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FOSTER-MILLER'S DEVELOPMENT OF DRY COAL FEED SYSTEMS

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PREFACE

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ABSTRACT

A critical problem with all coal conversion processes which operate above atmospheric pressure is the delivery of coal to the process. The techniques now employed for feeding pressurized processes, lock hoppers and slurry feed systems, have serious shortcomings which render them questionable choices for commercial coal conversion applications.

Foster-Miller is developing alternative (second generation) dry coal feeder systems for pressurized conversion processes under contract to the Energy Research and Development Administration. Four feeder concepts were carried through a laboratory scale development program. These concepts included:

1. A centrifugal solids feeder
2. A fluidized piston feeder
3. A linear pocket feeder
4. A compacted coal plug feeder

The centrifugal feeder conveys pulverized coal from atmospheric pressure to a high pressure receiver by subjecting the coal to high centrifugal forces. The fluidized piston feeder is analogous to a reciprocating slurry pump, but with a fluidized feed stream rather than a slurried feed stream. The linear pocket feeder concept employs a series of sealed pockets to move the coal into the pressurized receiver. The design is suitable for a wide range of coal sizes. The coal plug feeder is a very simple design in which the coal feed is compacted into briquettes to limit high pressure gas losses.

Laboratory model testing of all concepts has been completed with encouraging results. Prototype pilot plant scale versions of concepts 1-3 have been built and are now under test. Promising feed systems will ultimately be installed on ERDA sponsored pilot scale conversion plants such as Synthane and Bi-Gas.

DEVELOPMENT OF DRY COAL FEED SYSTEMS

1. Introduction

The objective of this 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 presently approved, apply to pilot plant applications. The eventual objective of the ERDA program is to develop coal feeders for demonstration plant applications. Feeder design considerations beyond the basic design specifications 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.

Table 1. Specifications for Coal Feeder Development

Parameters	Value
Feed Rate	3 to 5 tons per hour
Feed Size	Fine - 3/4 inch
Feed Pressure	100-1500 psi
Temperature	As required

The program plan to accomplish the above objective is broken down into five phases which include:

Phase I - Coal Feeder Conceptual Development

Phase II - Pilot Scale Coal Feeder Development

Phase III - Pilot Plant Feeder System Qualification Testing

Phase IV - Pilot Plant Coal Feeder Development

Phase V - Feed System Installation and Test

The first phase has been completed having been conducted from June to December of 1975. Phase II, The Pilot Plant Scale Coal Feeder Development stage, involves translating the concepts from Phase I into actual hardware and verifying projected performance capabilities. This phase was initiated in September of 1975 and should be completed by October of 1977. Phase III, Pilot Plant Feeder System Qualification Testing, involves the construction and test of feed systems for eventual pilot plant installation. In Phase III these feed systems would be operated on a test facility at Foster-Miller Associates (FMA). Phase III is expected to be carried out during 1978 and 1979. Phases IV and V involve the refurbishing of the pilot plant feed system, (Phase IV), and the actual installation and testing of the feed system on a pilot plant, (Phase V). It is anticipated that the initiation of the Phase IV and V efforts would occur about 1980. The present FMA program is funded through Phase II.

2. Background

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 thru 200 mesh) and fixed bed/stirred bed reactors requiring the coarsest feed size. (Typically 1 3/4 x 1/4 inch 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 high pressure conditions. In this paper, feeder application will be related to gasification bed type.

Table 2. Generic Classification of Gasification Reactors

Type	Examples	Coal Size
Entrained Bed	Bi-Gas, Koppers - Totzek	Pulverized (70 percent - 200 mesh)
Fluidized Bed	Hygas, Synthane	Minus 8-20 mesh (to 1/8 inch for direct combustion)
Fixed Bed/ Stirred Bed	Lurgi, G.F. gas	Coarse (1-3/4 x 1/4 inch 1/16 inch)

3. Phase I Results

The objective of Phase I was to evaluate all possible ways of feeding coal to pressurized reactors and to recommend several techniques for development into hardware. As a result of the Phase I effort, FMA generated a series of concepts which cover the possible range of applications. Parenthetically, FMA also concluded, as a result of Phase I effort, that there is no such thing as a universal feeder. The result of the Phase I effort was a recommendation for continued development of four different feeder concepts. These concepts can broken down roughly into two classes; mechanically sealed and coal sealed. The four concepts are as follows:

1. Linear Pocket Feeder 2. Fluidized Piston Feeder	Mechanically Sealed
3. Centrifugal Feeder 4. Coal Plug Feeder	Coal Sealed

Each of these concepts is described in detail below.

