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GASIFICATION IN PULVERIZED COAL FLAMES

Second Quarterly Progress Report
October - December 1975

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School of Mechanical Engineering
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Energy Research and Development Administration
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16. Abstracts <p>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.</p> <p>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.</p>					
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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 concerning the vortex type gasifier has been completed and a survey concerning the confined jet gasifier is underway. Preliminary design of the vortex gasifier is nearing completion. Test cell and coal handling facilities are in the final stages of design and coal handling equipment has been received. A mass spectrometer has been ordered and a preliminary survey of high temperature probes is complete.

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

The literature search concerning the vortex gasifier has been virtually completed and the search concerning the confined jet is underway. Initial design of the vortex gasifier (based on information derived from the literature search) is nearly complete.

Test cell design has reached the equipment selection stage and all equipment will be ordered within the next month. All equipment for the coal handling facility has been received with the exception of the coal crusher. A review of probing methods suitable

for high temperature, particle laden gas applications has been completed. The mass spectrometer has been ordered and delivery is expected in March.

III. TECHNICAL PROGRESS

Most of the material ordered for the coal handling facility has been received and equipment selection for the test cell is underway. A literature search concerning the vortex gasifier has been completed and a search concerning the confined jet is in progress. An initial investigation of high temperature probes for sampling in dust laden mediums has been completed. The mass spectrometer has been ordered.

Preliminary Vortex Gasifier Design

A preliminary vortex gasifier design is being developed as a result of the literature survey. A summary of this survey is included in Appendix A; the original version will appear in the First Annual Report. The reaction chamber (Figure 1) will be approximately 7 inches in diameter and 12 inches high. These dimensions should promote mixing, yet assure low flow disturbance by internal probing.

The pulverized coal/air mixture will enter through four equally spaced tangential nozzles in the upper portion of the chamber. Coal flow rates of 5 to 40 lbm/hr are planned. Steam for gasification will be injected to the core of the chamber from the bottom. We propose that this separate injection of fuel/air and steam, coupled with vortex flow characteristics, will establish two zones of reaction within a single reactor stage: exothermic combustion reactions in the annular zone and endothermic gasification reactions in the core.

Selection of the chamber wall material is constrained by the need for (1) strength and high temperature integrity at 1775⁰K, and (2) resistance to attack by slag and by both oxidizing and reducing environments. The material best suited to these needs seems to be a ramable plastic refractory. A wall thickness of at least 3 inches has been recommended for this material. Price and shipping

Figure 1. Vortex Gasifier Schematic

information have been obtained from two manufacturers.

An external heating element will be used to minimize wall heat losses. This is necessitated by the relatively large surface to volume ratio of this reactor. Semi-cylindrical or quarter-cylindrical electrical heating elements, available from several companies, will probably meet our needs.

Since gasification at 10-20 atmospheres is ultimately planned, provisions for pressure containment are being investigated. The pressure vessel must be of large enough diameter (30-36 inches) to enclose a sufficient amount of insulation, in addition to the reaction chamber and heater. Fabrication at university facilities is likely.

Although only exhaust sampling will be conducted initially, methods for internal probing are being considered. A torch ignitor will also be required. Location of this equipment has not been finalized; however, entry through the chamber roof on either side of the throat is a definite possibility.

The major aspects of this design are the symmetric reactant inlet arrangement, the separate combustion and gasification zones promoted by independent steam injection, pressure gasification, operation under slagging conditions, and the use of air with no oxygen enrichment. While several of these features have been previously employed by others, to the best of our knowledge no one has ever incorporated all of them in a single design.

Coal Handling Facility

All equipment except the crusher has been received. An explosion-proof cell equipped with an exhaust fan for positive ventilation has been selected for housing the facility. Initial clean-up of the cell has been completed; it is now ready for design and installation of electrical power and air supply. The cell is equipped with a remotely operated (water) fire extinguishing system. The cell design will allow for safe storage of processed and unprocessed coal as well as the processing equipment. A hood attached to the

exhaust fan will insure removal of all coal dust from the pulverizing and screening processes. Filtering of the effluent air will be provided to insure minimum coal dust discharge.

