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**DESIGN, FABRICATE AND TEST A COMPLETE
LABORATORY SCALE COAL FEEDER INJECTOR
SYSTEM**

Phase III Final Report
Contractor—Foster Miller Associates, Inc.

August 1980

Contract No. U.S.D.O.E. EX-76-C-01-1793

**U. S. Department of Energy
Assistant Secretary for Fossil Energy**

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DESIGN, FABRICATE AND TEST A
COMPLETE LABORATORY SCALE COAL
FEEDER INJECTOR SYSTEM

PHASE III FINAL REPORT
AS OF
30 APRIL 1980

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<p>16. Abstract This report summarizes the results of Phase III of the Coal Feeder Development Program carried out by Foster-Miller Associates, Inc., for the U.S. Department of Energy (Contract No. EX-76-C-01-1793).</p> <p>During Phase III development was continued on two feeder concepts which had demonstrated the most promise in Phase II. These included: the Linear Pocket Feeder (LPF) and the Centrifugal Feeder. As a part of the feeder development work, a new feeder test facility was developed with seven times the capacity of the test facilities used in the previous phase.</p> <p>The LPF prototype was subjected to a continuing cycle of test, evaluation, redesign, and retest. Total feeder operating time reached 345 hr. Solutions to all reliability problems identified to date have been developed. Development of a "second generation" pilot scale prototype is recommended.</p> <p>The 200 lb/in.² centrifugal feeder developed in Phase II was modified and used to develop design data for a second generation centrifugal feeder prototype. This prototype was designed to operate at backpressures to 500 psig and feed rates of 3 to 5 tons/hr. Testing of the feeder was terminated after 6 weeks to conserve funds for the LPF development work. The 500 lb/in.² feeder prototype represents a substantial advance over the very successful 200 lb/in.² prototype, with 300 available horsepower (versus 40 hp for the older unit). All feeder and test components have been designed for operation to 1000 psig to facilitate development beyond the 500 psig goal. Continued development of this promising concept is recommended.</p>				
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1. EXECUTIVE SUMMARY OF PHASE III DEVELOPMENT

1.1 Background

Foster-Miller Associates, Inc., (FMA) has developed and successfully demonstrated two techniques for feeding coal to pressurized coal conversion processes. The FMA feeder concepts cover the entire range of possible feed system applications. Both feeders have been demonstrated at pilot scale.

1.2 Linear Pocket Feeder (LPF) Development

The LPF has been tested for 345 hr on FMA feeder test facilities. Solutions have been developed and tested for all reliability problems encountered to date. The feeder has been tested repeatedly at design feed rates and back pressure (5 tons/hr at 500 psig) for runs of 1 hr. The feeder has operated continuously for 10 hr at a reduced feed rate (1/2 ton/hr) and design back pressure. Run times have been limited by test facility limitations (5 tons maximum capacity) rather than feeder limitations.

1.3 Centrifugal Feeder Development

The first generation centrifugal feeder prototype has fed pulverized coal (70 percent through 200 mesh) at feed rates in excess of 1 ton/hr against pressures to 200 psig. Subsequent development has reduced the feeder power requirements by 50 percent compared with the Phase II configuration.

A second generation centrifugal feeder prototype was designed and built for feed rates of 3 to 5 tons/hr against a 500 lb/in.² back pressure. Testing of the feeder was suspended to conserve funds for the linear pocket feeder development effort.

1.4 Test Facility Development

An upgraded feeder test facility has been developed. The facility has a capacity of 5 tons for testing pilot scale feeders at pressures to 1000 lb/in.². Essentially any coal type can be handled, with an upper size limit of 1.5 in.

1.5 Future Effort

It is probable that development of the linear pocket feeder will continue under the sponsorship of the U.S. Department of Energy (DOE) and the technical direction of the Morgantown Energy Technology Center.

Future development would address:

- Selection of a suitable process or processes to which the feeder system can be applied
- Development of a second generation LPF for subsequent verification testing and field application
- Verification testing of the second generation LPF prototype for a minimum of 500 hr
- Installation of a feeder on an operational pilot scale coal conversion test facility.

2. INTRODUCTION

2.1 Objective and Scope of Work

A number of research and development programs are currently underway to investigate and/or demonstrate coal conversion processes. A critical problem with all conversion processes which operate above atmospheric pressure is the delivery of coal to the process. Present commercial and pilot plant installations utilize either lock hopper or slurry feed systems to feed processes which operate at significant pressures (>50 psig). Both of these systems have shortcomings which bring into question their viability as feed systems for future commercial scale gasification processes. Lock hoppers are substantially more expensive than slurry feed systems in terms of both capital and operating costs. Unreliable valve performance has been cited as a serious operational problem with lock hoppers. With one reservation, slurry feed systems offer substantial economic and performance advantages over lock hopper systems. This reservation concerns the impact of the liquid used to slurry the coal on the process being fed. In some cases, the heat required to evaporate the slurrying liquid can have a substantial negative impact on process economics. The objective of this program is the successful development of alternative (second generation) dry coal feeder systems for pressurized coal conversion processes. The program to accomplish this objective has been defined through three phases as described below.

Phase I - Coal Feeder Conceptual Development

This phase was of 6 months duration and was essentially completed by the end of December 1975. The Phase I effort established coal feeder requirements and generated and evaluated concepts for coal feeders. Conclusions were made as to the desirability of each of the concepts generated and four feeder concepts were recommended for further development in Phase II of the program. This effort has been documented in the Phase I report dated March 1976 (1).

Phase II - Pilot Scale Coal Feeder Development

During the initial stages of Phase II, the development of four feeder concepts was pursued. Two of the four original concepts were eliminated from consideration during Phase II. Initially, the phase was conducted as five subprograms which included the development of the four feeder concepts and the feeder test loop. Development of each of the feeder concepts proceeded through one or more stages starting with the design

and testing of bench scale or process development units (PDU) and culminating in the design and test of pilot scale feeder prototypes. A coal feeder test loop was developed for the conduct of the prototype testing. Results of the Phase II effort have been documented in the Phase II report dated September 1978 (2).

Phase III - Pilot Plant Feeder Performance Testing

The feeder concepts selected for further development, based on the results of the Phase II effort, were designed and built to pilot plant scale specifications. The feeders were subjected to a performance test program on an expanded coal feeder test loop constructed for this task. The Phase III effort was initiated 1 October 1977. The selected feeder concepts for the Phase III effort were the FMA LPF and Centrifugal Feeder. Phase III results are presented in this report.

