

DEVELOPMENT OF COAL-FEEDING SYSTEMS
AT THE MORGANTOWN ENERGY RESEARCH
CENTER

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John Mark Hobday*

ABSTRACT

The Morgantown Energy Research Center (MERC) has developed a variety of systems since 1945 for feeding crushed and pulverized coal into coal conversion reactor vessels. This paper describes their past and current work on these systems including pneumatic methods for feeding pulverized coal, slurry feeders, and coal pumps, methods for steam pickup, and a method for drying a water-coal slurry in a steam-fluidized bed subsequent to feeding the coal into a reactor vessel.

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1. INTRODUCTION

The renewed emphasis on coal as a primary energy source and the investigation of a variety of conversion processes on a larger scale have resulted in increased research and development activity in coal feeding techniques and equipment. Processes for delivering/feeding the coal into the gasifier have usually been developed incidental to the process with varying degrees of success. The purpose of this paper is therefore to review and summarize MERC's experience and research on coal feeding systems in the last 30 years.

The development of coal feeding systems at MERC is divided into two parts for this presentation:

- A historical discussion covering the period from 1945-1965
- A discussion of progress from 1966 to date

Since our time is limited, my presentation does not contain detailed data. However, for those who are interested in the system's problems and current progress, a comprehensive bibliography is included which lists reports and documents generated by MERC on coal-feeding systems.

2. HISTORY (1945-1965)

The Bureau of Mines at Morgantown has done considerable research on a variety of coal-feeding systems including research on atmospheric and pressurized coal gasifiers as well as developing a coal-fired gas turbine. Most of these processes required the feeding of pulverized coal either to the gasifier (atmospheric or pressurized) or turbine combustor.

During this early stage of coal-feeding development, Morgantown successfully fed coal at varying rates from 2 grams (laboratory scale) to 2 tons (pilot scale) per hour from vacuum to 600 psig. Morgantown was also awarded four patents, three on feeders and one on unique controls for a feeder.

In the following paragraphs, I will discuss those feeding systems which Morgantown has either used or conducted research on during the 20 years from 1945-1965.

2.1 FLUIDIZED FEEDER

Purpose

The objective of using the fluidized feeder in coal gasification was to develop a system that will continuously feed pulverized coal at a uniform rate to a reactor with operating pressures up to 600 psig. Developmental work extended from the 1950's to the early 1960's. (4,12,17,21,26)

Features

The initial development at Morgantown started with a laboratory-scale feeder which injected coal at atmospheric pressure. As the investigations progressed, larger feeders were built until satisfactory performance was demonstrated at pilot scale. When the emphasis shifted to pressure gasification, the fluidized feeder was adapted for use at pressure; however, feeding the pulverized coal at pressure created definite problems.

A schematic diagram of the fluidized-feeder system is depicted in Figure 1. Coal is fluidized in the pressurized feeder by inert gas (carbon dioxide plus nitrogen) and recycled by the recycle compressor which maintains a bed density of about 20 lbs/ft³. A dense, fluidized stream flows continuously through a calibrated coil to the pressure gasifier. Excess fluidized gas leaves the top of the feeder through an internal centrifugal dust collector; passes through a knockout chamber for further de-dusting; is recompressed by the compressor; and is cooled before re-entry into the feeder. A small amount of inert gas is added continuously to replace the conveying gas leaving with the coal.

The Morgantown pilot-scale fluidized coal feeder, used with the pressure gasifier, was equipped for zone fluidization which limits the circulation of fluidizing gas and prevents the carryover of particles into the recycle system, particularly the recycle compressor. Zone fluidization functions (Figure 2) as follows. Fluidizing gas enters as two separate streams, auxiliary fluidizing gas and main fluidizing gas. Auxiliary fluidizing gas provides limited fluidization of the main coalbed and ensures migration of finely divided coal particles from the main bed into the central column. Main fluidizing gas creates a fully fluidized zone within the central column. Fluidized coal is withdrawn from the central zone through a feeder discharge