The equipment received includes a Gilson screen shaker, screens sized from #70 to #400, and a Holmes #500 Pulverizer. A Holmes #201 coal crusher is on order. Work will commence on detailed design of the electrical supply system and cell layout shortly. Completion of the cell is expected by June.

Test Cell

A complete flow schematic has been developed for the cell which will allow common use of flow control and measuring equipment by both gasifiers (Figure 2). The schematic has been approved by a member of the Purdue Safety Committee. Equipment selection based on the schematic is now in progress.

The flow system design will allow operation up to 20 atmospheres and provides for transporting coal by either steam or air. Flow rates are sufficient for combustion or gasification up to 40 lbm coal/hr. The primary air system will deliver 70 lbm air/hr, the secondary air system will deliver 600 lbm air/hr, and the steam system will deliver 60 lbm steam/hr.

We had anticipated that some portions of the previous air system in the cell could be used. Closer inspection revealed that it would not be adequate for proper control and safety. The existing control room pneumatic loaders and tubing can be used for low pressure operation; however, they will have to be replaced before high pressure operation.

All tubing in the test cell will be stainless steel. Valves and fittings will be selected for safe operation at 450 psig and maximum expected temperatures. The cell will be arranged so that the position of the manual valves used for selecting which gasifier system is in operation can be determined from the control room. If possible, remotely operated shutoff valves will be placed so that their status can also be determined visually from the control room.

Figure 2. Gasification Cell Flow Schematic

All manually operated shut-off valves, including those handling high temperature air and steam are available from valve stocks in the Mechanical Engineering Department. Selection of remotely operated shutoff valves for the air system has been made and these will be ordered shortly. The remotely operated valves for steam service have not been selected yet due to the difficulty of finding economical valves capable of operating at high temperatures.

Since the flow measurement system must measure steam at high temperatures, selection of metering devices has proceeded rather slowly. The steam supply will include a feedwater system actuated by a low-water solenoid valve. The flow of water will be intermittent, and measurement of feedwater instead of steam is not possible. Accurate measurement of saturated steam is also impossible since the quality cannot be accurately determined. The steam measurement must therefore take place downstream of the heater; the measuring device must then operate at temperatures in excess of 800°K .

It is highly desirable to have the flow measurements provide a direct mass flow readout. This eliminates the necessity and inaccuracy of temperature and pressure measurement and correction. In addition, selected steady flow conditions can be achieved more easily since mass flow can be read directly and adjustments made to control valves without lengthy correction calculations. Flow measurement equipment selection is proceeding along these lines, and final selection and ordering are anticipated shortly.

Selection of the boiler for the steam supply system is almost complete. Quotes have been received from four manufacturers for an electrical boiler operating at 350 psig and supplying 60 lbm/hr of saturated steam. The most economical appears to be a Coates Electric resistance heated type boiler manufactured by CAM Industries, Inc. The feedwater system will consist of a pump and feedwater heater. The feedwater will probably not require heating for low pressure operation, so design of this heater will be deferred until the remainder of the system is complete. It was originally assumed that the feedwater pump would be quoted with the boiler. This did not

happen, so feedwater pump selection is just beginning.

High temperature heaters will be required for both the steam and air systems. These heaters will be designed to heat the air and steam to 800⁰K at maximum flow rates. They will be electrically heated and controlled by pyrotrollers. Detailed design is presently underway.

A Vibra Screw feeder has been received for use at low pressure. The feeder will have to be modified for high pressure operation. A high-pressure feeder design supplied by J. Mima of ERDA-Pittsburgh is also a possibility. Either design will be compatible with the cell flow system; the high-pressure feeder will be constructed after successful operation at low pressures.

The design of the control console and electrical/pneumatic remote control system has not been finalized, pending completion of equipment selection for the test cell flow system. The design will incorporate all flow and input condition controls on a single console with measurement functions on a separate control panel. Monitoring of flows and temperature will be by chart recorder. Four chart recorders, including one 16 point recorder, are available. Pressure measurements will be made either directly from gages or through the chart recorders.

All controls will be designed for fail safe operation, and the system will allow orderly or emergency shutdown of all cell components from the control room. Actuation of both a water and a CO₂ fire extinguishing system will be possible from the control console.