2.2 Feeder Performance Specifications

The objective of the DOE coal feeder program is to develop alternative dry coal feed systems for pressurized coal conversion processes. The specifications for this development are as indicated in Table 1. It should be noted that these specifications, as addressed in Phases I through III, apply to pilot plant applications. The eventual objective of the DOE coal feeder program is to develop coal feeders for demonstration plant applications. Some feeder design considerations beyond those presented in Table 1 include: power consumption, gas losses, gas added to the process, reliability, maintainability, wear, coal preparation required before feeding, coal degradation caused by the feeder, metering capability, development requirements and packaging flexibility.

2.3 Conversion Plant Feed Requirements

There are a large number of coal conversion processes which represent potential applications for feed systems. In Table 2 gasification processes are broken down generically in terms of bed type. This breakdown by gasification reactor bed type gives an application hierarchy in terms of feed size with entrained bed reactors requiring the finest feed size (typically 70 percent through 200 mesh) and fixed bed/stirred bed reactors requiring the coarsest feed size (typically 1-3/4 x 1/4 in. for a Lurgi reactor). It should be noted that this generic breakdown leads to no hierarchy in terms of either pressure or state of development. In each class of gasifiers there are both developed and experimental processes, as well as processes which operate at both atmospheric and elevated pressure conditions.

TABLE 1. - Specifications for coal feeder development

Parameter	Value
Feed rate	1 to 5 tons/hr
Feed size	Fine - 3/4 in.
Feed pressure	100 to 1500 lb/in. ²
Temperature	As required

TABLE 2. - Generic classification of gasification reactors

Type	Examples	Coal Size
Entrained bed	Bi-Gas, Koppers - Totzek, Texaco	Pulverized (70 percent - 200 mesh)
Fluidized bed	Hygas, Synthane	Minus 8 to 20 mesh (to 1/8 in. for direct combustion)
Fixed bed/ Stirred bed	Lurgi, GE gas	Coarse (1-3/4 × 1/4 in.)

As originally conceived, the FMA feeder concepts were selected to collectively cover all possible applications. Based on the results of the Phase III program effort, the LPF is suitable for fluidized bed and fixed/stirred bed applications with potential for development for entrained bed applications. The centrifugal feeder is most suitable for entrained bed applications with a development potential for fine fluidized bed applications.

3. PHASE III FEEDER DEVELOPMENT

In Phase I of the program (1), a survey of coal feeder requirements and the state-of-the art of coal feeder development was conducted. Based on this survey, a large number of dry coal feeder concepts were generated and evaluated. Four feeder concepts, each one potentially superior to existing dry coal feeders in terms of economics and/or performance, were selected for development in Phase II of the program.

In Phase II, bench scale operating models of the four feeder concepts were developed and tested to evaluate technical feasibility and to generate design data for further development of the concepts. The four concepts encompassed the complete range of potential gasification process applications. Upon completion of the bench scale testing, pilot scale models of three of the feeder concepts were developed and tested (2).

The FMA LPF and centrifugal feeder were selected for further development in Phase III, based on the Phase II program results. Pilot scale prototypes of the feeders were constructed and/or performance tested on an expanded coal feeder test loop. The two feeder concepts under development in Phase III are described below and the development of each concept is detailed in the subsections which follow.

The LPF uses a sealed conveyor arrangement to feed coal with high pressure water being employed to displace pressurized gas from the returning pockets. The concept provides continuous coal feed with a high coal capacity for a given cross-sectional area. The LPF is essentially insensitive to coal size and coal properties and is especially well suited to coarse coal feed. "Linearizing" the pocket feeder concept allows modular design which in turn allows optimization of each of the feed functions; coal input, sealing, coal discharge, and gas recovery. The modular design also improves accessibility to simplify maintenance. The LPF concept is suitable for near term applications, specifically, fixed and stirred bed gasification reactors and pressurized fluidized bed direct combustors, as well as feeding pulverized coal to entrained bed gasifiers.

The centrifugal feeder is a centrifugal pump for dry solids. This feeder approach can be characterized as a "high risk/high payoff" concept. The concept offers the most potential improvement over state-of-the-art feed systems of the FMA feeders, but it is also the feeder approach with the highest development risk. The centrifugal feeder operates in a continuous mode and

is therefore relatively compact. In scaling up the feeder for commercial applications, substantial savings are predicted in capital and operating costs per ton of coal. Since the concept uses moving coal to seal against pressure, the hardware is mechanically very simple. However, successful development of this concept requires the solution of subtle and complicated two-phase gas/solids flow problems. The concept is basically suitable for fine coal feed to entrained bed and fluidized bed gasification applications.

3.1 LPF Development

3.1.1 Feeder Description

3.1.1.1 Principles of Operation

The FMA LPF uses a sealed conveyor to feed coal, with high pressure water being employed to displace pressurized gas from the conveyor as it leaves the pressurized zone. The system is designed to provide a number of advantages to the user. For example, the LPF provides continuous coal feed with a high coal capacity for a given cross-sectional area and is essentially insensitive to coal size and coal properties. Linearizing the pocket feeder system allows modular design, which, in turn, allows separation and optimization of each of the feed functions: coal input, sealing, coal discharge, and recovery of high pressure gas. The modular design also improves accessibility, simplifying and speeding maintenance. The LPF concept is suitable for application to all types of gasifiers: fixed bed, stirred bed, fluidized bed, and entrained bed as well as pressurized fluidized bed combustion.

The LPF is shown schematically in Figure 1. It is essentially a tubular conveyor in which a series of sealing pistons are connected together to form pockets. The pockets are filled with coal, carried to the discharge area, emptied, and then filled with water to displace pressurized gas back into the discharge area.

Referring to Figure 1, coal enters the feeder through the hopper, is then pulled through the close tolerance sealing section, and is dumped into a high pressure vessel. Within the pressure vessel, the coal drops from the pockets, the pockets become filled with high pressure gas, and then the pockets move to the gas-water transfer station where high pressure water displaces the gas from the pockets. The high pressure water is moved to the water discharge station where it is discharged into the water reservoir. The chain moves around the drive sprocket and along the return guides, where it is stripped of water by

FIGURE 1. - Schematic of linear pocket feeder.

high velocity air. It then moves over the idler sprocket and back to the hopper section where the feeding cycle begins again.

3.1.1.2 Prototype Pilot Scale Feeder

A pilot scale LPF was designed and built for feed rates of up to 5 tons/hr at pressure differentials of 500 lb/in.². A detailed description of the prototype design effort is provided in the Phase II report (2). A cutaway illustration of the prototype is presented in Figure 2. The flow of coal into and out of the feeder is indicated in the figure. External plumbing connections are eliminated for clarity. The actual machine and associated test equipment are shown in Figures 3 and 4.

The performance capabilities of the prototype are shown in Table 3.