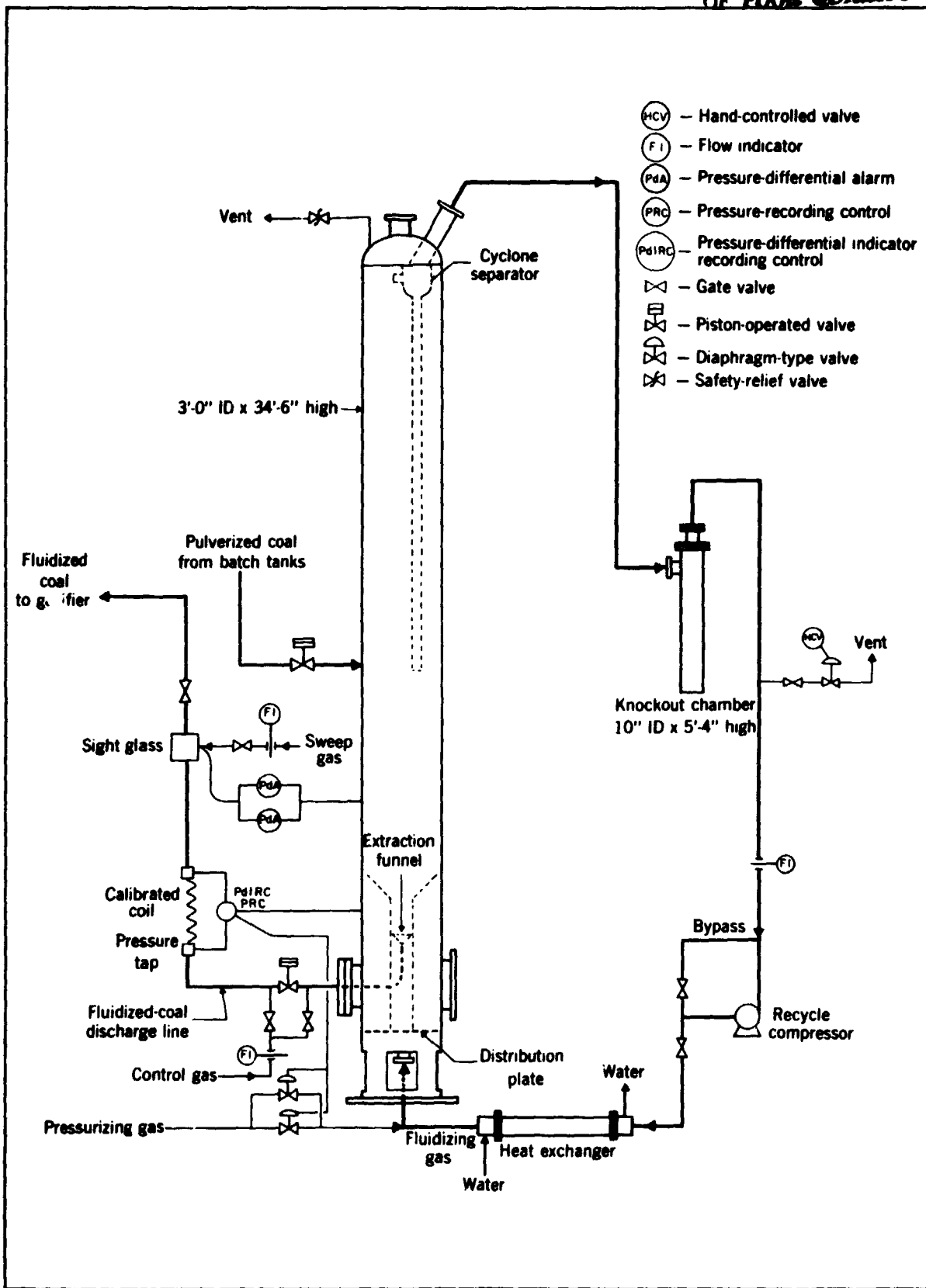


Figure 1. Pilot-Scale Fluidized Feeder Utilizing Zone Fluidization

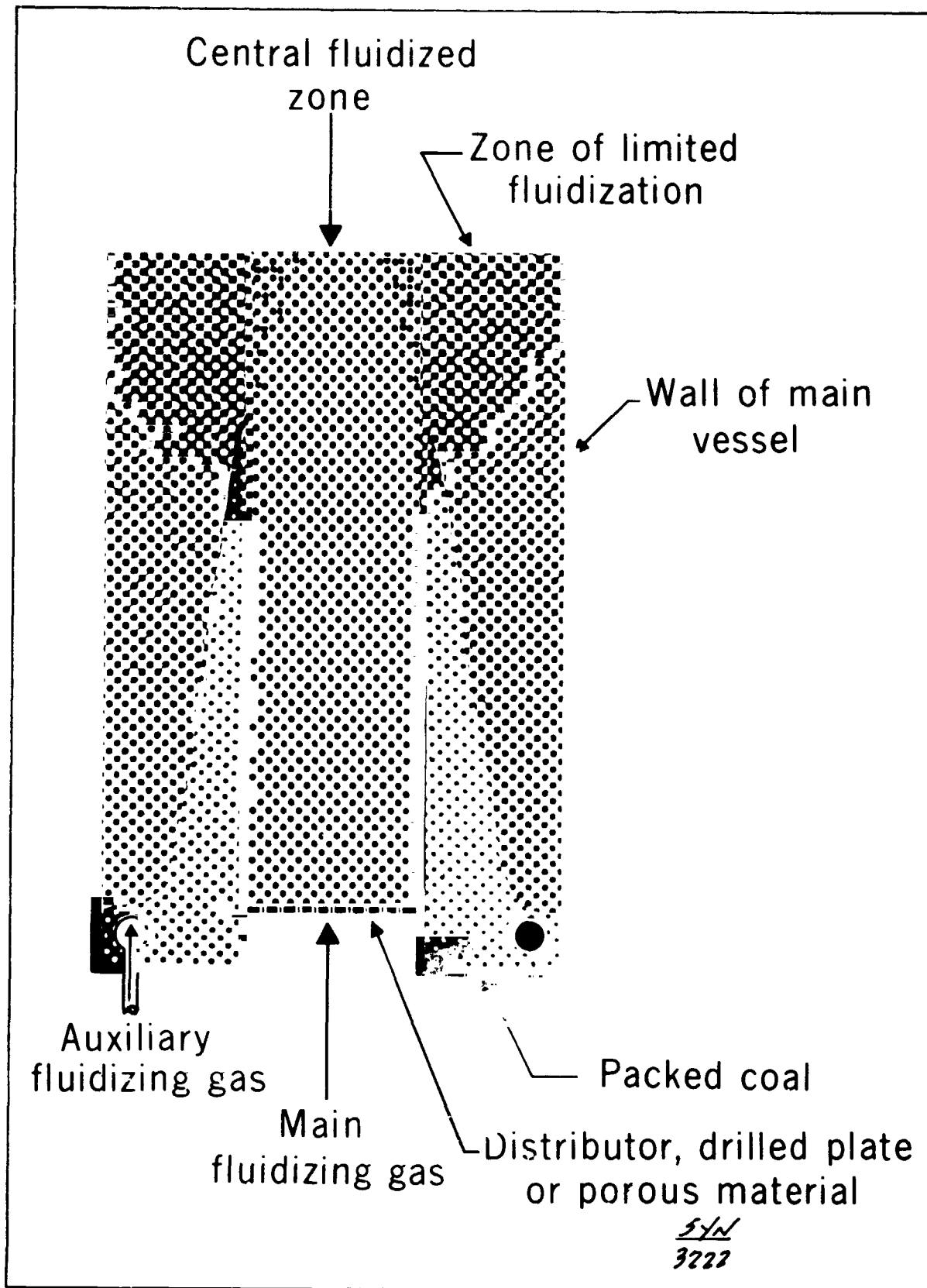


Figure 2. Zone Fluidization Technique

line. The gas distribution plate near the bottom of the continuous feeder supports a 6-foot high central fluidizing column, with a 13-inch diameter, topped by a 70° funnel. The 60° extraction funnel shields the coal delivery tube, preventing erratic flow.

Results

The fluidized coal-feeding equipment satisfactorily demonstrated an accurate method of feeding coal to a pressure vessel at 450 psig with a capacity of 1 to 2 tons/hour (tph). Two coal metering devices, calibrated coil and weigh cell system, worked satisfactorily and fluidizing gas requirements were low. Equipment was also developed for storing and transferring pulverized coal. Scale tanks were used for transferring coal between buildings. They were pressurized at the top with the coal and gas leaving at the bottom. The valves at the exit controlled the flow. Transfer rates of 1 to 8 tph were achieved.

Figure 3 shows the fluidized feeder on the weigh cells. The feeder is the tall cylindrical vessel. The recycle-gas line runs from the top of the feeder to the bottom. A surge tank for the inert gas supply is in the foreground, and the calibration receiver with conical bottom is on the scales at the right.

2.2 PULSE FEEDER

Purpose

During the late 1950's, Morgantown gained experience in pulse feeders through an improvement to a laboratory size apparatus. This work was performed while studying dust collection. (34,35)

Features

The pulse feeder is a laboratory type feeder for entraining powdered solids in a pulsating gas stream, wherein the powder is fluidized in a vertical tube and is withdrawn intermittently at the bottom.

The system operates as follows. The pulsating air is admitted to the feeder at a controlled rate through the orifice just above the dust-outlet nozzle. At each impulse peak, a small quantity of the carrier air flows up through the dust-outlet nozzle and the dust bed and escapes through a bleed-air tube above the dust bed. At the low-pressure point in each impulse, the

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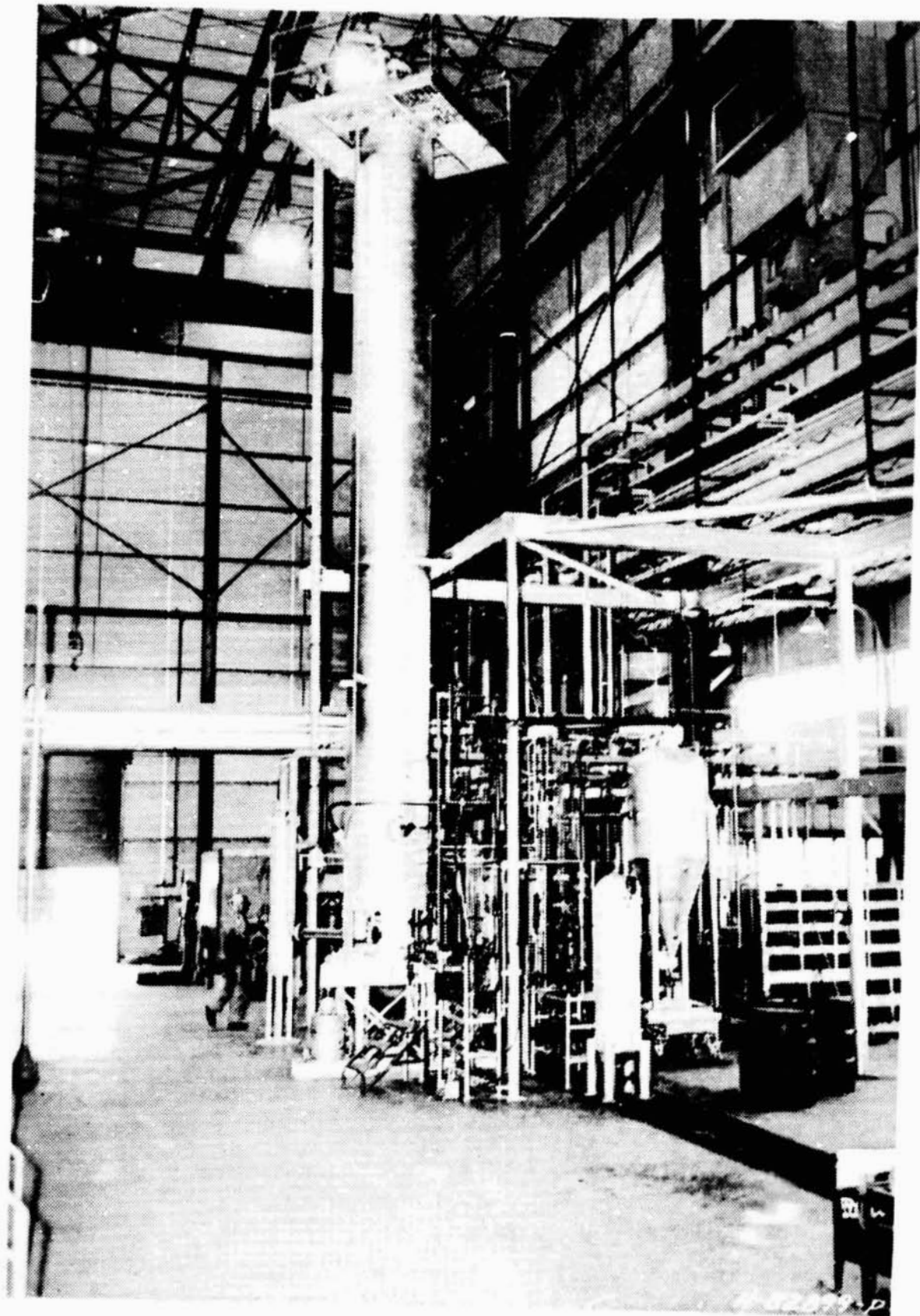


Figure 3. Fluidized Coal Feeder and Related Equipment

air flow through the nozzle reverses, and a small increment of dust is entrained by the pulsating carrier-air stream. This operation results in a continuous flow of pulsating air through the bleed-air line and an intermittent discharge of dust from the outlet nozzle. Feed rate will remain constant if the average operating pressure and the pressure differential across the dust-outlet nozzle and dust bed are maintained constant. See Figure 4 for an illustration of the system.

Results

Findings showed that the system had a range of feed rates from 1 to 200 gm/hr. However, the system may not be feasible for scale-up.

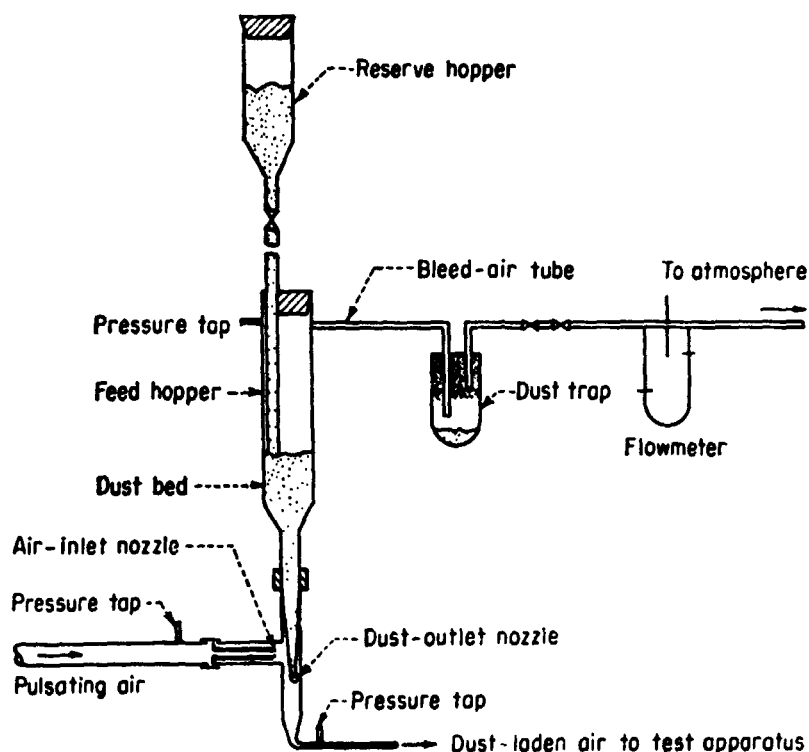


Figure 4. Pulse Feeder

2.3 BAILEY FEEDER (STEAM PICKUP)

Purpose

It became necessary to develop a reliable coal-feeding system in conjunction with the Bureau's programs on coal gasification. The Bailey feeder (also referred to as the steam pickup coal feeder) was modified and incorporated into the pilot plant, which gasified pulverized high-volatile A bituminous coal with oxygen and superheated steam.