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

Based on extensive consultation with seven leading manufacturers of mass spectrometers, we recently ordered a UTI Q-30C precision quadrupole mass spectrometer system from UTHE Technology International, Sunnyvale, California. A delivery date of March 15, 1976, is anticipated thus providing sufficient time for us to become familiar with the instrument.

Only the Q-30C system meets all of the program requirements for a mass spectrometer:

- (1) mobility (ion pump)
- (2) integrated storage oscilloscope and recorder
- (3) automatic scan function and bakeout.
- (4) rapid response, high pressure inlet system
- (5) flexibility
- (6) heated inlet system.

In addition, only UTI expressed a willingness to help integrate their mass spectrometer system to our probe/gasifier assembly.

Initial experiments by Dr. Bruce Raby of UTI confirm that the Q-30C system can easily resolve a gas mixture similar to that expected during coal gasification (5.85% CO_2 , 3.94% CO , 7.91% H_2 , 2.06% CH_4). Multiple least squares analysis can be used to calculate species concentrations (CH_4 , CO , CO_2 , H_2 , O_2 , N_2 , H_2O) with an expected accuracy of 2-5% (Damoth and Montgomery, 1972; Singh, 1970; Fuchs et al., 1974). Use of a Faraday cup, rather than the electron multiplier, will enhance response linearity. Direct measurement of H_2O concentration presents no problem with the heated inlet system. Hydrogen measurements are feasible (even with an ion pump) for $[\text{H}_2] < 15\text{-}25\%$. Distinguishing CO from N_2 is achievable for $\text{CO}/\text{N}_2 > 0.01$ (Damoth and Montgomery, 1972; Singh, 1970).

The UTI Q-30C mass spectrometer is designed as a total system. A vacuum module, display and control module, and quadrupole mass analyzer (UTI 100C) are included. Signal voltages are obtained by a combination Faraday cup/electron multiplier. The inlet system is capable of continuously monitoring a gas stream at 5-20 psia

(response time-250 millisec). The entire mass range can be scanned in as little as 75 millisec. The mass range is 1-300 AMU, with an ultimate sensitivity of 100 ppb.

2. Probe Design

Measurement of both temperature and concentration usually requires separate probes; for example, a bare or radiation shielded thermocouple and a water or steam cooled sampling probe. A bare thermocouple is adequate if the chamber walls are heated. Gas sampling probes may be sonic or isokinetic in nature. These techniques are adequate but cumbersome; hence, we are investigating the possibility of simultaneous measurement of temperature and gas phase concentrations via a single probe.

Three techniques are suitable for simultaneous measurement of temperature and species concentration in particle-laden flows: (1) sonic pyrometer (2) suction pyrometer and (3) pneumatic pyrometer (Chedaille and Braud, 1972). Ease of construction and calibration favor the sonic and suction pyrometers. Both methods operate by promoting high heat transfer rates between the gas and a bare thermocouple placed inside the probe (Chedaille and Braud, 1972). The sonic pyrometer is uncooled, while the suction pyrometer is generally water-cooled; hence, calibration is more difficult for the suction pyrometer. However, the latter has been used successfully in pulverized coal flames. Sonic probes are fabricated from mullite or alumina; thermal cracking must be avoided.

Successful operation in particle-laden flows is mostly a result of proper orientation and design of the probe inlet (Chadaille and Braud, 1972). Recently, Fuchs et al. (1974) achieved good results in a high pressure fluidized bed gasifier by welding stainless steel wire mesh to the probe tip. Such design considerations will be analyzed in greater detail during the next six months. At present we are leaning towards the suction pyrometer, with a filtered inlet located along the probe circumference.

A sampling line must be used to connect the probe to the

mass spectrometer inlet. This line should obviously be as short as possible. In addition, it must be heated to avoid water condensation (Fuchs et al., 1974). At high pressures, a porous flow restrictor may be required for successful mating with the Q-30C inlet module (Fuchs et al., 1974). Teflon rather than stainless steel should be used to (1) minimize adsorption of polar species such as water (Fristrom, 1975), (2) minimize catalytic reactions and (3) minimize adherence of tars and solids.