3.1.2 LPF Development

The technical feasibility of the LPF concept was demonstrated in Phase II. The objective of the Phase III effort was to develop, debug, and demonstrate the LPF under conditions which

TABLE 3. - LPF performance

Item	Measurement
Feed rate; tons/hr	5
Tube ID; in.	3.5
Overall length; ft	20
Pressure; psig	500
Leakage; scfm (at 500 psig, 5 tons/hr, 2.2 ft/sec)	6
Specific leakage; scf/ton	72
Total system power; hp (at 500 psig, 2.2 ft/sec)	47
Total system specific power; (hp-hr)/ton	9.4
Line pull; lb	400 to 600 lb
Line pull power required; hp	3 to 4
Coal size; in.	-3/4*
*Top size increases with tube diameter. Ten-inch model can feed minus 1-3/4 in. coal.

FIGURE 2. - Cutaway view of LPF (material flows indicated).

FIGURE 3. - Prototype LPF.

FIGURE 4. - Prototype LPF mounted on original test facility

simulated field operation. This effort consisted of a continuing cycle of test, evaluation, redesign, and retest. At the conclusion of the Phase III effort, the LPF prototype had been operated for a total of 345 hr. In the subsections which follow the redesign effort and test results are discussed in detail.

3.1.2.1 Critical Component Redesign

Initial redesign of the feeder was based on the results of Phase II testing (83 hr of total operating time). Not all of the redesigned components and subsystems were eventually procured and tested since some anticipated problems did not develop and efforts were focussed on problems of immediate concern. Areas where problems were identified and where solutions were developed and implemented are summarized below:

- a. The pin joints which connect the conveyor links wore out during the Phase II testing. Alternative joint designs and materials were evaluated throughout the Phase III program. This effort is detailed in the next subsection.
- b. The alumina sealing rings did not wear, but ring fracture was a problem. Alternative sealing ring materials were procured and tested in Phase III. This effort is detailed in the next subsection.
- c. The variable speed direct current drive motor was replaced with a hydraulic motor. This change was made to enhance system safety as the electric motor was a potential ignition source.
- d. A new feeder chain was designed incorporating the preferred joint design developed during Phase III. The redesign also included enlarging the chain links to allow operation at 1000 psig. This chain was procured, but was not installed or tested due to funding limitations.
- e. New sprockets were designed and procured. The sprockets have replaceable teeth to allow:
 1. Easy adaptation of the sprocket to changes in the chain design
 2. To facilitate testing of alternative sprocket tooth materials.

Many other areas of the feeder were redesigned, but the redesigned components and/or subsystems *were not procured and tested* because the existing hardware performed adequately during the test program. Areas addressed were as follows:

- a. The hopper station was redesigned to improve feed characteristics. The station length was doubled to allow the coal more time to settle before entering the sealing tube.
- b. All feeder tubes were redesigned to have the same inside diameter and tolerances. The material for all tubes was changed to the Xaloy® type which was being used in the sealing tube. The tubes were ordered, but the order was later cancelled to conserve funds for testing.
- c. The gas/water station was redesigned to increase capacitance (thus improving level control), and provide automatic flushing of fines carried over from the unloading station. An order for this item was also placed and then cancelled.
- d. Detail changes to the machine which were necessary to accommodate the redesigned subassemblies and components noted above were designed (mounting brackets, etc.)
- e. Conceptual designs for several alternative conveyor chain configurations were developed. These included an approach utilizing a wire rope rather than individual links and a "hidden pin" design which incorporated the joint within the piston body.
- f. A sealed link joint design was explored. Space limitations prevented our implementing this approach on the existing machine. Subsequent testing indicated that the required joint life could be achieved without going to a sealed design.

The critical component redesign efforts discussed above were undertaken as a response to problems observed or anticipated in testing the feeder prototype. In the following subsection, a chronology of the Phase III LPF prototype testing is presented. Changes to the machine are discussed as they occurred and the impact of the changes is evaluated.

3.1.2.2 Phase III LPF Testing

At the beginning of the Phase III test program the prototype LPF had been operated for 83 hr. The original "borofuse" sealing tube had been replaced with an Xaloy sealing tube at 30 hr. The original hardened aluminum water station tube had been replaced with an electroless nickel coated stainless steel tube, also at the 30-hr point.

During the first 83-hr of operation, occasional breakage of the alumina sealing rings had been noted. Therefore, ten of the alumina rings were replaced with titanium carbide rings at the 83-hr point.

The clevis and rod end holes and linking pins were essentially worn out at the conclusion of the Phase II testing. The holes were bored out and enlarged pins were installed as a "fix." A design change was initiated at this point to use tungsten carbide bushings in the clevis and rod end holes with hardened pins to join the links.

Phase III testing was initiated after 83 hr of Phase II testing. A chronology of the Phase III test results is presented below.

For the Phase III testing a coal recycle loop was developed to allow continuous operation of the feeder. The recycle system allows continuous operation with coal but does not allow continuous operation against pressure. The basic test loop allowed operation against pressure for approximately 7 min at a 5 tons/hr feed rate. Pressure runs were conducted at least every 50 hr to check system performance.

Phase III Testing, 83 to 100 hr

Under continuous operation (8 hr/day), the alumina sealing rings were breaking at the rate of about 1/hr. No problems were noted with the 10 titanium carbide sealing rings. The performance of the machine against pressure was unchanged at 100 hr. At this point, all remaining alumina sealing rings were replaced with tungsten carbide sealing rings.

Phase III Testing, 100 to 216 hr

After 216 total hours of prototype testing, no sealing tube or seal ring wear was detectable, based on measurement (to 0.0001 in.) and leakage testing. No problems were detected with either the titanium carbide or tungsten carbide sealing rings.

At 216 hr the rod and clevis end hole and link pin "fix" were worn out. The fix had lasted 133 hr. The tungsten carbide clevis and rod end bushings and 440°C stainless steel pins were available at this time. Many of the carbide bushings did not meet dimensional requirements for outside diameter and roundness. The pins were Rc 53-55 instead of the Rc 61 specified. The new pins and bushings were installed despite these problems.

Phase III Testing, 216 to 234 hr

After 18 hr of testing with the carbide bushings, the conveyor chain was disassembled and examined. Nine fractured bushings were found. In addition, some evidence of the carbide bushings wearing the pins was noted.

Analysis of the bushing fractures showed that a combination of out-of-round rod and clevis holes coupled with the out-of-round bushings and/or alignment problems in inserting the bushings could have caused the fractures. Pin wear was attributed to the relatively soft pins running against the edges of the carbide bushings.

All the carbide bushings were removed and bearing steel drill jig bushings were ordered to effect a short term fix.