3.1 Linear Pocket Feeder

The first of the FMA concepts to be discussed is the linear pocket feeder illustrated schematically in figure 1. This feeder is essentially an enclosed tubular conveyor with very tight clearance. The device is pressure balanced across the receiving vessel so that the only driving forces required are those necessary to overcome friction. Referring to figure 1, the feeder can be broken down into five different sections; the feed section, the sealing section, the unloading section, the gas transfer section, and the return section.

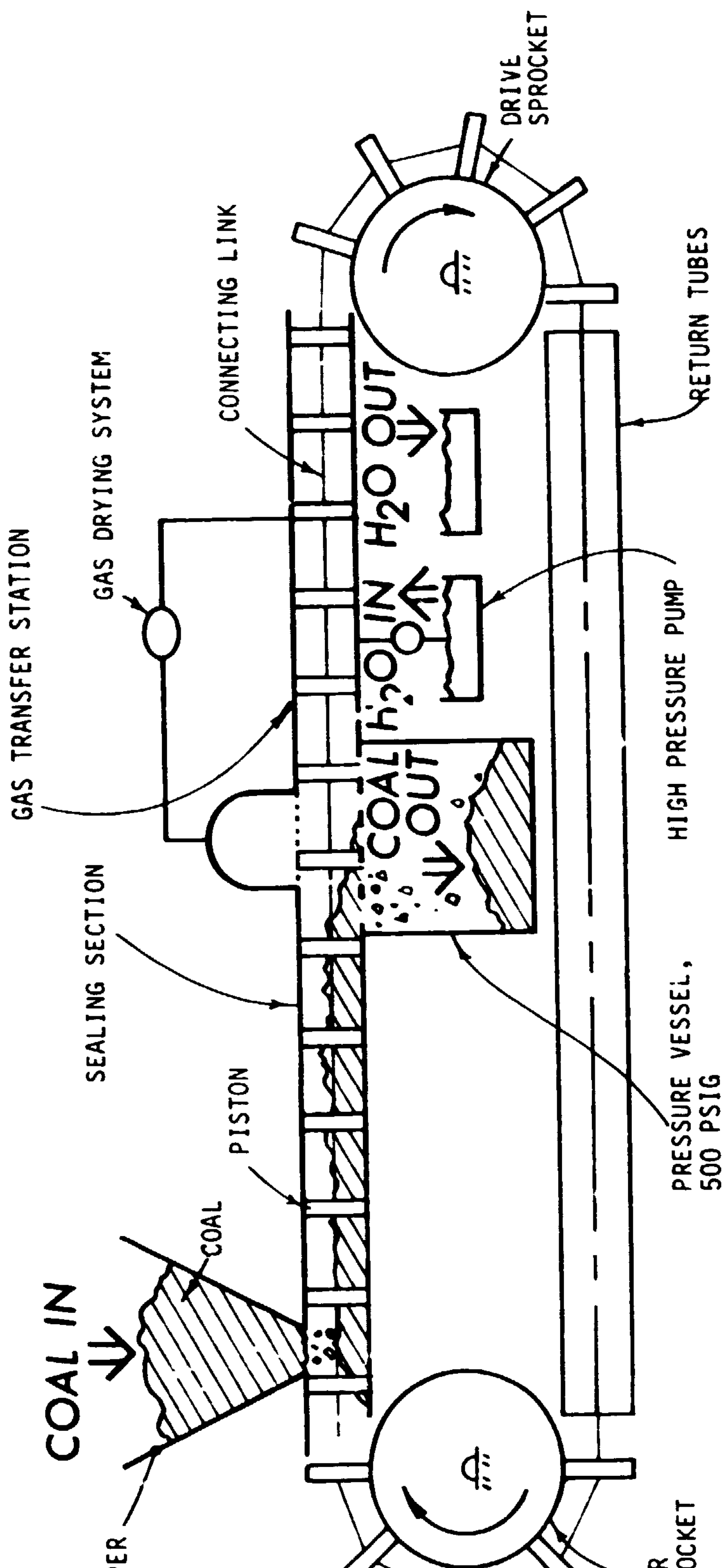


Figure 1. Schematic of Linear Pocket Feeder

In the feed hopper section coal is fed into the conveyor. This is followed by the sealing section where the conveyor flights pass through a close fit tube where they seal against the receiver vessel pressure. In the coal discharge section, the coal is dropped out of the conveyor and into a pressurized vessel. As the conveyor moves out of the discharge section, the space between the conveyor flights remains filled with high pressure gas. In the fourth section, the gas displacer section, high pressure water is pumped into the conveyor to displace the gas back into the receiver. As the conveyor comes out of the gas displacer section, the water is dumped into a sump and recycled. At this point the conveyor flights are dried off and pass thru a return section, which is merely a guide section to return the conveyor flights to the coal feed section.

In analyzing the linear pocket feeder functionally, it can be seen that this feeder or any other feeder has three basic functions to perform. The first of these functions is sealing against pressure, the second is transporting the coal, and the third is metering the coal. In the case of the linear pocket feeder, the sealing function is performed by means of a series of mechanical seals, the transportation function by the positive displacement action of the conveyor, and metering is controlled by the linear speed of the conveyor.

The linear pocket feeder is a straight forward feeder concept featuring redundant sealing and a simple efficient gas displacer technique. The feeder is suitable for all sizes and types of coals. The linear pocket feeder concept is suitable for near term applications, specifically, fixed and stirred bed gasification reactors and pressurized fluidized bed direct combustors.

3.2 Fluidized Piston Feeder

A cross sectional drawing of the fluidized piston feeder concept is presented in figure 2. The moving parts of the feeder