The primary purpose of operating the pilot plant, equipped with steam-pickup feeding, was to determine the operability of the gasifier fed by this method as compared to the results obtained when the gasifier was fed with the fluidized coal feeder. Development extended from the late 1950's to the early 1960's.

Features

A Bailey feeder (star-wheel feeder) was used to feed a mixture of coal and steam to the pressure gasifiers.^(36,38,50) Figure 5 illustrates this process. Lock hoppers were used for pressurizing the coal. Between the hoppers was a 4-inch motor-driven ball valve. The system operated with 70% through 200-mesh coal. The star-wheel feeder was mounted at the bottom of the main hopper (Figure 6), and regulated the coal flow to the water-cooled tee where the superheated steam and coal mixed.

Results

The system's capacity was from 1 to 2 tons of coal per hour. It had an advantage over the fluidized feeder in that it required no recycle gas. However, its disadvantage was that close control of the differential pressure across the feeder was required to maintain uniform rates.

2.4 ORIFICE FEEDER

In support of a Bureau of Mines' program on coal gasification process development during the late 1960's, an orifice-type feeder was developed. A patent was subsequently issued.⁽³²⁾

Features

The orifice feeder was a laboratory-type feeder applicable to continuous uniform coal feeding. As shown in Figure 7, the feeder can discharge into a pneumatic pickup line or a screw conveyor into a fluidized bed and directly into a pressurized reactor.^(3,22,32)

The device consists of a chamber with multiple, vertically spaced orifices aligned and decreasing progressively in size from top to bottom. Material is introduced through the entry at the top of the chamber. When using this feeder to introduce coal into a pressurized reactor, it has been found advantageous to maintain a slight positive gas pressure, relative to the reactor pressure. Lock hoppers may also be conveniently used with this system.

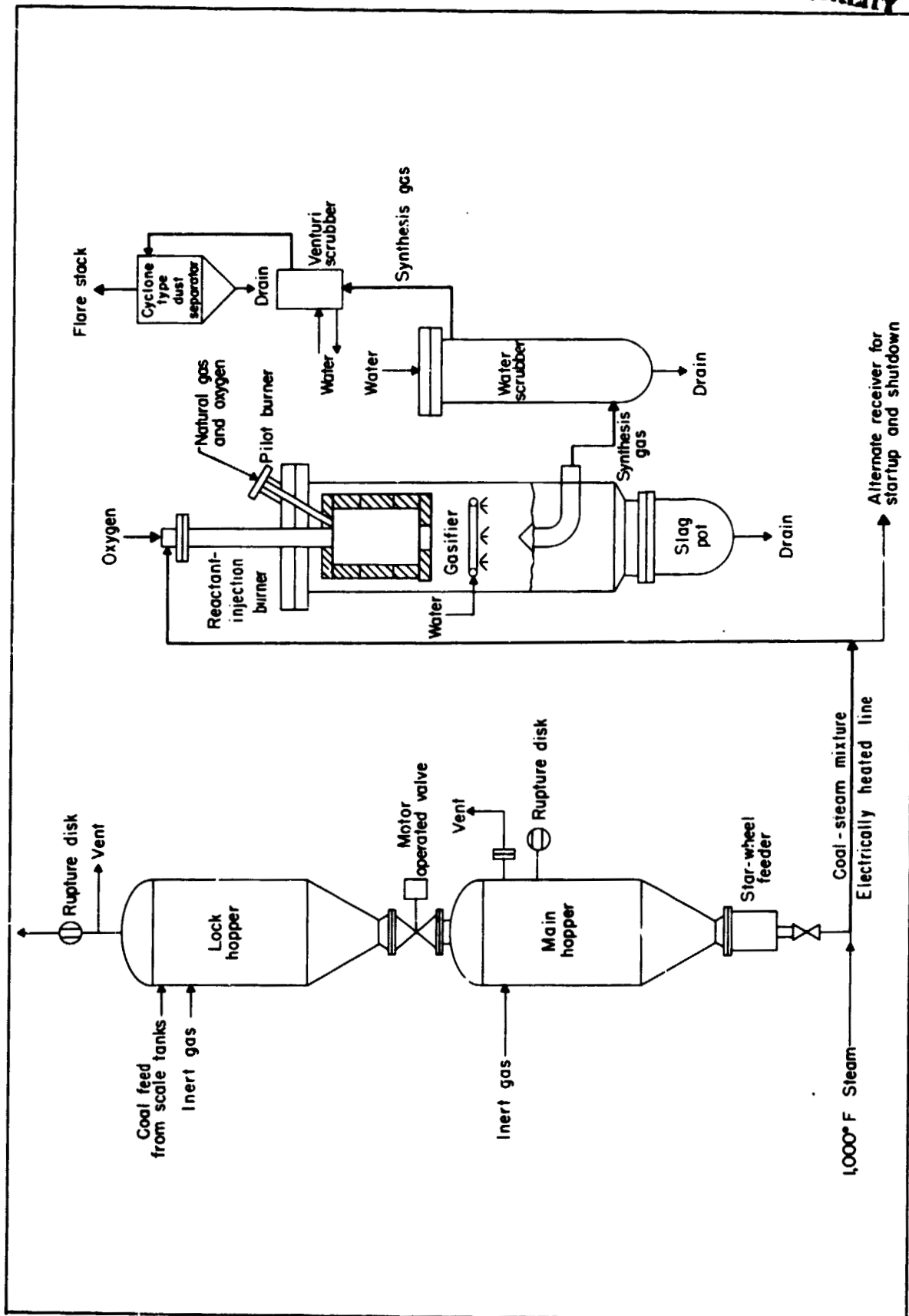


Figure 5. Pressure Gasification Pilot Plant Equipped with Steam Pickup Coal Feeder

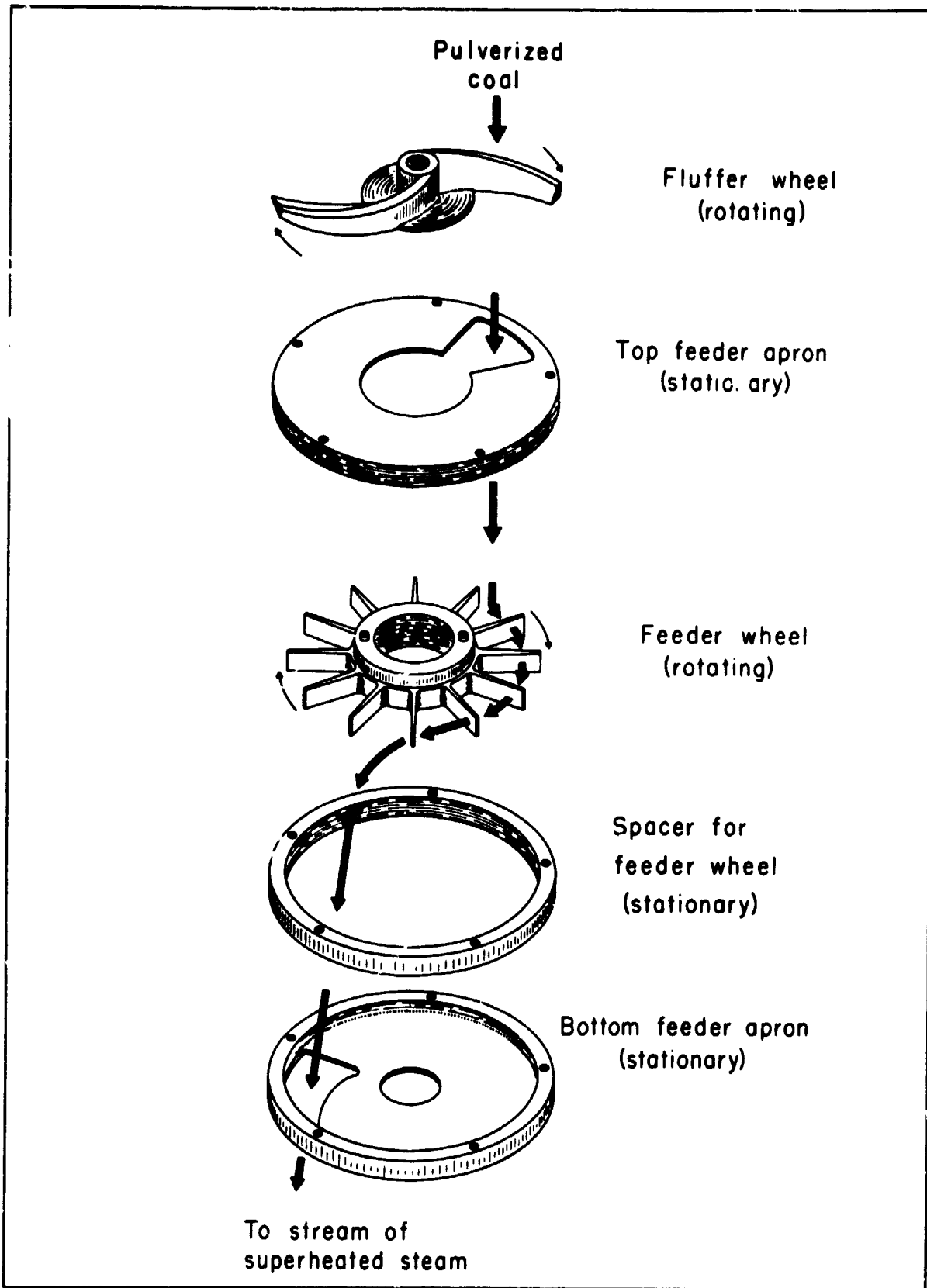
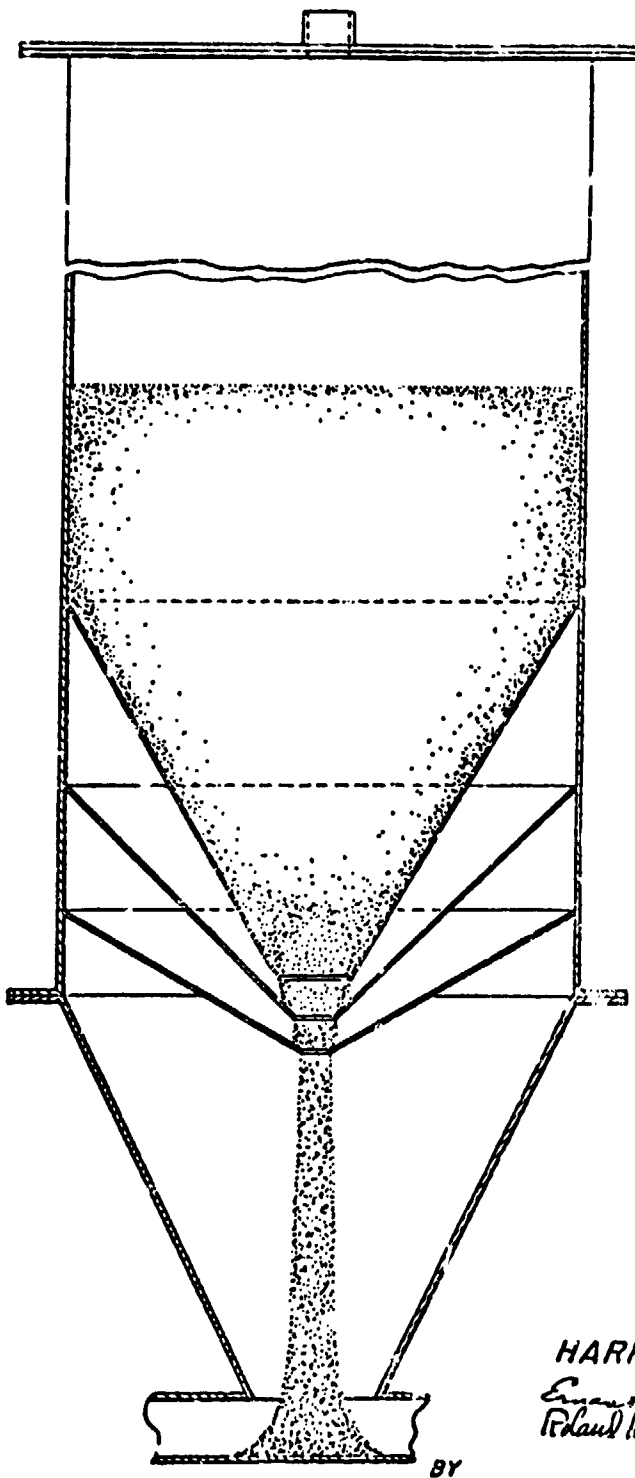