Eight links were selected with proper hole dimensions and matched with tungsten carbide bushings of the proper dimension. Borofused, D2 tool steel pins were used for five joints and hardened stainless steel pins were used for the remaining three joints.

Phase III Testing, 234 to 235 hr

The LPF was operated with a 70 percent through 200 mesh coal. The machine was not operated against pressure and the gas/water transfer station was not operated. Line pull remained constant and low (200 to 400 lbf). Operation with pulverized coal presented a potential explosion hazard facility. A decision was made to defer further testing with pulverized coal until the feeder had been installed on the new test facility.

Phase III Testing, 235 to 275 hr

The feeder was operated for 40 hr with coarse coal (1 in. by 0) to check the performance of the carbide joint bushings and pins. Two rod end bushings fractured. Both appeared to be caused by out-of-round holes in the rod ends.

There was no measurable wear for either the 400°C Rc 56 stainless steel or borided D2 pins.

Phase III Testing, 275 to 278 hr

At the 275 hr operating point the feeder was disassembled, inspected, and installed on the new test facility. The sealing rings showed no measurable wear (to ± 0.0001 in.). In installing the feeder on the new test facility, the electric drive motor was replaced with a hydraulic drive motor.

The new test facility (described in Section 4) enables the feeder to be run against pressure for 1 hr at 5 tons/hr versus the 7 to 8 min pressurized run time possible with the original facility.

Pulverized coal testing began with a test run, with coal, and with the gas/water transfer station operating. The machine operated satisfactorily with no problems noted.

The feeder was then operated with pulverized coal (70 percent through 200 mesh) against a 500 psig back pressure. Several runs were made of 2 to 4 min duration at a feed rate equivalent to 4.5 tons/hr. Line pull was substantially greater than that encountered when feeding the usual 3/4 in. by 0 coal. Power requirements peaked at 20 hp versus the 3 to 4 hp typical with coarse coal. The gravity discharge was not satisfactory and a substantial amount of coal carried over into the gas/water transfer station. This made it clear that in designing an LPF for pulverized coal, the coal should be discharged into a pneumatic conveying system which will ensure that the coal is flushed from the conveyor.

Phase III Testing, 278 to 302 hr

At 278 hr into the test program, four material combinations were in use for the conveyor joints. One combination was a fix to allow continued testing and three combinations represented candidate final design approaches. In each case the holes in the links were bushed with nominal 1/2 in. by 3/8 in. bushings. The links were jointed by nominal 3/8 in. pins. The joint alternatives are summarized below:

- a. Hardened stainless pins/tool steel bushings (fix)
- b. Hardened stainless pins/tungsten carbide bushings (design alternative)

- c. Borofused pins/tungsten carbide bushings (design alternative)
- d. Stainless pins with a flame sprayed tungsten carbide coating/tungsten carbide bushings (design alternative).

The three design alternatives have all performed well from 278 to 302 hr.

Phase III Testing, 302 to 345 hr

At the 302 hr point, changes were again made to the conveyor joints. All nontest joints were bored out to a 1/2 in. plus inside diameter and 1/2 in. hardened stainless pins were used to join the links. This represented a "running fix" and not a proposed solution to the joint wear problem. Potential solutions are represented by the "test joints."

From 302 to 330 hr the LPF was subjected to extended duration pressure testing on the 5-ton capacity batch test loop. The following tests were completed against a 500 lb/in.² pressure differential:

- a. Two runs at a 5 tons/hr feed rate of 1 hr duration each
- b. One run at a 1 ton/hr feed rate of 5 hr duration
- c. One run at an 0.5 ton/hr feed rate of 10 hr duration.

The machine operated flawlessly during all testing.

From 330 to 345 hr the performance of the machine deteriorated rapidly. This deterioration was evident from an abrupt increase in gas leakage and back leakage of water into the coal receiver vessel.

After 345 total hours of testing, 262 hr in Phase III, the machine was completely disassembled and inspected. Of the 345 hr of testing, 77 hr were at pressure differentials of 100 to 500 lb/in.², with the majority of the pressurized operation (50 hr) against a 500 lb/in.² differential.

3.1.2.3 Test Evaluation

At the outset of the Phase III test program, the feasibility of the LPF had been demonstrated. Several reliability problems

had been detected with the prototype machine. The items of concern included:

- a. Fracturing of the alumina sealing rings
- b. Wear of the conveyor joints.

Multiple solutions to both of these problems were developed during Phase III. Both tungsten carbide and titanium carbide sealing rings were tested without breakage and little or no wear. Three material combinations were tested for the conveyor joints. Tungsten carbide bushings were used with pins of hardened stainless steel, borided tool steel, and stainless steel, plasma sprayed with tungsten carbide. The borided tool steel pins gave the best performance, showing no wear after 110 hr of testing.

At the conclusion of the Phase III test program, one new reliability problem had been detected. Inspection of the prototype feeder revealed that the sealing tube had worn an average of 0.009 in. in the vertical axis and 0.007 in. in the horizontal axis (315 hr). The tungsten carbide sealing rings (245 hr) had worn an average of less than 0.001 in. and the titanium carbide sealing rings (262 hr) had not worn. Detailed failure analysis, including consultation with the sealing tube vendor, showed that the tube matrix material had corroded and allowed the carbide particles to separate from the matrix. In continued operation, the carbide particles acted as an abrasive and accelerated the matrix breakdown. Based on the performance of the prototype, most of the wear occurred during the last 15 hr of operation. The corrosion problem can be overcome by either controlling the chemical composition of the water (or other liquid) in the gas transfer station and/or changing matrix materials. Both approaches will be pursued in any subsequent development.

No other critical problems were noted in the final inspection.

3.1.3 Conclusions and Recommendations on Phase III LPF Development

Based on 345 hr of prototype testing, the following conclusions can be drawn with regard to the LPF:

- a. The technical feasibility of the LPF concept has been demonstrated.

- b. Solutions to all reliability problems identified during the test program have been developed, and in all but one case (seal tube corrosion), demonstrated.
- c. The results of limited pulverized coal (70 percent through 200 mesh) testing indicate that the present LPF prototype and feeder test facility are not well suited to feeding pulverized coal. The major feeder related problem is excessive line loads and the major test facility problem is incomplete removal of the coal at the discharge station, leading to subsequent fouling of the gas/water transfer station with coal. The solution to these problems was beyond the scope of the Phase III program.