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 coal handling facility design and begin construction.
- (3) Complete design and equipment selection for the test cell and begin construction.
- (4) Finalize the design of the steam and air heaters for the test cell and have them constructed by the Mechanical Engineering shops.
- (5) Finalize design and begin construction of the vortex gasifier.

V. RESULTS AND CONCLUSIONS

The major results achieved during the past quarter are the following:

- (1) completion of the vortex gasifier literature survey
- (2) preliminary design of the vortex gasifier
- (3) development of the test cell flow scheme
- (4) preparation of coal handling facility
- (5) selection of mass spectrometer system.

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VII. APPENDIX A: SUMMARY OF VORTEX GASIFIER LITERATURE SURVEY

Introduction

A cyclone reaction system generally consists of a cylindrical chamber into which air or oxygen is tangentially injected. Fuel is introduced to the system either axially or tangentially, with reaction primarily occurring inside the chamber. The products of reaction leave the chamber through a centrally located exit hole at either end. Obviously, design specifics vary according to intended use.

The two main advantages offered by cyclone reaction are a high degree of turbulence and a lengthy residence time for the fuel/air mixture. However, the complex processes taking place within the cyclone chamber are as yet not fully understood. Predictions of aerodynamic behavior within cyclones are usually based on either crude models or empiricism.

The objectives of this literature review are twofold:

- (1) to investigate flow properties of a cyclone
- (2) to investigate the performance of pulverized coal gasification within a cyclone.

Fluid Dynamics of Cyclone and Vortex Flows

1. Flow Modeling

Cyclone and vortex flow modeling discussions may be conveniently separated into two parts: (1) flow in the radial plane, in which tangential and radial velocities are considered, and (2) flow in the longitudinal plane, in which axial velocities and flow reversals are considered. A vortex may be described as a fluid motion in which the streamlines are concentric circles (Daily and Harleman, 1966). As will be seen, a cyclone flow is more accurately characterized by streamlines which spiral radially inward.

The most prevalent flow model assumes a tangential velocity profile of Rankine form. In this model, the flow near the wall of the chamber is assumed to be a potential or free vortex flow in which angular momentum is always conserved. The tangential velocity is

inversely proportional to chamber radius. In the core of the chamber, the flow is a rotational or forced vortex flow in which tangential velocity is directly proportional to chamber radius. Perry et al. (1950), Agrest (1965), Roschke (1966b), Ustimenko and Bukhman (1968), Schmidt (1970), and Dahmen and Syred (1975) have all cited part or all of this model. In addition, most of these investigations have indicated the existence of axial flow reversals. These are affected by the relative locations of chamber entries and exits, by chamber endwall boundary layers (Schmidt, 1970), and by chamber length/diameter ratio (Roschke, 1966a).

According to Schmidt (1970), particles introduced tangentially at the vortex sink of the flow travel in a cyclic path (Figure 3). First they move to the center of the vortex and from there upward along the vortex filament (spout) at the axis. Centrifugal force moves particles outward from the spout to the potential flow, which runs toward the chamber bottom where the cycle starts anew. Heavier particles, which have a greater centrifugal force applied to them, are moved back to the potential flow sooner than finer particles. As these particles are reduced in size by reaction, they circulate higher along the vortex spout, until either reaction is complete or they leave the reactor.

2. Cyclone and Vortex Chamber Reaction

In cyclone gasification processes, exothermic combustion reactions are used to drive endothermic gasification reactions. Reactant location and particulate residence time can be controlled by appropriate chamber injection methods, since these control mixing history. The two primary methods employ axial or tangential injection. Using a CO_2 tracer gas, Schmidt (1970) found that the central axial introduction of gaseous fuel was far from ideal and gave poor mixing of fuel and air. Tangential introduction of fuel yielded much better results. The number and size of tangential nozzles can also affect the flow field, since nozzle velocities will vary.