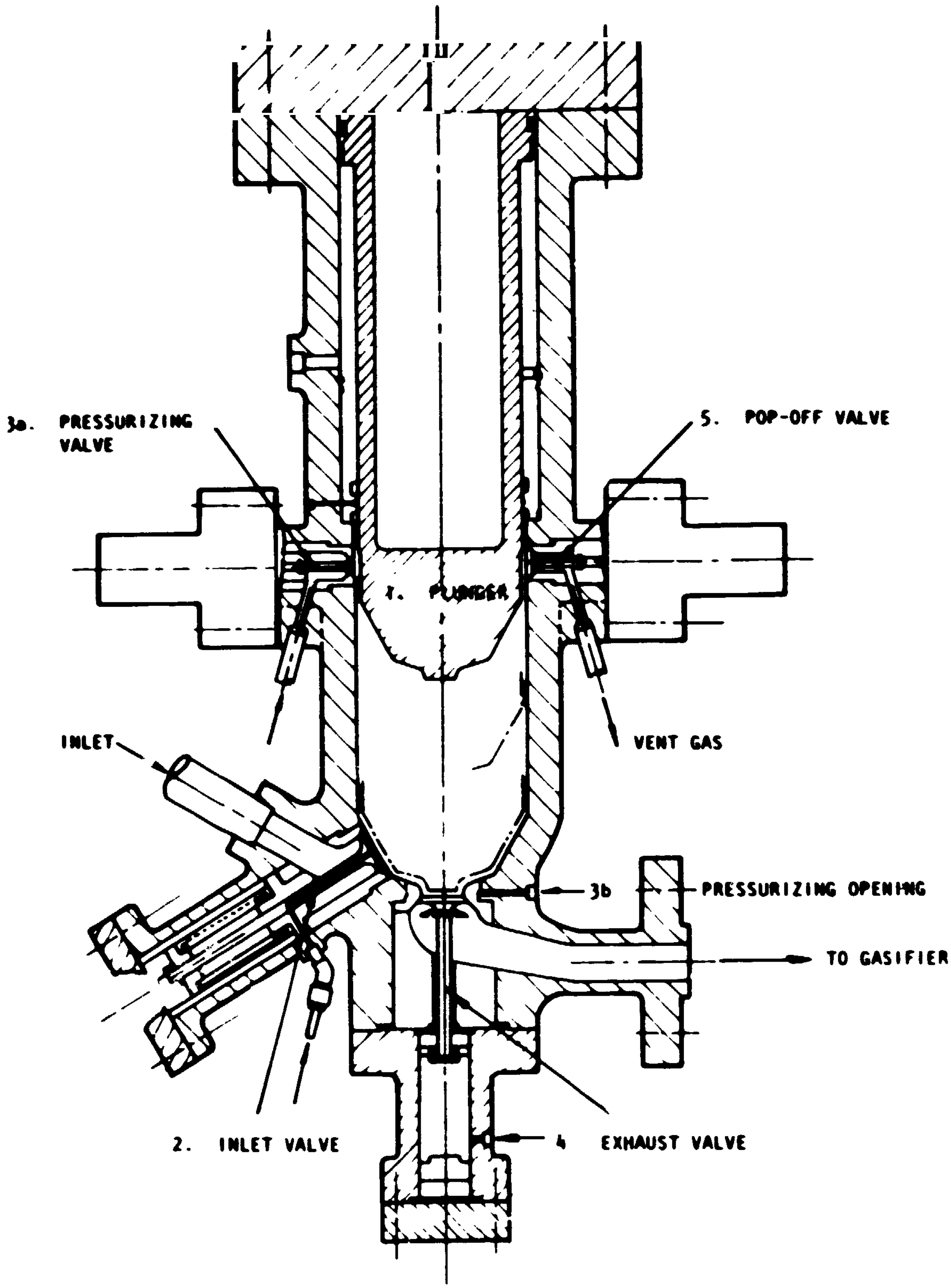


Figure 2. Fluidized Piston Feeaer

consist of valves for coal inlet and discharge, a pressurizing valve, a pressure relief (the "pop-off" valve), and a displacer piston. The operating sequence of the feeder is depicted in figure 3. In figure 3a a feed stroke has been completed. Figure 3b illustrates a coal intake stroke during which the coal inlet valve is opened, the displacer piston is withdrawn and a charge of fluidized coal is drawn into the feed cylinder. In figure 3c the pressurizing valve has opened, allowing the feed cylinder pressure to reach a value slightly above the pressure of the receiving vessel. At this point, the discharge valve is opened and the coal is flushed on out of the cylinder. It should be noted that the coal is not pushed by the piston but is flushed out by the gas. The piston serves as a gas displacer only. After the coal is flushed out of the cylinder, the displacer piston is stroked all the way down, the intake exhaust valve closes, and the residual gas in the cylinder is vented through the pop-off valve (figure 3d).

Analyzing the concept functionally, sealing is performed mechanically by valves, coal transport is accomplished pneumatically, and metering, as in any batch type device, is controlled by the cycle rate of the feeder.

This concept has been characterized as a "small, high cycle rate lock hopper". It is important in evaluating the concept to appreciate how the fluidized piston feeder differs from the conventional lock hopper. The device does indeed cycle much more rapidly than a typical lock hopper. This high cycle rate is made possible because the coal is handled in a fluidized state. The high cycle rate of the piston feeder allows the device to be much smaller than a lock hopper of comparable feed rate. The small size of the device, in turn, makes it easier to adapt a displacer piston to the design to limit gas losses. Furthermore, by using pneumatic techniques to transport coal, more packaging flexibility is possible than with the gravity transport mode of the lock hopper.