It is recommended that development of the LPF be continued with the objective of installing a prototype feeder on an operating pressurized coal conversion facility. To achieve this objective the following steps are recommended:

- 1. Design and development of an LPF prototype reflecting the knowledge gained in development effort to date
- 2. Performance testing of the prototype feeder with a variety of coal types and sizes and with alternative solid fuels such as lignite, peat, and wood
- 3. Endurance testing of the prototype feeder with a feedstock which is appropriate for a specific pilot plant installation
- 4. Installation and testing of a prototype feeder on an operational pressurized coal conversion pilot plant.

3.2 Centrifugal Feeder Development

3.2.1 Feeder Description

The centrifugal feeder can be viewed as a centrifugal pump for solids. The solids, pulverized coal in the case of the gasification application, are moved from atmospheric pressure into higher pressure zones by being subjected to high centrifugal forces. The centrifugal g forces are induced by spinning a set of arms containing the feeder passages (sprues) around a vertical axis of high speeds, as illustrated schematically in Figure 5. The coal particles are constrained to flow through

FIGURE 5. - Schematic representation of the centrifugal feeder.

the feeder sprues in a contact mode (termed choked flow) thus forming a low permeability moving plug. The back leakage of high pressure gases through this plug is minimized by proper choice of coal properties (particle size distribution in particular), operating speeds, and feed passage geometry.

Coal is supplied from a hopper positioned over the inlet of the feeder impeller. The feeder rotor is fully enclosed in the high pressure zone. Flow into and away from the rotor is by gravity. The feed pipe (downcomer) which discharges coal into the eye (hub) of the rotor is stationary so as not to centrifuge the coal against the sides of the feed tube and thus restrict the inlet flow. At the eye of the rotor, the solids are separated from the entrained gas and the gas is directed out a vent tube.

Bearings and seals are critical components in the design of the centrifugal feeder. Bearing requirements are met with off-the-shelf units. Seal requirements are met with advanced technology liquid cooled face seals. Clean purge gas is employed at several points to keep coal particles away from sliding surfaces.

In Phase II a prototype centrifugal feeder was developed which fed pulverized coal (70 percent through 200 mesh) at feed rates of over 1.5 tons/hr at a pressure differential of 200 lb/in.²(2). Based on the results of the Phase II development effort, design, and testing of a "next generation" centrifugal feeder was undertaken.

The Phase III Centrifugal Feeder development program was broken down into two major tasks:

- a. The development of additional theoretical and operating data on the centrifugal feeder concept, using a modified version of the existing 200 lb/in.² centrifugal feeder prototype.
- b. The design, fabrication, and testing of a new centrifugal feeder prototype for 500 lb/in.² operation at feed rates of 3 to 5 tons/hr.

The results of these tasks are discussed in following subsections.

3.2.2 Development of the Modified 200 lb/in.² Feeder Prototype

The objective of continued work with the 200 lb/in.² feeder prototype was to gather additional information on the centrifugal feeder concept with regard to the following areas:

- a. Determine the power requirements of the prototype feeder and how the requirements are broken down by subassembly.
- b. Study techniques to reduce the drag on the feeder rotor. Shrouding of the rotor and streamlining of the rotor are the drag reduction techniques which were to be investigated.
- c. Evaluate the possibility of operating the feeder in a pump configuration (operate the rotor within a casing) rather than the rotor-within-a-vessel configuration which has been employed in previous testing.
- d. Evaluate feeder metering techniques. In previous testing, feed rate has been a function of rotor speed for a given rotor geometry. In this task, mechanical techniques for controlling feed rate at a fixed number of revolutions per minute will be examined.
- e. Obtain data on the pressure profile along the feeder sprues during operation. This information will be used to verify the analytical model of feeder performance and thus increase our confidence in using the model as a design tool.

All test work on items a and b was completed and is discussed below.

Additional support work with the 200 psig centrifugal feeder prototype was suspended in August 1978 in order to maximize effort on the 500 psig prototype development. No further work with the 200 psig prototype is contemplated at this time. *The 200 psig prototype has exceeded its original performance goals by feeding in excess of 1-1/2 tons/hr of pulverized coal against a 200 psig back pressure with no gas loss from the receiving vessel. Back pressure limits were established by the ASME code limits of the receiving pressure vessel and not by feeder capability.*

Test Results

Testing of the modified 200 lb/in.² centrifugal feeder prototype began in February 1978. Initial testing was directed at determining the power requirements of the feeder. It was found that 40 to 45 percent of the power input to the feeder is consumed by the sprue discharge hoppers (drag) and 40 to 45 percent by the drive train (hydraulic motor, bearings, seals, and belts). Only 10 to 20 percent of the input power was consumed by rotor drag. Drive train power consumption was much larger than had been estimated.

The feeder was then tested with a shroud system to determine the impact of this modification on rotor drag. The shrouded rotor configuration is similar to the feeder configuration which would be employed when operating in a "pump" mode. The shroud had no measurable impact on rotor drag.

A streamlined rotor blank was fabricated which incorporated the sprue discharge hoppers within the rotor (Figure 6). This eliminated the hopper drag and halved the rotor drag, resulting in a 45 to 55 percent reduction in overall feeder power requirements. The 500 lb/in.² feeder rotor was designed to this streamlined configuration.

3.2.3 Development of a 500 lb/in.² Centrifugal Feeder

The "second generation" centrifugal feeder prototype was designed to operate at back pressures to 500 psig and feed rates of 3 to 5 tons/hr. The feeder and support equipment were designed to ASME code requirements for operating to 1000 psig so that, if 500 psig operation could be achieved, feeder revisions to operate at higher pressures would be minimal.

Fabrication and assembly of the 500 psig feeder prototype was completed in mid-December 1978. The assembled feeder is shown in Figure 7. The rotor is mounted within a housing which is in turn mounted to a 36 in. flange. In Figure 8, the flange and feeder assembly are attached to a lifting fixture prior to installation in the receiver pressure vessel. Figure 9 shows the rotor and bearing assembly removed from the feeder housing. The splined drive shaft is installed in this photo. In Figure 10, the rotor is viewed from above. The main coal inlet can be seen in the center of the rotor and the inlet to one of the four feeder sprues is visible. Figure 11 gives a closer view of one of the four sprue outlets.

FIGURE 6. - Streamlined centrifugal feeder rotor.

FIGURE 7. - Centrifugal feeder assembly.

FIGURE 8. - Centrifugal feeder assembly and mounting fixture.

FIGURE 9. - Feeder rotor and drive shaft.

FIGURE 10. - Centrifugal feeder rotor.

FIGURE 11. - Feeder sprue outlet.

Test Results

Testing of the prototype feeder began in mid-December 1978. All development work on the feeder was suspended at the direction of the DOE program manager in February of 1979. This was done so that all remaining contract funds could be applied to the LPF development effort. The test results achieved are summarized below:

- a. The machine has been operated at speeds to 4500 rpm.
- b. Coal has been fed at pressure differentials to 85 psig.
- c. Some coolant leaks from the main seals. This does not appear to hamper coal flow through the feeder.
- d. The procedures used to measure coal flow to and through the feeder do not yet give the required information reliably and accurately.