It is important to distinguish particulate residence time

Figure 3. Particle Movement in Rotary Flow (Schmidt, 1970)

from gas residence time. Gas residence time is determined primarily by reactor volume and volumetric flow rate. Particulate residence time can be significantly longer. Agrest (1965) reported particulate residence times 12 to 15 times longer than gas residence times in a non-slagging operation. Semenov and Semenenko (1969) describe how, in a slagging reactor, a coal particle will continually interact with the molten wall layer until it burns to such a size that it is carried away by gas flow.

Flow patterns produced under burning conditions are usually similar to those in the isothermal state. Schmidt (1970), for example, comments on flame patterns for a vortex tube burning methane and propane. For cold flow studies, propane was replaced with carbon dioxide, whose concentration is more easily measured than that of the fuel and whose molecular weight is almost exactly that of propane. Concentration profiles of carbon dioxide compared favorably with the flame patterns. Similarly, Syred and Beer (1974) believe that, with due caution, isothermal results can often be extrapolated to burning conditions.

3. Geometric Parameters

The geometric chamber parameters which strongly influence flow are the length/diameter ratio (L/D), the ratio of throat diameter to chamber diameter (D_e/D), and the number of tangential inlet nozzles (Baluev and Troyankin, 1967). As L/D increases, tangential velocities diminish throughout the chamber volume. The D_e/D ratio influences reactant mixing and drag loss, while the number of tangential nozzles controls the symmetry of the swirling flow. Baluev and Troyankin recommend L/D values of 1.5 - 1.8, D_e/D values of .4 - .7, and at least two tangential nozzles. This geometry will provide sufficient mixing and residence time, reasonable drag losses, and symmetric flow.

Gasification of Pulverized Coal Within Swirling Flows

1. Gasification Methods

Coal gasification systems may be divided into three groups:

(1) fixed-bed, (2) fluidized-bed, and (3) entrainment systems. The main advantages and disadvantages of each method have been reviewed by von Fredersdorff and Elliott (1963) and Laurendeau (1975).

Entrainment systems seem to be the most attractive. Pulverized coal (coal size: 10^{-4} - 10^{-2} cm) provides the greatest gas solid contact, hence the highest volumetric reaction rate. The resulting high temperatures ($1500 < T < 1800^{\circ}\text{K}$) suppress tar and clinker formation and allow ash removal under slagging conditions. Furthermore, coal type is irrelevant. However, cocurrent flow is a significant disadvantage since it reduces coal inventory and makes the establishment of endothermic regions difficult, resulting in decreased product heating value. The generation of recirculation zones by vortex chamber designs partially offsets this disadvantage.

2. Gasifying Medium

The gasifying medium consists of some combination of air, oxygen, and steam. Oxygen is used for production of high calorific content synthesis gas; air, for nitrogen-containing power gas. Steam is the primary source of hydrogen. Table I categorizes gasifying media, chamber flow type and method of heat supply for the major gasification studies.

3. Heat Transfer

In any coal gasification system, the gasification reactions are endothermic (Laurendeau, 1975). Consequently, heat must be supplied to the process. This can be done in one or more of three ways: (1) by transfer through the chamber wall, (2) by generation within the process, or (3) by introduction as sensible heat in the entering reactants.

4. Rate Controlling Processes

There is varied opinion on whether the rate of surface reaction or mass transfer controls the overall reaction rate at temperatures prevailing in entrainment gasifiers. However, it is

Author(s)	Gasifying Media						Flow		Heat Supply		
	Air	Air-O ₂	Air- Steam	Air-O ₂ Steam	O ₂	O ₂ - Steam	Plug	Swirling	External	Internal	Entering Reactants
von Fredersdorff (1949)		x		x				x		x	x
Perry et al. (1950)						x		x		x	x
Elliott et al. (1952)						x		x		x	x
Traenckner (1952)	x							x		x	x
Sebastian (1952)					x	x	x			x	x
Nistler (1957)	x							x		x	x
Yagi and Kunii (1957)			x	x				x	x	x	x
Holden et al. (1960)						x	x			x	x
Strimbeck et al. (1960)				x		x	x			x	x
Coates et al. (1975)				x		x	x		x	x	x

TABLE I. CLASSIFICATION OF VARIOUS GASIFIERS

generally agreed that, as chamber temperature increases, the rate of reaction becomes increasingly dependent on the rate of pore and boundary layer diffusion (Elliott et al., 1952; Sebastian, 1952; Traenckner, 1953). Tangential particle injection improves mass transfer by establishing relative velocity between particles and gas. These relative velocities are induced by the opposing effects of centrifugal force on the particles and radial pressure gradient.