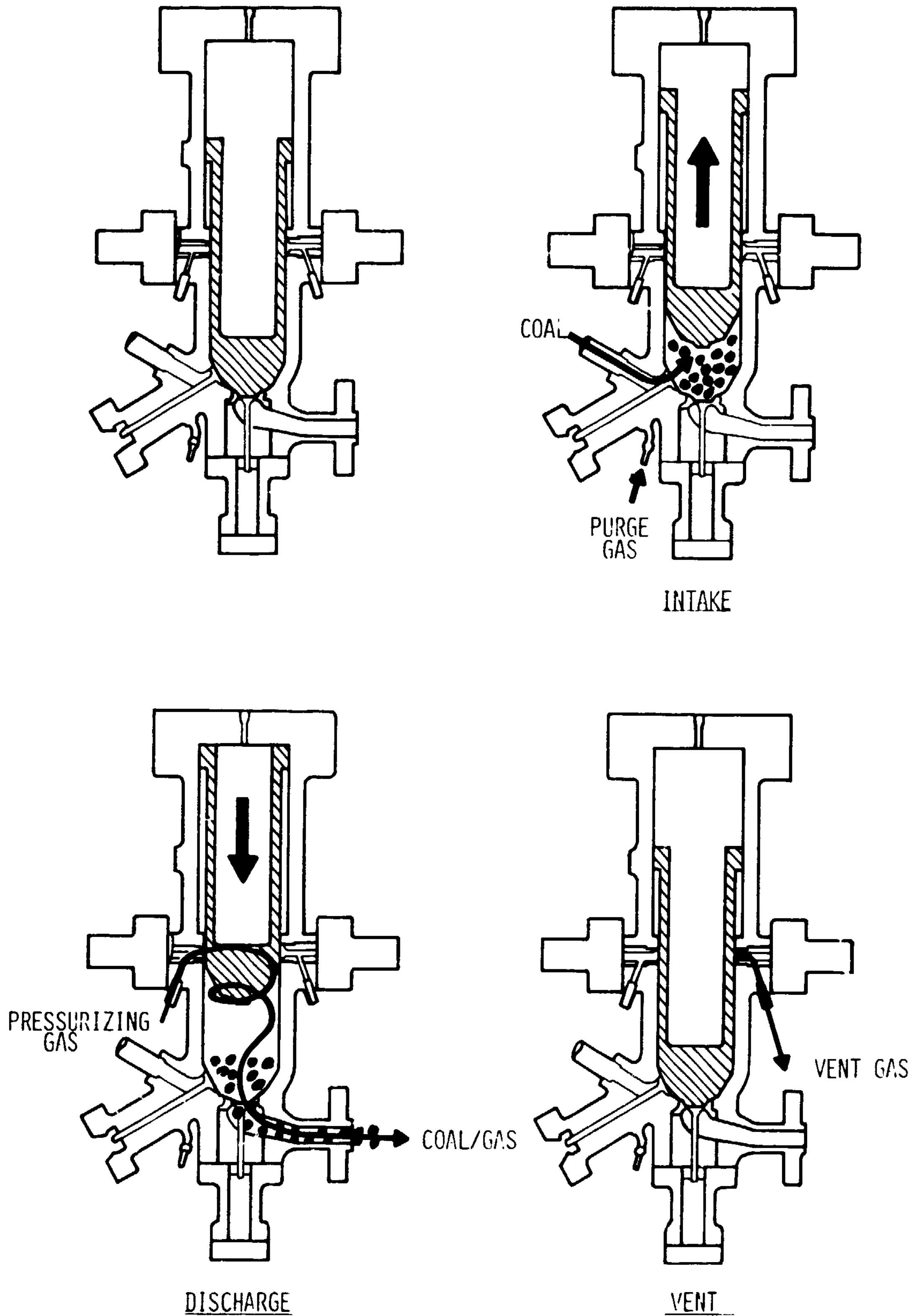


Figure 3. Fluidized Piston Feeder Operational Sequence

Key development areas for the piston feeder concept are valv·s and seals. The concept should be capable of feeding minus 1/4 inch coals making it suitable for fluidized bed and entrained bed gasification applications.

3.3 Centrifugal Feeder

The centrifugal feeder is one of FMA's two "coal sealed" feeder concepts. The concept can be viewed as a centrifugal pump for solids or, alternatively, as a standpipe which has been reduced in length by placing it in a high "g" field created by centrifugal force. The centrifugal feeder concept is illustrated schematically in figure 4. The feeder consists of an atmospheric pressure supply hopper, a pipe which supplies coal to the feeder head (downcomer), and the feeder head. An open tube is provided to allow the gas which is entrained in the coal flowing to the feeder head to be vented to the atmosphere (figure 5). As coal is supplied to the feeder head through the stationary downcomer, it is picked up by an impeller and driven into the feeder passages (termed sprues). Figure 6 illustrates the manner by which the coal creates a dynamic seal as it moves through the feeder sprues. The moving coal is permeable and gas can leak through the coal (Vg). For the feeder to seal, the coal flow rate (Vc) must equal or exceed the gas flow rate. In the ideal "null" mode (Vc=Vg) there is no net gas loss from the receiver and no gas is conveyed into the receiver with the coal. In practical applications the feeder would probably be run with a slight net gas input to the receiver to ensure stable operation.