If the development were to continue, the first items to be addressed would be:

- a. Minimizing leakage from the main seals
- b. Improving our ability to measure coal flow to and through the feeder.

The 500 psig prototype is a substantial advance over the very successful 200 lb/in.² prototype. The unit has 300 available horsepower (versus 40 hp for the older unit) and all feeder and test components have been designed for operation to 1000 psig. It is unfortunate that funding is not available to continue development of this promising concept.

4. COAL FEEDER TEST FACILITY DEVELOPMENT

As part of the Phase III program effort FMA designed, built, and operated a batch type test facility on which to test pilot scale feeder prototypes. The new feeder facility has a capacity of 5 tons versus the 0.7-ton capacity of the Phase II test facility. This has increased the feeder test run time at maximum feed rate from 8.4 min to 1 hr.

The coal feeder test loop is illustrated schematically in Figure 12. A pictorial representation of the actual loop is presented in Figure 13. The loop consists of a supply vessel, a structure to support the test feeders and materials handling equipment used to move the coal from the feed vessel outlet to the feeder inlet, a 5-ton solids capacity receiver vessel, a belt and bucket elevator system to recycle the coal from the receiver vessel to the supply vessel, and a vent and baghouse system to contain coal blow back.

In operation, the feed vessel is loaded from ground level through the bucket elevator. When the supply vessel is full, the bucket elevator is stopped. Using procedures appropriate for the test feeder, a test run is conducted with up to 5 tons of coal being fed from the supply vessel to the receiver vessel. The receiver vessel may be pressurized up to 1000 psig during the test run. Upon completion of the test run, the receiver vessel is vented to atmospheric pressure and unloaded. The coal charge may be recycled to the supply vessel or discarded and a new coal charge loaded. In the event of a feeder failure which allows the receiver vessel to blow back, the blow back is routed through the baghouse to contain the coal.

FIGURE 12. - Coal feeder test loop schematic layout.

FIGURE 13. - Coal feeder test loop.

5. COAL FEEDER SYSTEM DESIGN AND ECONOMIC EVALUATION

The ultimate objective of the DOE Coal Feeder Program is to develop dry coal feed systems suitable for commercial scale coal conversion plant applications. To assess the FMA feeders in this context, conceptual feed system designs have been developed.

Specifications and economic projections for each feed system have been developed for pilot, demonstration, and commercial scale applications. For uniformity, each system has been designed for a 1000 psig back pressure, with plant scale defined as follows:

- a. Pilot Scale - 120 tons/day (one feeder train)
- b. Demonstration Scale - 1200 tons/day (one feeder train)
- c. Commercial Scale - 15,000 tons/day (three feeder trains)

The feeder system interfaces have been defined as:

- a. Coal in a process ready state upstream of the feeder
- b. An intermediate receiver vessel (not the reactor) downstream of the feeder.

Other system configurations are also possible, including configurations in which the feeder meters directly into the reactor vessel. Conceptual designs, specifications, and cost projections for the FMA feeder systems are presented in the following subsections.

5.1 LPF System

Figure 14 depicts a conceptual design for incorporating the LPF in an operating gasification plant. The discharge from the feeder is directed to an intermediate storage vessel. It is assumed that a mechanical or pneumatic transport system carries the coal from the pressurized intermediate vessel to the reactor vessel.

The operation of this system is essentially similar to the operation of the prototype unit described previously except that a weigh belt system is used to supply the feeder.

Ancillary equipment will include the atmospheric pressure feed hopper, the power supply for the drive system, the pump and pump motor, the gas purging and drying systems, and miscellaneous plumbing hardware.

FIGURE 14. - Linear pocket feeder system.

Table 4 gives system specifications for pilot, demonstration and commercial scale plants and Tables 5, 6 and 7 show the corresponding economic evaluation for each application.

The LPF is also adaptable to lower pressure gasifiers such as Lurgi-type processes. For this reason, system specifications and costs have been tabulated and included for a back pressure of 500 psig. Table 8 gives the system specifications for pilot, demonstration, and commercial scale plants and Tables 9, 10, and 11 give the economic evaluation for each.

TABLE 4. - LPF specifications (1000 psig)

Parameter	Pilot Plant	Demo Plant	Commercial Plant
Tons/day	120	1200	15,000
Tons/hr	5	50	630
Pressure, psig	1000	1000	1,000
Number of Feeders	1	1	3
Approximate Size Diameter, in.	3.5	10	22
Chain Speed, ft/sec	2.2	2.2	1.9
Hp required	94	451	5,695
Specific Power (hp × hr/ton)	18.8	9.02	9.04
Fill Factor	0.5	0.7	0.7

TABLE 5. - LPF system cost estimate

LPF - Pilot Plant Scale (5 tons/hr) - 1000 psig		
Cost Elements	Item Costs	Totals
Feeder Cost	\$220,000	
Weigh Belt System	3,000	
Miscellaneous	<u>10,000</u>	\$233,000
Installation	26,000	
Debugging	<u>10,000</u>	36,000
Design Services	60,000	60,000
(1) Total Capital Cost		329,000
Operating Costs/year		
Labor	40,000	
Utilities	14,025 (\$0.025/kWhr for 8000 hr)	
(a) Total	<u> </u>	54,025
Maintenance Costs/year		
Labor	2,000	
Material	<u>15,000</u>	
(b) Total		17,000
(2) Total Direct Cost (a + b)		71,025
(3) Annual Cost of Capital (100% Financed, 20 year; 12%)		43,470
(4) Total Annual Operating Cost (2 + 3)		114,495
Annual Operating Cost/Ton; \$/ton		2.86
Annual Operating Cost/ 10^6 Btu; \$/ 10^6 Btu		0.1431
Capital Cost/tons/hr; \$/tons/hr		\$ 65,800

TABLE 6. - LPF system cost estimate

Demonstration Plant Scale (50 tons/hr) - 1000 psig		
Cost Elements	Item Costs	Totals
Feeder Cost	\$800,000	
Weigh Belt System	19,600	
Miscellaneous	<u>25,000</u>	\$844,600
Installation	100,000	100,000
Debugging	<u>25,000</u>	125,000
Design Services	125,000	
(1) Total Capital Costs		1,099,600
Operating Cost/year		
Labor	40,000	
Utilities	67,289 (\$0.025/kWhr for 8000 hr)	
(a) Total		107,289
Maintenance Cost/year		
Labor	5,000	
Material	<u>45,000</u>	
(b) Total		50,000
(2) Total Direct Cost (a + b)		157,289
(3) Annual Cost of Capital (100% Financed, 20 year; 12 %)		144,630
(4) Total Annual Operating Costs (2 + 3)		301,919
Annual Operating Cost/Ton; \$/ton		0.7548
Annual Operating Cost/ 10^6 Btu; \$/ 10^6 Btu		0.0377
Capital Cost/ton/hr; \$/tons/hr		\$ 21,892

