flow around the nozzle portion in spaced ducts, such that the nozzle is heated and acts as a radiation shield (Figure 2b). The proportionality factor between the thermocouple reading and the actual gas temperature has been found to depend only on the probe configuration, and the heat capacity ratio of the sample gas (Chedaille and Braud, 1972). No corrections for radiation or conduction are needed and calibration can be done in low temperature air (Terbush, 1958).

Design considerations were also given to high sampling temperatures and particulate fouling. Temperatures as high as 1800°K may be encountered and a refractory material must be used. Boron nitride was chosen for the uncooled portion of the probe (excluding the thermocouple) due to its machinability and good thermal properties. Particles can be reduced by sampling normal to the free-stream flow (Figure 2b). This method is not effective in swirling flows, however, and consideration is being given to an inlet filter made from zirconia fibers.

IV. WORK FORECAST

During the next three months we expect to accomplish the following:

- 1) Continue the literature search concerning the confined jet gasifier system
- 2) Complete the coal handling facility
- 3) Complete electrical design and begin construction of the test cell

- 4) Design calibration system for the mass spectrometer
- 5) Finalize design and begin construction of the gas sampling probe
- 6) Order material and begin construction of the vortex gasifier.

V. RESULTS AND CONCLUSIONS

During the past quarter, we have been concerned with the design of hardware for testing the gasification processes proposed. As mentioned previously, we have received and tested the mass spectrometer, nearly finalized design of the vortex gasifier, improved the test cell schematic and ordered most of the equipment. We have also designed a probe and sampling system.

VI. REFERENCES

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