5. Pressure Gasification

Economic considerations make pressure gasification attractive. Gasification rates per unit of reactor volume increase with pressure, while percent heat loss correspondingly decreases. When high pressure producer gas is desired, operating costs can be reduced by compressing reactants rather than products (the reactants occupy a lower volume). Furthermore, gas heating value increases due to an equilibrium shift toward greater methane concentration (von Fredersdorff and Elliott, 1963).

6. Operating Variables

Von Fredersdorff and Elliott (1963) have reviewed much of the work that has been done on fully-entrained suspension gasification. It is immediately apparent that there are many operating variables involved. The most common independent variables are related to reactant feed rate and temperature, and to chamber temperature and pressure. Variables related to gasifier design, fuel type, and method of reactant feed are also considered independent, since they generally are held fixed. More common dependent variables include some indication of process efficiency and relations determined from the make gas yield and composition. The following classification, revised from Sebastian (1952) and Coates (1975), is chosen from a practical operating standpoint:

I. Independent process variables

1. Shape and dimensions of gasifier
2. Method of feeding reactants

3. Composition and physical properties of the coal charged
 4. Particle size (μm)
 5. Coal throughput or feed rate, $\left(\frac{\text{lbm}}{\text{ft}^3 \text{hr}}\right)$ or $\left(\frac{\text{lbm}}{\text{hr}}\right)$
 6. Injection temperature of the reactants, ($^{\circ}\text{K}$)
 7. O_2 /coal and/or air/coal input ratio, (lbm/lbm)
 8. H_2O (steam)/coal input ratio, (lbm/lbm)
 9. Chamber pressure and temperature, (atm) and ($^{\circ}\text{K}$)
- II. Dependent process variables
10. Percent coal (carbon) gasified, (%)
 11. Composition and heating value of the gas produced, (%) and (BTU/SCF)
 12. Producer gas output rate, (SCF/lbm coal)
 13. Gas exit temperature, ($^{\circ}\text{K}$)
 14. Type, quantity, and size of residue
 15. Heat losses from gasifier, (%)
 16. Thermal and cold gas efficiency, (%)

Many frequently mentioned variables, which are not listed, can be defined in more fundamental terms. Gas residence time, for example, can be found from the coal feed rate, O_2 -air- H_2O /coal ratios, and the inlet temperature and pressure of the reactants.

7. Summary of Major Dependencies

At operating conditions, O_2 /coal ratio influences gasifier performance most. Percent carbon gasified, gas exit temperature, and percent heat loss all increase with O_2 /coal ratio. H_2/CO ratio decreases with O_2 /coal ratio. The effect of O_2 /coal ratio on make gas yield is not clear cut.

Coal throughput (lbm/hr-ft^3 reactor volume) or coal feed rate (lbm/hr) is probably the second most important operating variable. It should be mentioned that coal throughput is a more fundamental variable than coal feed rate since it eliminates reactor volume as a criterion in evaluating gasifier performance. Percent

carbon gasified is not strongly dependent on throughput. However, an increase in throughput does result in a decrease in percent heat loss and increases in gas exit temperature and gas yield.

The effect of H_2O /coal ratio definitely depends on the degree of steam superheat. Generally, higher superheat enhances gasifier performance. The primary function of steam, however, is to control the H_2/CO ratio.

No major differences were noted in gasification with or without air. Unfortunately, extensive performance data on gasification with air only are not available.

In general, trends in a pressure gasifier follow the same pattern as in an atmospheric gasifier. The major differences are a result of the opposed effects of residence time and heat loss; residence time is the controlling factor at low pressure, while heat loss is the controlling factor at high pressure.

The decrease in heat loss with respect to pressure may explain the ability of Holden (1960) to gasify coal in an 8 inch diameter chamber with no external heating. This possibility suggests that performance data from a small scale pressure gasifier with and without external heating could be beneficial.