TABLE 7. - LPF system cost estimate

Commercial Plant (15,000 tons/day) - 1000 psig		
Cost Elements	Item Costs	Totals
Feeder Cost (3 feeders)	\$4,800,000	
Weigh Belt System (3 weigh belts)	150,000	
Miscellaneous	<u>120,000</u>	
		\$5,070,000
Installation	500,000	
Debugging	<u>150,000</u>	
		650,000
Design Services	200,000	200,000
(1) Total Capital Cost		5,920,000
Operating Costs/year		
Labor	100,000	
Utilities	848,874 (\$0.025/kWhr for 8000 hr)	
(a) Total		948,874
Maintenance Costs/year		
Labor	30,000	
Material	<u>500,000</u>	
(b) Total		530,000
(2) Total Direct Cost (a + b)		1,478,874
(3) Annual Cost of Capital (100% Financed, 20 year; 12%)		782,211
(4) Total Annual Operating Cost (2 + 3)		2,261,085
Annual Operating Cost/Ton; \$/ton		0.4522
Annual Operating Cost/ 10^6 Btu; \$/ 10^6 Btu		0.0226
Capital Cost/tons/hr; \$/tons/hr		\$ 9,472

TABLE 8. - LPF specifications (500 psig)

Parameter	Pilot Plant	Demo Plant	Commercial Plant
Tons/Day	120	1,200	15,000
Tons/hr	5	50	630
Pressure; psig	500	500	500
Number of Feeders	1	1	3
Approximate Size Diameter, in.	3.5	10	22
Chain Speed, ft/sec	2.2	2.2	1.9
Hp Required	47	226	2,841
Specific Power (hp - hr/ton)	9.4	4.51	4.51
Fill Factor	0.5	0.7	0.7

TABLE 9. - LPF system cost estimate

LPF - Pilot Plant Scale (5 tons/hr) - 500 psig		
Cost Elements	Item Costs	Totals
Feeder Cost	\$170,000	\$183,000
Weigh Belt System	3,000	
Miscellaneous	<u>10,000</u>	
Installation	26,000	36,000
Debugging	<u>10,000</u>	
Design Services	42,000	42,000
(1) Total Capital Cost		261,000
Operating Costs/year		47,030
Labor	40,000	
Utilities	<u>7,030</u> (\$0.025/kWhr for 8000 hr)	
(a) Total		
Maintenance Costs/year		17,000
Labor	2,000	
Material	<u>15,000</u>	
(b) Total		
(2) Total Direct Cost (a + b)		64,030
(3) Annual Cost of Capital (100% Financed, 20 year; 12%)		34,486
(4) Total Annual Operating Costs (2 + 3)		98,516
Annual Operating Cost/Ton; \$/ton		2.46
Annual Operating Cost/ 10^6 Btu; \$/ 10^6 Btu		0.1231
Capital Cost/tons/hr; \$/tons/hr		\$ 52,200

TABLE 10. - LPF system cost estimate

Demonstration Plant Scale (50 tons/hr) - 500 psig		
Cost Elements	Item Costs	Totals
Feeder Cost	\$700,000	
Weigh Belt System	19,600	
Miscellaneous	<u>25,000</u>	
		\$744,600
Installation	100,000	
Debugging	<u>25,000</u>	
		125,000
Design Services	125,000	125,000
(1) Total Capital Cost		994,600
Operating Costs/year		
Labor	40,000	
Utilities	36,644 (\$0.025/kWhr for 8000 hr)	
(a) Total		73,644
Maintenance Costs/year		
Labor	5,000	
Material	<u>45,000</u>	
(b) Total		50,000
(2) Total Direct Cost (a + b)		123,644
(3) Annual Cost of Capital (100% Financed, 20 year; 12%)		131,417
(4) Total Annual Operating Cost (2 + 3)		255,061
Annual Operating Cost/Ton; \$/ton		0.6377
Annual Operating Cost/ 10^6 Btu; $\$/10^6$ Bt		0.0318
Capital Cost/tons/hr; $\$/tons/hr$		\$ 19,892

TABLE 11. - LPF system cost estimate

Commercial Plant (15,000 tons/day) - 500 psig		
Cost Elements	Item Costs	Totals
Feeder Cost (3 feeders)	\$4,200,000	
Weigh Belt System (3 weigh belts)	150,000	
Miscellaneous	<u>120,000</u>	\$4,470,000
Installation	500,000	
Debugging	<u>150,000</u>	650,000
Design Services	200,000	200,000
(1) Total Capital Cost		5,320,000
Operating Cost/year		
Labor	100,000	
Utilities	424,437 (\$0.025/kWhr for 8000 hr)	
(a) Total		524,437
Maintenance Costs/year		
Labor	30,000	
Material	<u>500,000</u>	
(b) Total		530,000
(2) Total Direct Costs (a + b)		1,054,437
(3) Annual Cost of Capital (100% Financed, 20 year; 12%)		702,933
(4) Total Annual Operating Cost (2 + 3)		1,757,370
Annual Operating Cost/Ton; \$/ton		0.3515
Annual Operating Cost/ 10^6 /Btu; \$/ 10^6 /Btu		0.01757
Capital Cost/tons/hr; \$/tons/hr		\$ 8,512

5.2 Centrifugal Feeder System

The prototype centrifugal feeder was built with features to aid developmental work and information gathering. A practical feeder, for installation and operation in working plants, has always been envisioned as a compact pump with its own unique drive system, atmospheric pressure solids feed arrangement, seals and discharge (shown in Figure 15).

Figure 16 depicts a conceptual design for a centrifugal system, as installed on a coal conversion plant. The feeder is driven from below and the discharged solids are picked up in a pneumatic conveying system which carries them into an intermediate storage vessel. The face seals are liquid cooled and the cooling liquid is recirculated through a water cooled heat exchanger. The drive train and power supply package is either hydraulic or electric depending on the feeder size and power requirements.

Ancillary equipment will include the atmospheric pressure feed hopper, power supply to the drive train, face seal coolant system, and the conveying gas system.

The coal feed hopper operates at atmospheric pressure and is designed to hold coal for 15 min at feeder operating capacity. The cone included angle is 40 deg to aid gravity flow. However, provisions will be included for continuous fluidization of the cone. This, in turn, requires an air lock in the feed intake and a vent with a filter for the gases.