Figure 6. Exploded View of Star-Wheel Feeder

Dec. 23, 1969

H. G. LUCAS
PARTICLE FEEDER WITH WALLS OF PROGRESSIVELY
INCREASING RESISTANCE
Filed Aug. 13, 1968

3,485,420



INVENTOR
HARRY G. LUCAS
Edward J. Cohen
Richard H. Shubert
ATTORNEYS

BY

Figure 7. Orifice Feeder

Results

Coal char experience demonstrated a constant feed rate of 4 gm/hr to 27.5 kg/hr into a fluidized bed. The system solved the problem of uncontrolled flow rate due to nonuniformity of particle size. The inventor also claimed that the system has a scale-up capability.

2.5 LDC COAL-FEEDING SYSTEM

Purpose

The Bureau of Mines conducted a comprehensive research and development program on a direct coal-fired gas turbine plant. The LDC coal-feeding system is one of the pneumatic systems tested for pulverizing and feeding coal to the combustors. The feeding system was previously developed and operated by Locomotive Development Committee, Bituminous Coal Research, Inc., for use in locomotives utilizing coal. For the Bureau's purpose of evaluating the effects of coal firing on turbine life, this system was installed in preparation for the 1500-hour coal-fired turbine run during the fall of 1962.

Features

The LDC feeding system supplies 3500 lb/hr coal at 86 psig to the turbine's combustors. Coal crushed to 3/16-inch x 0 and containing about 3% moisture and 6% ash is fed into the top of the coal pump and fills the pockets of the rotor. The coal is rotated to the bottom of the pump, where air sweeps the coal from the pockets at 90 psig and carries it into the pulverizer. The pulverizer operates at approximately 86 psig and 3600 RPM and reduces the coal to 90% through 200 mesh. The pulverizer requires 100 hp when coal is ground under pressure as compared to 35 hp when coal is ground at atmospheric pressure, primarily because of increased windage losses. The coal/air mixture leaving the pulverizer flows through the 2½-inch pipe to the combustors. This system contains relatively compact equipment. Figure 8 shows the coal-feeding system; ^(40,43) Figure 9 illustrates the coal pump.

Results

The overall system was seriously limited by the pulverizer's operating life; erosion of the parts resulted in an unbalanced rotor. The pump also had problems with seals and running clearance.

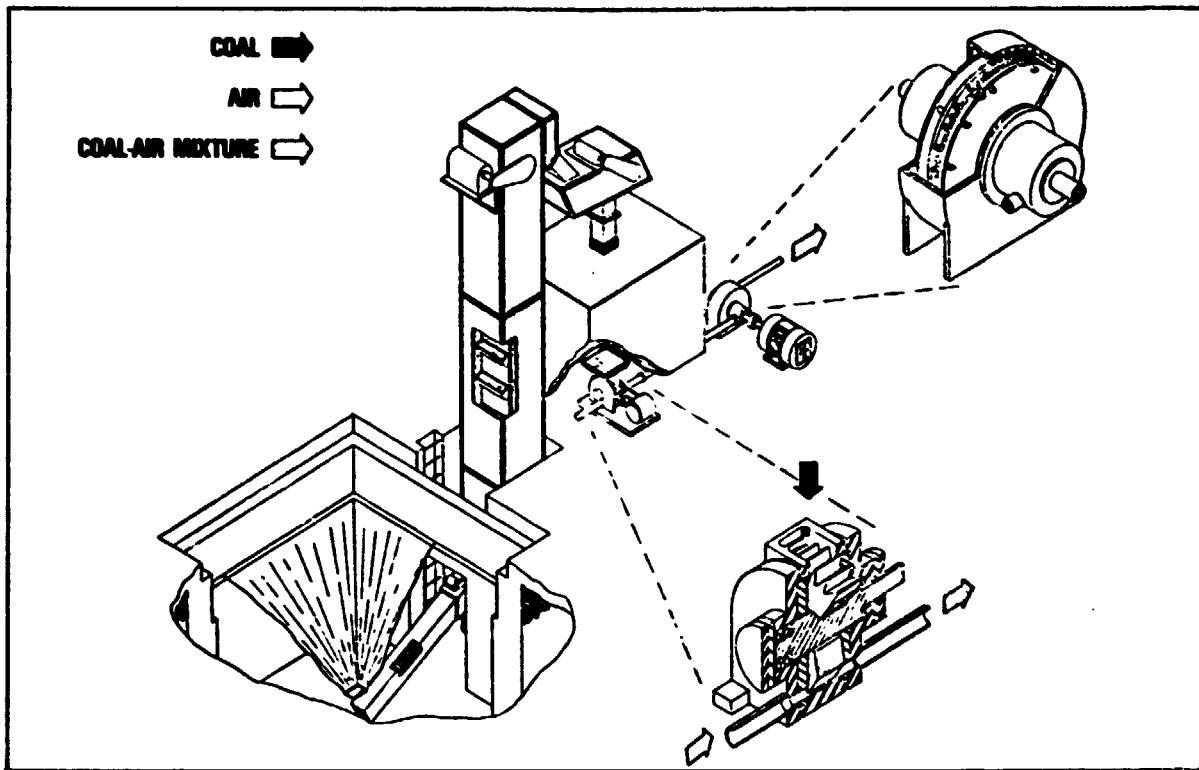


Figure 8. Coal Feeding System Using LDC Components

Later reports indicate that the Koppers Company improved the seals so that a higher degree of success was obtained while operating at a pressure of approximately 50 psig.

2.6 FULLER-KINYON PUMP

Purpose

The Fuller-Kinyon pump was installed to determine if it would work at 90 psig pressure differential and feed directly to the process, thereby eliminating the need for lock hoppers.

Features

Basically, the pump (Figures 10 and 11) consists of a high-speed screw with a gradually reducing pitch section at the delivery end. The coal being conveyed is advanced by the screw from the hopper section into a short barrel section where it is compressed to form a seal against blowback. The coal is then discharged into a stream of inert gas which carries the coal to the process.

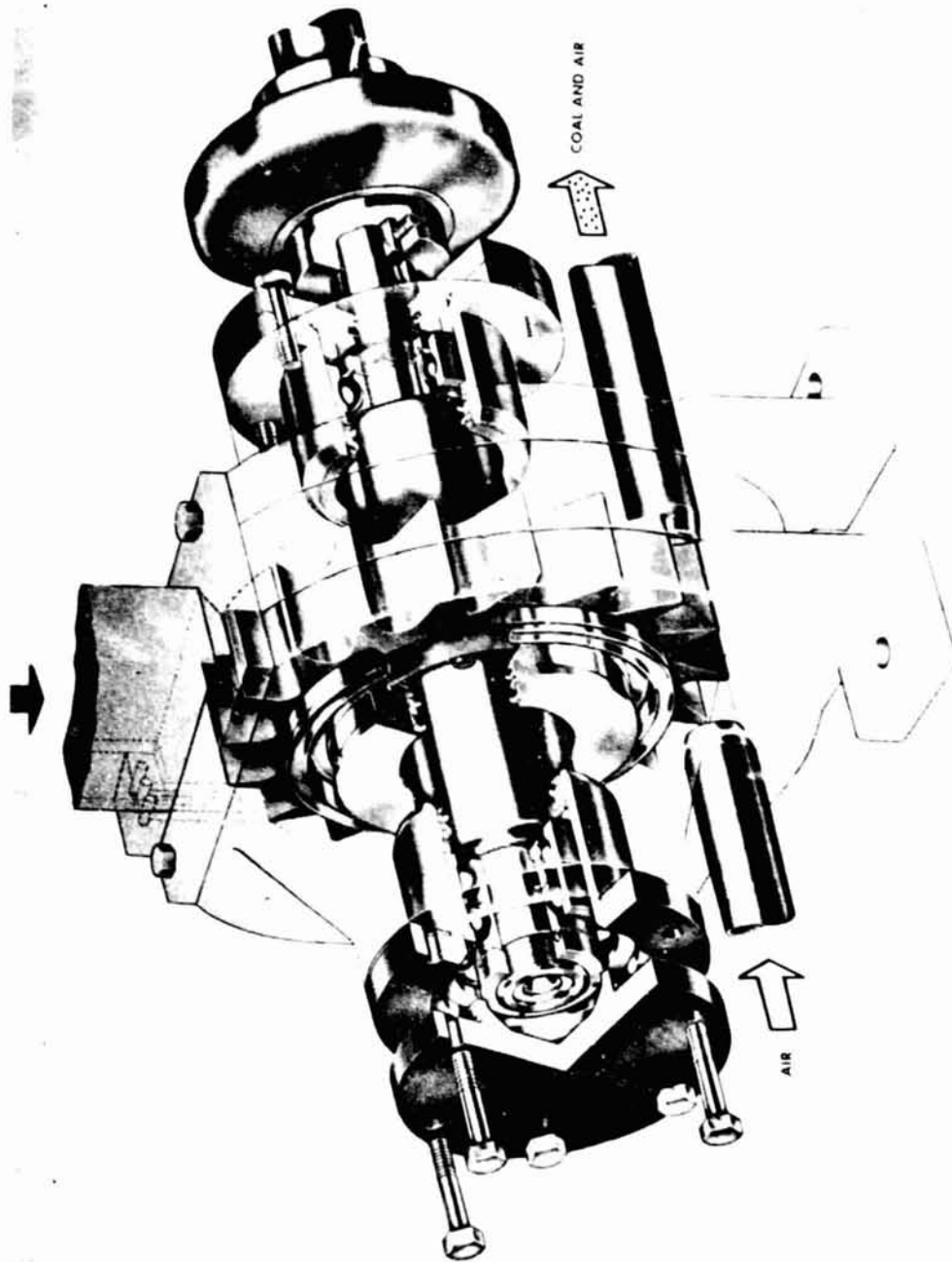


FIGURE 9. L.D.C. COAL PUMPS

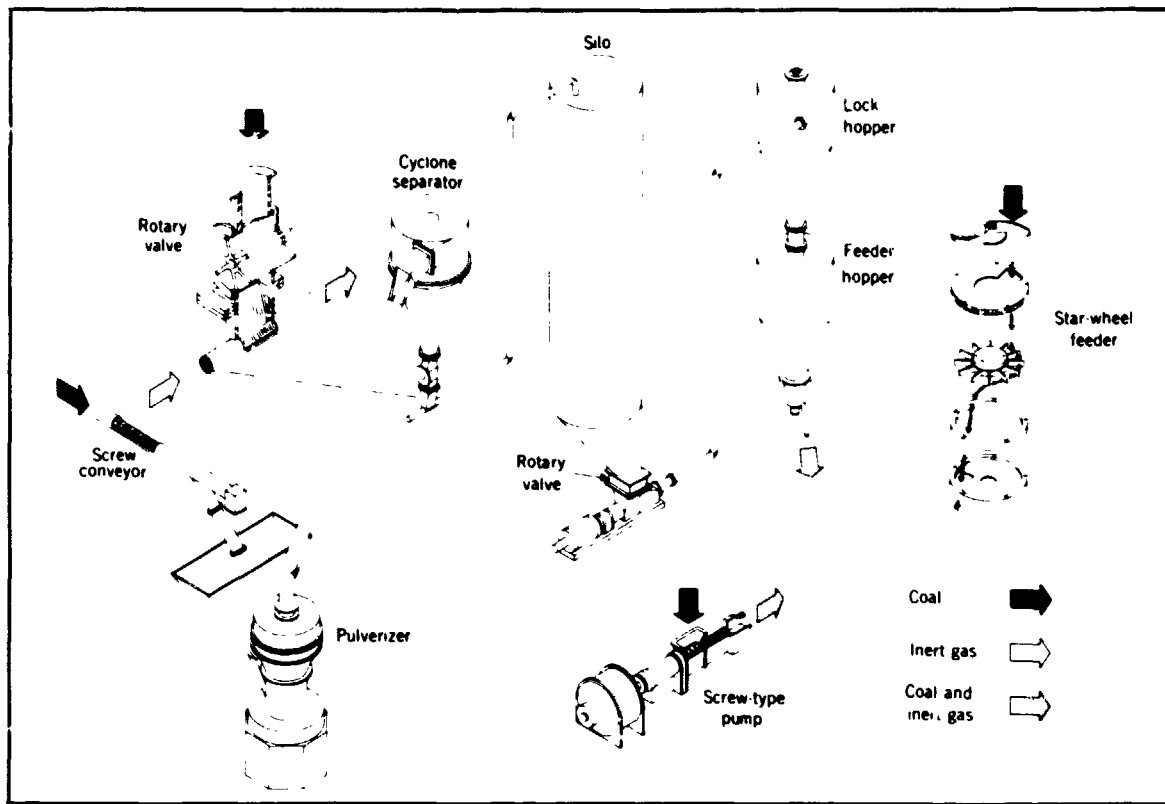


Figure 10. Star-Wheel Coal Feeding System

Results

The coal-feeding system with the Fuller-Kinyon pump satisfactorily fed approximately 3500 pounds of coal per hour to the turbine combustor with a pressure differential of 15 psig. The Fuller Company is currently working on improving the pressure rating.

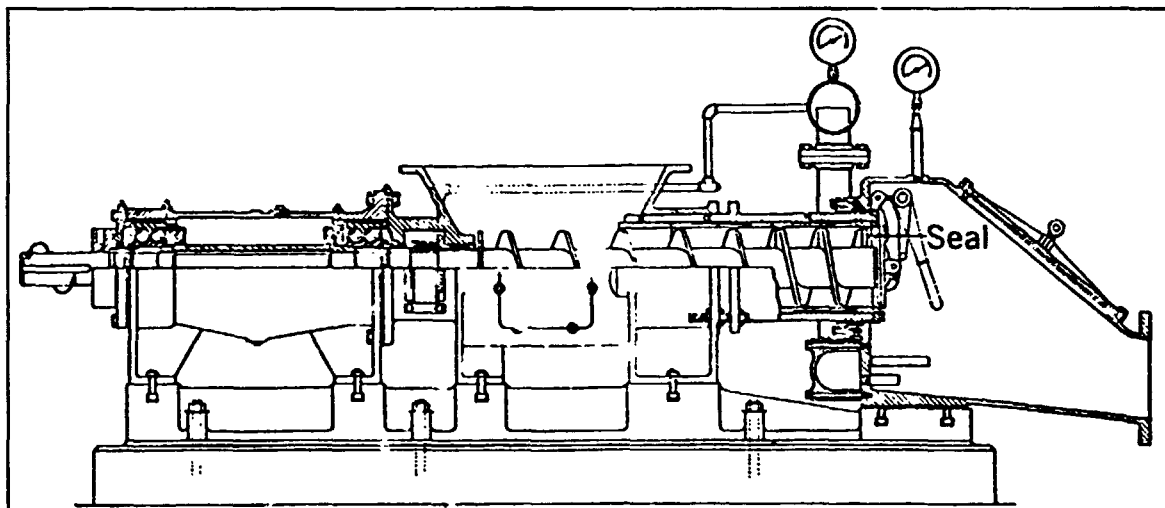


Figure 11. Fuller-Kinyon Pump Schematic

2.7 STAR-WHEEL COAL FEEDER WITH INERT GAS AS THE CARRIER GAS

Purpose

To overcome the pulverizer problems, the star-wheel coal feeder system was developed, installed, and tested for the same 1500-hour test run on a gas turbine in 1962. One objective of this program was to determine the system's reliability.

Features

The system (Figure 10) contained several standard commercially available feeders. (35,37,38,40,44,45) The first was a standard screw conveying 3/16-inch x 0 coal; the second was a rotary valve operating at 7 to 15 psig differential. Another rotary valve at the bottom of a 10-ton capacity storage silo was designed and built at MERC and operated with balanced pressures. The Fuller-Kinyon (screw-type) pump operated with a 15 psig differential pressure. The lock hopper star-wheel feeder combination was used with the star-wheel feeder operating as described in the steam-pickup or Bailey feeder.

Results

The system was automated, completely reliable, and satisfactorily transferred pulverized coal to the coal-fired gas turbine for about 2000 hours. The demonstrated rate was 3500 pounds of coal per hour. The disadvantages of the system were the cost of inert gas and the complexity of the system.

2.8 PETROCARB FEEDER

Purpose

During the early 1960's, the Bureau of Mines gained experience with the Petrocarb feeder while investigating the feasibility of pneumatic transport of pulverized coal in small lines. The program's objective was to develop basic information on pressure drops in a pneumatic system.

Features

The Petrocarb system installed at MERC consisted of a weigh hopper and a receiver hopper. The weigh hopper and receiver hopper were connected by 250 feet of 2-inch or 3-inch pipe, and operated as a batch system. Inert gas (88% N₂, 12% CO₂) was used as the conveying medium.

Results

The system had the capacity to feed coal at a rate of 60 tph at pressures up to 100 psig. Since this is a sophisticated rate control system, it depends largely on instrumentation. The system performed satisfactorily for a complete series of tests which lasted about four months.

3. RECENT PROGRESS (1966-1977)

The feeders discussed in this section are recent or on-going projects at the Morgantown Energy Research Center.

3.1 LOCK HOPPER SYSTEM

Purpose

From mid-1960 to early 1970, the lock hopper coal-feeding system was used in the MERC gas producer. The feeding system was to deliver coal (2 inches x 0) at pressures up to 300 psig.

Features

In the lock hopper operation, coal is dropped from a feed hopper into a lock hopper at atmospheric pressure. The lock hopper is then pressurized to slightly above the coal gasifier operating pressure. The coal is discharged from the lock hopper, the hopper is isolated, and the pressurizing gas is vented in preparation for the next feeding cycle. In the first setup on the producer, the coal was choke fed to the gasifier by lock hoppers. In the second (present) setup (Figure 12), the coal is transferred through a rotary valve and an inclined screw into the gasifier. The screw is MERC-designed and fabricated and serves as a scraper rather than a feeder.