The feeder consists of the pump casing, rotor with sprues, the drive shaft with seals, bearings, cooling and pressurizing ports, and a rotating coal intake port with its own seal and seal cooling pressurizing ports. Advanced, but state-of-the-art, hardware will be used for the bearings and seals with gas or liquid cooling provided. Fluidized coal flows down the inlet tube to the hub of the rotor where the solids are separated from the gases. The solids are directed into the sprues while the gases are vented, at near atmospheric pressure, through a filter. A "boiler feed" type hydraulic power supply system is proposed for the power package to the rotor. This equipment is commercially available for large capacities and high pressures. The seal and bearing coolant system, shown in the figure, uses a liquid. The package comes with a coolant pump, reservoir and a heat exchanger where the cooling liquid, in turn, is cooled with utility cooling water.

FIGURE 15. - Centrifugal feeder - pump configuration.

FIGURE 16. - Centrifugal feeder system.

Specifications for centrifugal feeder systems for pilot, demonstration, and commercial gasification plant applications are given in Table 12. System cost estimates for these applications are presented in Tables 13 through 15.

5.3 Summary Comparison of the FMA Coal Feeders

The two FMA coal feeders together are capable of meeting all projected needs for feed systems for pressurized coal gasification and direct combustion applications.

The *LPF* is suitable for feeding all types and sizes of coal for fixed bed, stirred bed, fluidized bed, and entrained bed gasification applications at pressures to 1000 psig and above. The feeder is also well suited to feeding pressurized fluidized bed direct combustion boilers.

The *centrifugal feeder* is suitable for feeding pulverized coal to entrained bed gasifiers at pressures to 1000 psig. The concept is also likely to be suitable for fine coal feed to fluidized bed gasification processes at pressures to 500 psig.

Projected performance and economic data for the FMA feed systems are summarized in Table 16.

TABLE 12. - Centrifugal feeder system specifications

Parameter	Pilot Plant	Demo	Commercial
Tons/day	120	1200	15,000
Tons/hr	5	50	630
Pressure, lb/in. ²	1000	1000	1,000
Number of Feeders	1	1	3
Unit Capacity, tons/hr	5	50	210
Approximate Rotor Size Diameter, ft	2.25	2.7	4
Sprue Outlet Diameter, in.	0.28	0.46	0.75
Sprue Inlet Diameter, in.	1.5	2.5	3.5
Speed rpm	5000	4250	3,550
Downcomer Diameter, in.	1.6	4.25	9.75
Hp required	175	650	3 × 3,050

TABLE 13. - Centrifugal feeder system cost estimate

Pilot Plant (5 tons/hr) - 1000 lb/in. ²		
Cost Elements	Item Costs	Totals
Feeder	\$ 46,800	
Hydraulics	10,750	
Miscellaneous	<u>10,750</u>	
		\$ 68,300
Installation	136,600	
Debugging	<u>55,000</u>	
		191,600
Design Services	110,000	110,000
(1) Total Capital Cost		369,900
Operating Costs/year		
Labor	80,000	
Utilities	26,250 (\$0.025/kWhr for 8000 hr)	
(a) Total		116,250
Maintenance Costs/year		
Labor	22,000	
Material	<u>25,800</u>	
(b) Total		28,000
(2) Total Direct Cost (a + b)		144,250
(3) Annual Capital Cost (12%)		44,400
(4) Total Annual Cost (2 + 3)		188,650
Annual Operating Cost; \$/ton		4.71
Annual Unit Cost; \$/10 ⁶ Btu		0.189
Capital Cost; \$/tons/hr		\$ 73,980

TABLE 14. - Centrifugal feeder system cost estimate

Demonstration Plant (50 tons/hr) - 1000 lb/in. ²		
Cost Elements	Item Costs	Totals
Feeder	\$ 71,500	
Hydraulics	80,625	
Miscellaneous	<u>10,750</u>	
		\$162,875
Installation	244,300	
Debugging	<u>82,500</u>	
		326,800
Design Services	275,000	275,000
(1) Total Capital Cost		764,675
Operating Costs/year		
Labor	132,000	
Utilities	<u>107,250</u>	
(a) Total		239,250
Maintenance Costs/year		
Labor	4,400	
Material	<u>70,950</u>	
(b) Total		75,350
(2) Total Direct Cost (a + b)		314,600
(3) Annual Capital Cost (12%)		91,760
(4) Total Annual Cost (2 + 3)		406,360
Annual Operating Cost; \$/ton		1.015
Annual Unit Cost; \$/10 ⁶ Btu		0.040
Capital Cost; \$/tons/hr		\$ 15,294

TABLE 15. - Centrifugal feeder system cost estimate

Commercial Plant (15,000 tons/day) - 1000 lb/in. ²		
Cost Elements	Item Costs	Totals
Feeder	\$138,675	
Hydraulics	161,250	
Miscellaneous	<u>10,750</u>	
		\$310,675
Installation	466,000	
Debugging	<u>82,500</u>	
		548,500
Installed Equipment Cost (for 210 tons/hr)		859,175
Installed Equipment Cost (for 630 tons/hr)		2,577,525
Design Services	440,000	
(1) Total Capital Cost		3,017,525
Operating Costs/year		
Labor	176,000	
Utilities	<u>1,475,500</u>	
(a) Total		1,651,500
Maintenance Costs/year		
Labor	16,500	
Material	<u>191,350</u>	
(b) Total		207,850
(2) Total Direct Cost (a + b)		1,859,350
(3) Annual Capital Cost (12%)		362,100
(4) Total Annual Cost (2 + 3)		2,221,450
Annual Operating Cost/ \$/ton		0.4407
Annual Unit Cost; \$/10 ⁶ Btu		0.0177
Capital Cost; \$/tons/hr		\$ 4,789.7

TABLE 16. - Projected feed system specifications for
pilot, demonstration, and commercial scale
gasification plants

Parameter	Linear Pocket Feeder	Centrifugal Feeder
Pressure, psig	1,000	1,000
Capital Cost, tons/hr		
Pilot Plant (120 tons/day)	\$65,800	\$73,980
Demo Plant (1,200 tons/day)	21,892	15,294
Commercial Plant (15,000 tons/day)	9,472	4,789.7
Operating Cost/ton		
Pilot Plant	2.86	4.71
Demo Plant	0.7548	1.015
Commercial Plant	0.4522	0.4407
Specific Power, hp × hr/ton		
Pilot Plant	18.8	35
Demo Plant	9.04	13
Commercial Plant	9.04	14.5

6. REFERENCES

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