Results

Based on our previous experience, the lock hopper system is the most reliable and trouble-free system for feeding dry solids. However, the first problem occurred when this system was used with our gas producer and required larger valves (10 inch) to facilitate feeding of large size coal. The system operates, but valve maintenance has been a constant problem. The system rate is 1 ton per hour for pressures up to 300 psig.

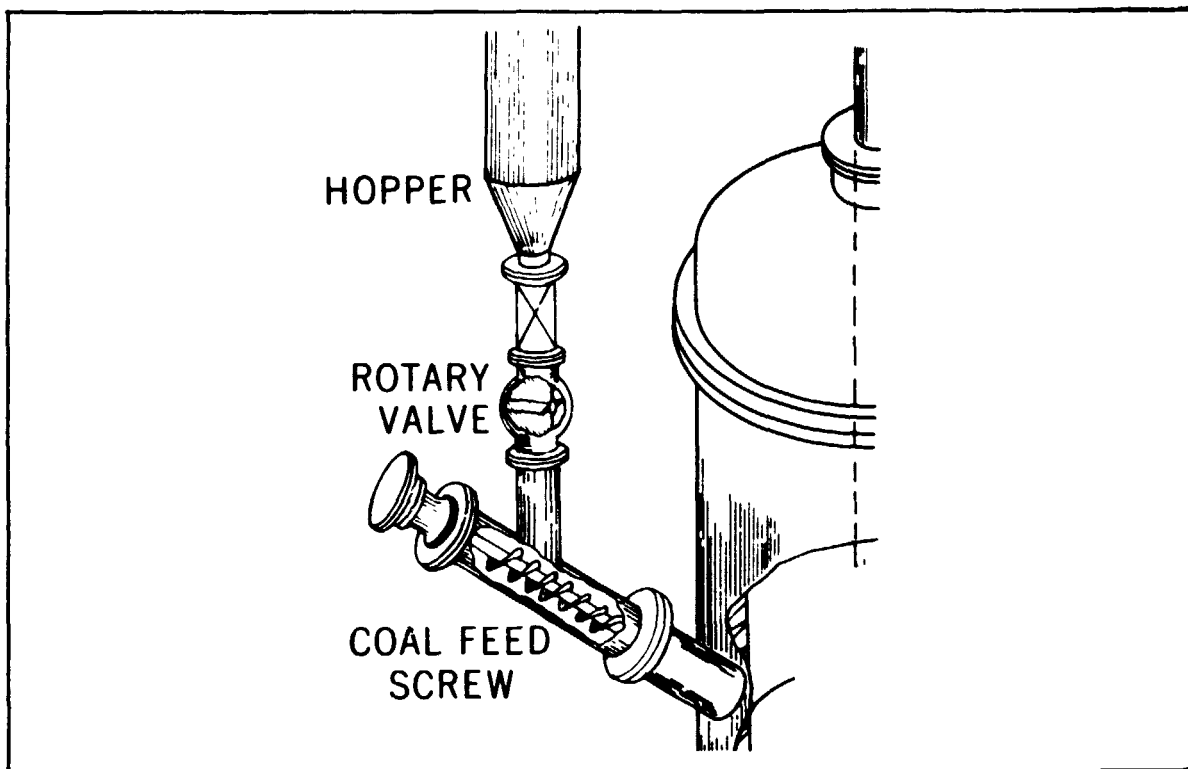


Figure 12. Lock Hopper System with MERC Gas Producer

3.2 VALVE DEVELOPMENT FOR LOCK HOPPER SYSTEM

Purpose

Over the past two years, a valve R&D effort has been underway at MERC. The objective is to develop valves which will be operable, easily maintainable, and have a long life when used in lock hopper systems in coal conversion plants. This development program was initiated to solve the continuing problems of using larger valves and higher pressures in lock hopper systems. (10)

The project was divided into two programs:

- Prototype Valve Test Program
- State-of-the-Art (SOA) Valve Test Program

The objective of prototype valve testing is to design an efficient lock hopper valve capable of handling solids with long life and minimum maintenance cost. The valve designs should also have scale-up capability for use in pilot plant testing and subsequently for commercial plant use.

The prototype valves being furnished ERDA by contract will be available for evaluation in May 1978, with units for pilot plant operation to be available a year later. To bridge this gap, commercially available designs or slight design modifications are required to provide valves for the current pilot plants and early demonstration plants. The SOA Program has been initiated to help identify appropriate valves.

The objective of SOA valve testing is to generate a valve life cycle and engineering data base that will provide a comparative baseline from which to measure improvements achieved by the prototype valves.

Features

For the purpose of this testing, a generic classification was developed to identify types of valves for specific lock hopper applications. Figure 13 depicts typical lock hopper valve applications and indicates the four different types of service:

- Type I - Feed system valves generally located at the inlet to a loading or injection lock hopper
- Type II - Feed system valves typically located between the loading lock hopper and the gasifier or reactor
- Type III - Discharge system valves usually located at the gasifier or reactor outlet. These discharge into the char or ash lock hopper
- Type IV - Slurry discharge system valves located at the ash lock hopper outlet.

MERC has the capability to test valves with solids up to 600 psig and ambient temperature. By fall of this year, that capability will be increased to 1200 psig and 600^oF. Two additional systems are currently under design and scheduled for completion next year, one for testing Type IV slurry discharge valves and the other for testing with solids at temperatures up to 2000^oF. MERC also has a metrology laboratory to support this program and works closely with Oak Ridge National Laboratory, Argonne National Laboratory, and the Bureau of Mines for materials selection and failure analysis.

Results

SOA valves have been selected and ordered from nine supplying companies. Selection was made on the basis of a technical evaluation of those design

features that showed promise of reducing the primary valve failure mode of seat scoring. Eight valves have been through a screening test and the metrology laboratory. Tests with solids are scheduled for June 1977.

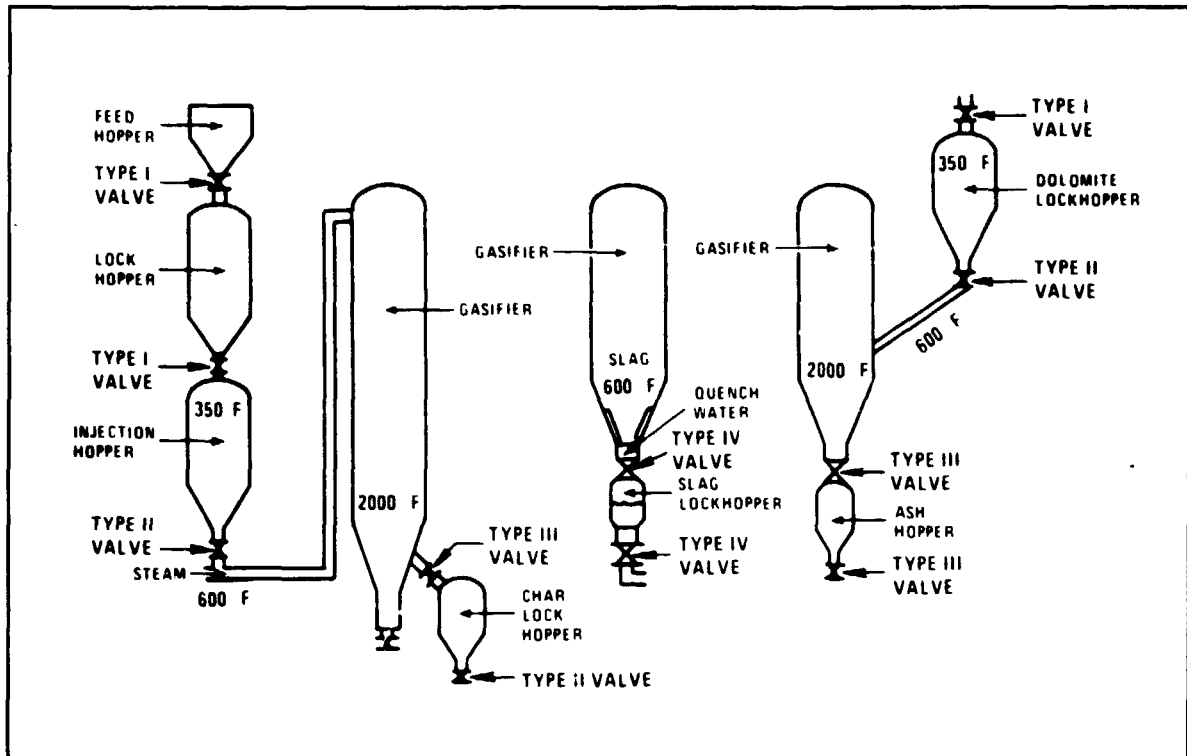


Figure 13. Typical Lock Hopper Valve Applications

3.3 SLURRY FEEDER

Purpose

The development of a steam-dried slurry-feed system is a program which started in FY 1977 and is expected to be completed in three years. The objective is to develop a coal-feed system for high-pressure processes using crushed coal. The method is to pump a coal-water slurry to achieve operating pressure and then dry the slurry in a vertical lift dryer using superheated steam. Steam was selected since it is anticipated that it will be used in other parts of the conversion process. This development program provides technology support for plants such as Bi-Gas.

Earlier work on coal-in-water suspensions fed to a pressurized gasifier started in the early 1960's. Although research and development work has been intermittent, the MERC programs, involving coal-slurry feeding, continued step-by-step to try to find solutions for problems encountered in earlier work.

Previous work with slurry feeding at pressures to 450 psig showed that major problems arose when indirect heat exchange was used to vaporize the water in the slurry. Temperatures had to be limited to about 600° to 650°F to avoid problems from plasticity of the coal. Also, even at these relatively low temperatures, problems occurred when part of the ash dissolved in the water and was deposited downstream on the inside wall of the steaming section.

Features

This current slurry-feeding project uses superheated steam to dry a pressurized coal-water slurry in an entrained bed, thereby eliminating problems of indirect heating. MERC is developing the system (Figure 14) in a pilot plant nominally operating at rates of 300 to 1000 lb/hr of coal-water (50wt% of coal) slurry. The slurry will be pumped into a vessel at 250 psig where it will be contacted by superheated steam. Water in the slurry will be vaporized, creating a stream of dry coal contained in superheated steam at pressure. The two components will be split in cyclone separators and steam will be vented. Eventually, steam will be recycled through a compressor and superheater.

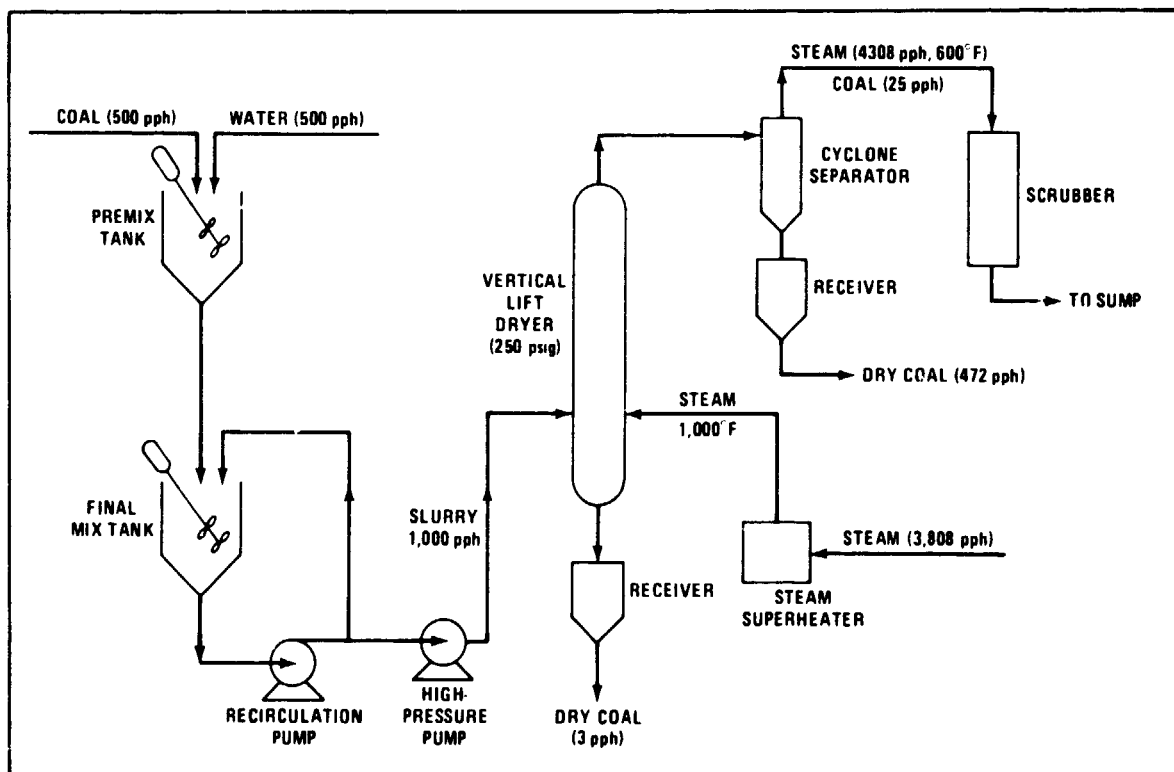


Figure 14. Steam-Dried Coal Slurry Feed System

The series of MERC development work on coal slurries are discussed in detail in several references listed in the bibliography. (8,9,10,11,25,51,55)

Results

The design is complete, and construction of the system has started. Operation is scheduled to begin in early October 1977.

3.4 ROTARY PISTON FEEDER

Purpose

The research program on new design concepts for coal pumps was initiated locally to improve dry coal-feeding systems. Detailed designs of feeding mechanisms will be developed, and sealing wear as well as lubrication problems will be investigated. A low pressure (100 psig) prototype will be built and tested.

Features

The pump will consist of a rotary feeder with a piston (Figure 15) that seals the feeder void after the coal is dumped into the pressurized vessel, thereby preventing gas loss. Various means of activating the piston to give the desired feeding action into the pressurized chamber will be investigated. The present design uses a fixed cam with a roller follower to activate the piston and piston spring. The main advantages of the system are its compact size, simplicity in operation, minimum use of gas, and variable capacity depending on the number of cylinders used in the unit. In addition, this pump may be used on all sizes of coal from run-of-mine to pulverized.

Results

This program is in process. (10) Shop drawings for the prototype are complete, and construction on the prototype will begin this year. Cost of this program to date is less than \$50,000.

3.5 EXTRUSION FEEDER

Purpose

In 1970, MERC's program on formed coke investigated production of a uniformly sized blast-furnace fuel using a hot extruder. While working on this program, it was recognized that the same technique may be applied to high-pressure coal feeding.

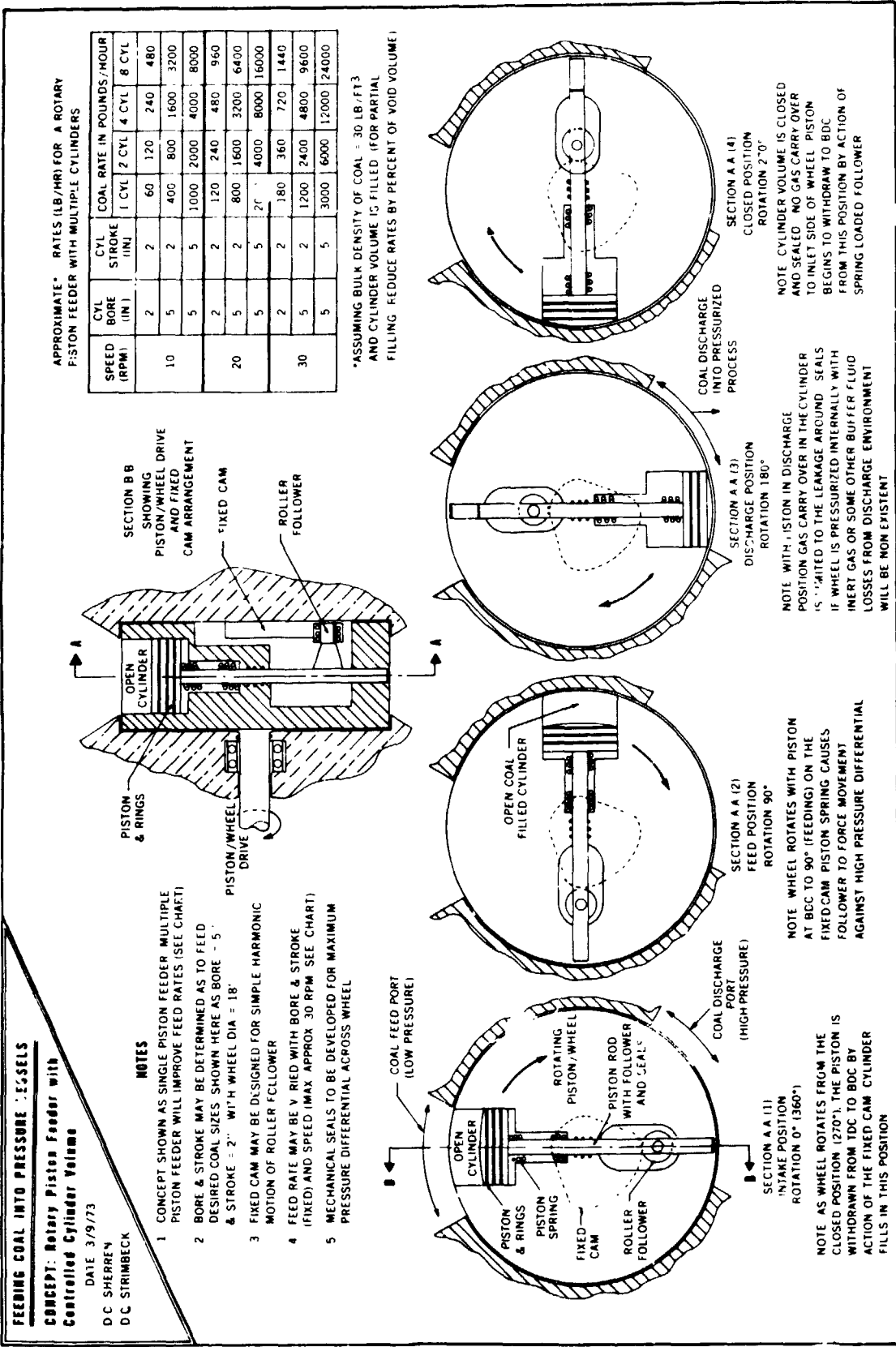


Figure 15. Rotary Piston Feeder

Features

A commercially available laboratory-size extruder (Figures 16 and 17) was improved for use in the Formed Coke Program. It consists of a powerful drive system and a wide selection of speed ranges, a modified barrel and auger, and automatic temperature controls. The barrel is a 2½-inch, schedule-40, stainless steel pipe electrically heated by resistance coils wrapped around the pipe and insulated to prevent appreciable heat loss. The barrel is divided into two sections, conveying and forming. Each section requires about 1500 watts for heating the barrel to proper operating temperature. The auger is heated by a cartridge-type heater located within the center of the shaft.

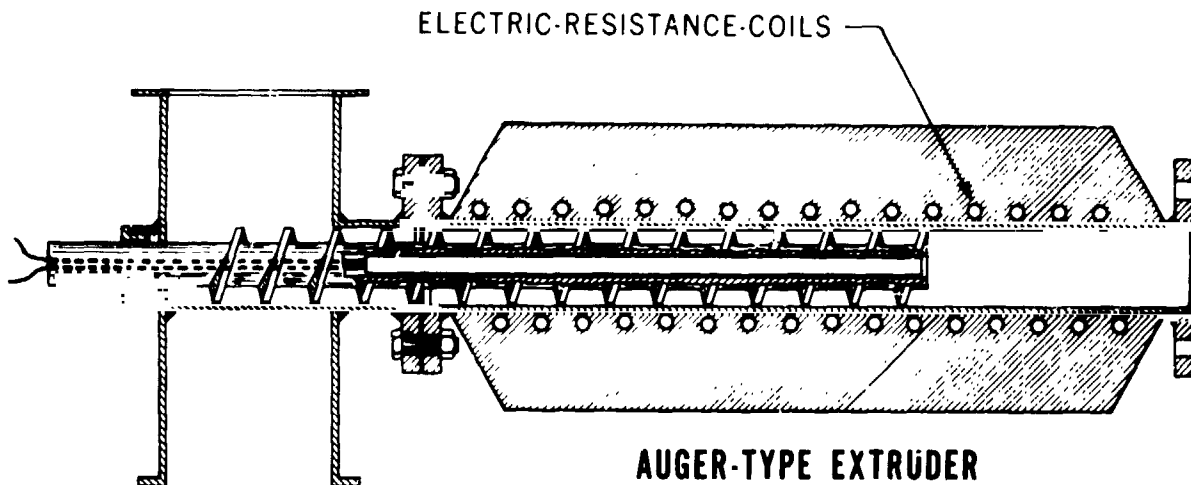


Figure 17. Extruder Schematic

Results

The problems encountered were coke clogging of the auger or barrel, premature coking, excess volatile matter buildup which caused "blowouts," and incomplete heat transfer throughout the coal mixture. To solve these problems, coals were blended, preheating was tried, and variable screw depths were used in conjunction with tapered barrels. These attempts were only partially successful. The program emphasis shifted and the program was stopped. As a result, the initial plan of developing the extruder as a feeder was not pursued.

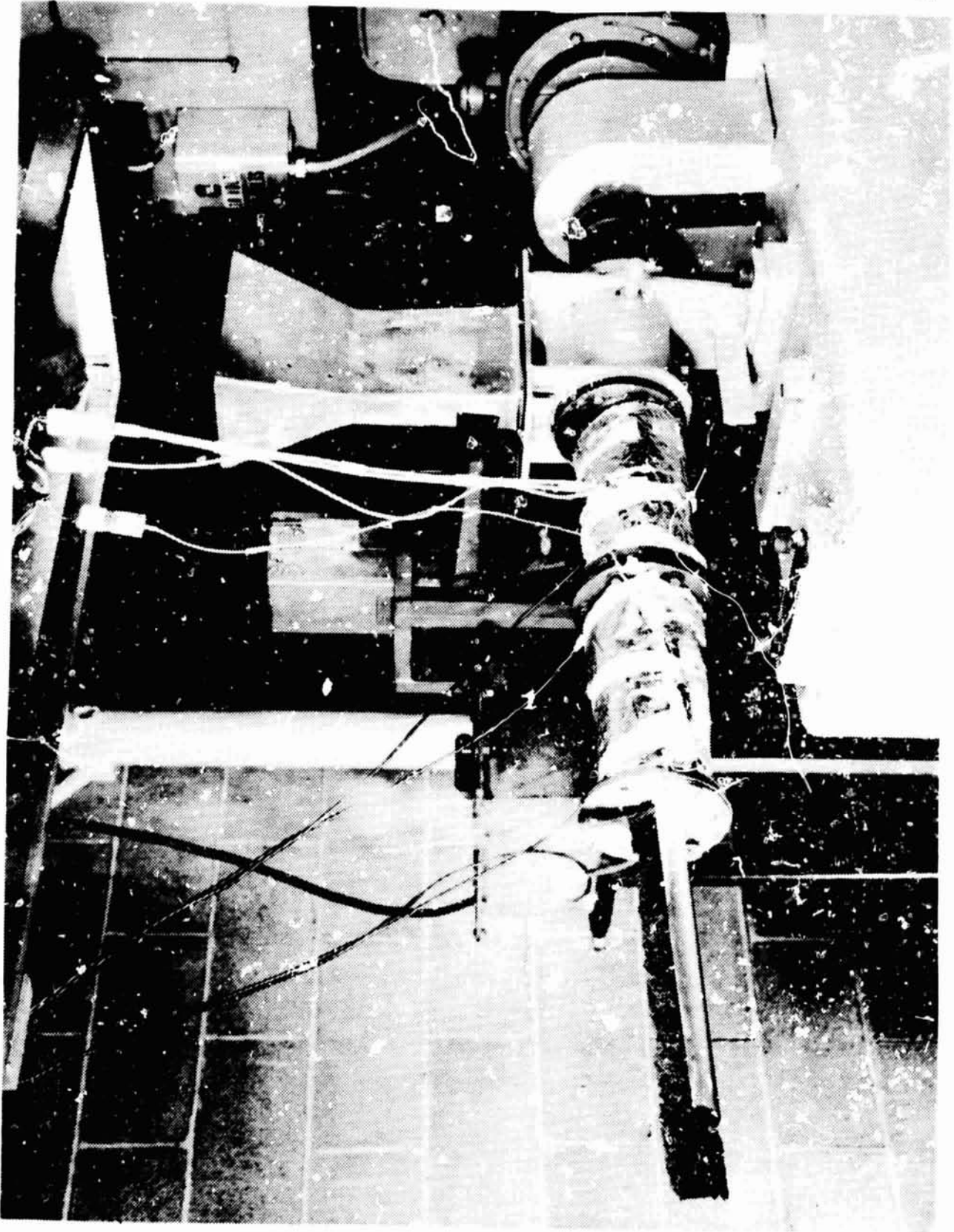


Figure 16 Auger Extruder

3.6 FUTURE TESTING

Starting in 1978, MERC will begin full-scale testing of two coal extrusion systems. An 1 to 5 tph high-pressure extruder being developed by Ingersoll Rand will be installed in the 42-inch pressurized fixed-bed gas producer. Tests will be conducted in the 100 to 300 psig range. A smaller 100 pph atmospheric-pressure unit will be installed in the 18-inch atmospheric fixed-bed gasifier. The objective of both of these tests is to provide in-field operating data and experience with both extrusion systems. Design, procurement, and fabrication of the modifications are underway. Delivery of the extruders is planned for January 1978.

4. CONCLUSION

Among the coal-feeding systems discussed, the lock hopper system is the most widely used. Such a system is very successful, especially when using smaller valves (less than 4 inch) and at lower pressures (up to 450 psig). For the future, in addition to improvements in lock hoppers, other feeding systems need to be developed which are smaller and which have low capital and operating costs, require minimum pressurizing gas, and include mechanical design requiring minimum maintenance.

The current activities on coal-feeding development at the Morgantown Energy Research Center are presented in Figure 18 (exclusive of positive-displacement piston-type coal pump). This chart identifies various alternatives to feeding coal at pressure. However, each of these systems needs further development before it can be adapted to a particular coal conversion process.

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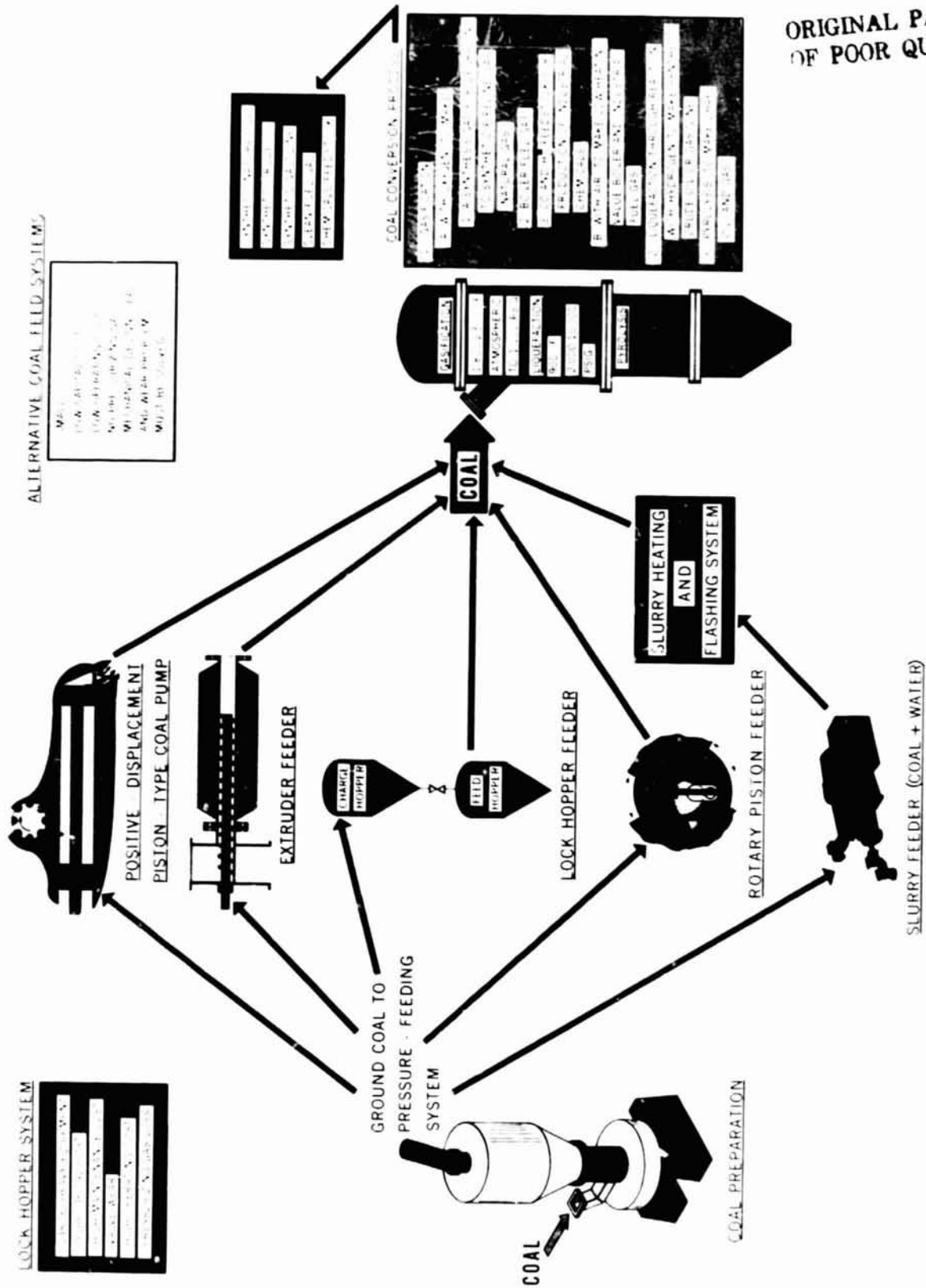


Figure 18. Alternative Coal Feed Systems

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