In functional terms, the centrifugal feeder concept operates in a continuous mode, seals with moving coal, transports by centrifugal force, and meters by controlling the rotational speed of the feeder head. While the centrifugal feeder is mechanically simple, the successful development of the device requires the solution of subtle and complicated two-phase flow problems. The concept is basically suitable for fine coal feed in entrained bed gasification applications.

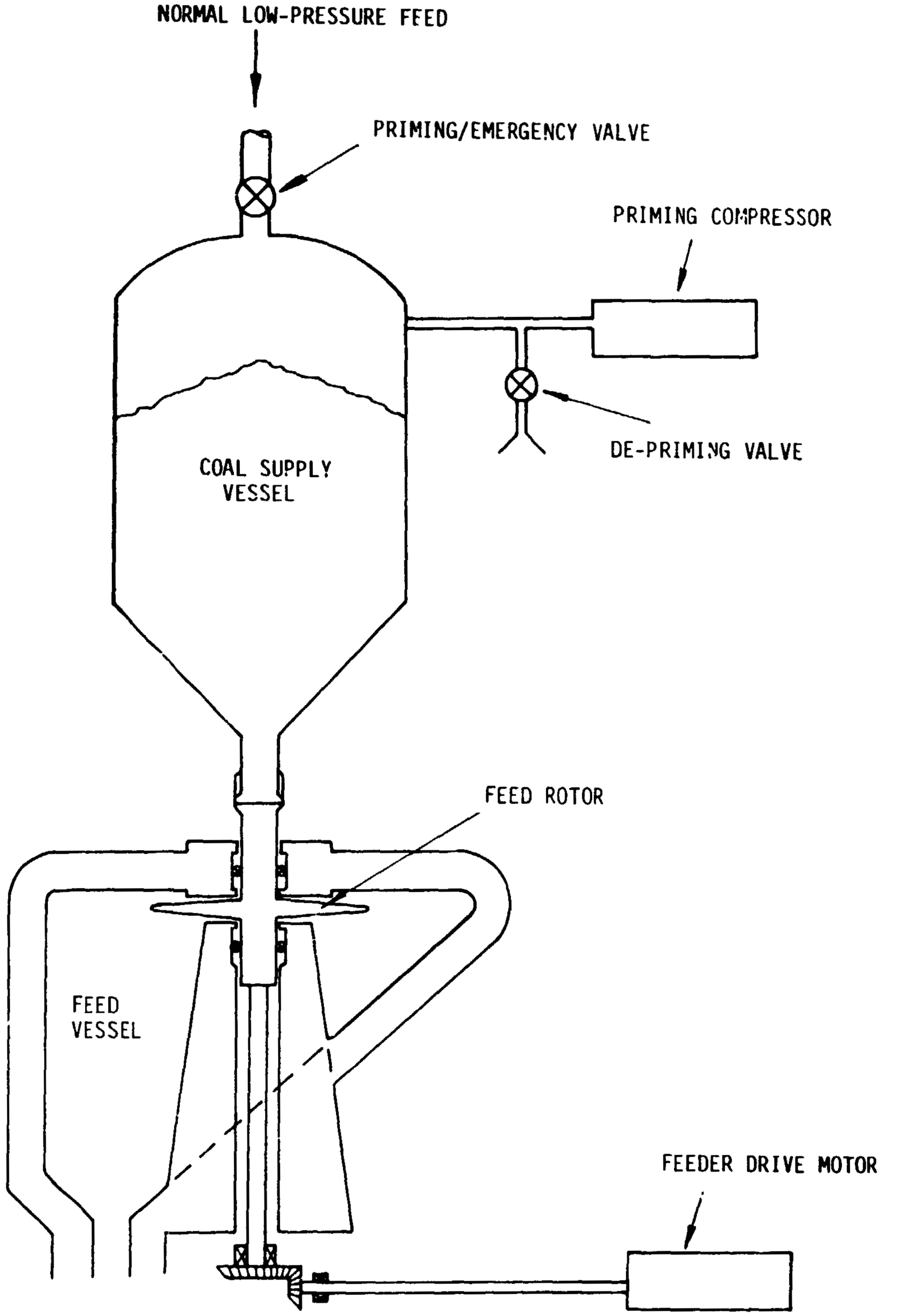


Figure 4. Schematic Diagram of a Centrifugal Feeder System

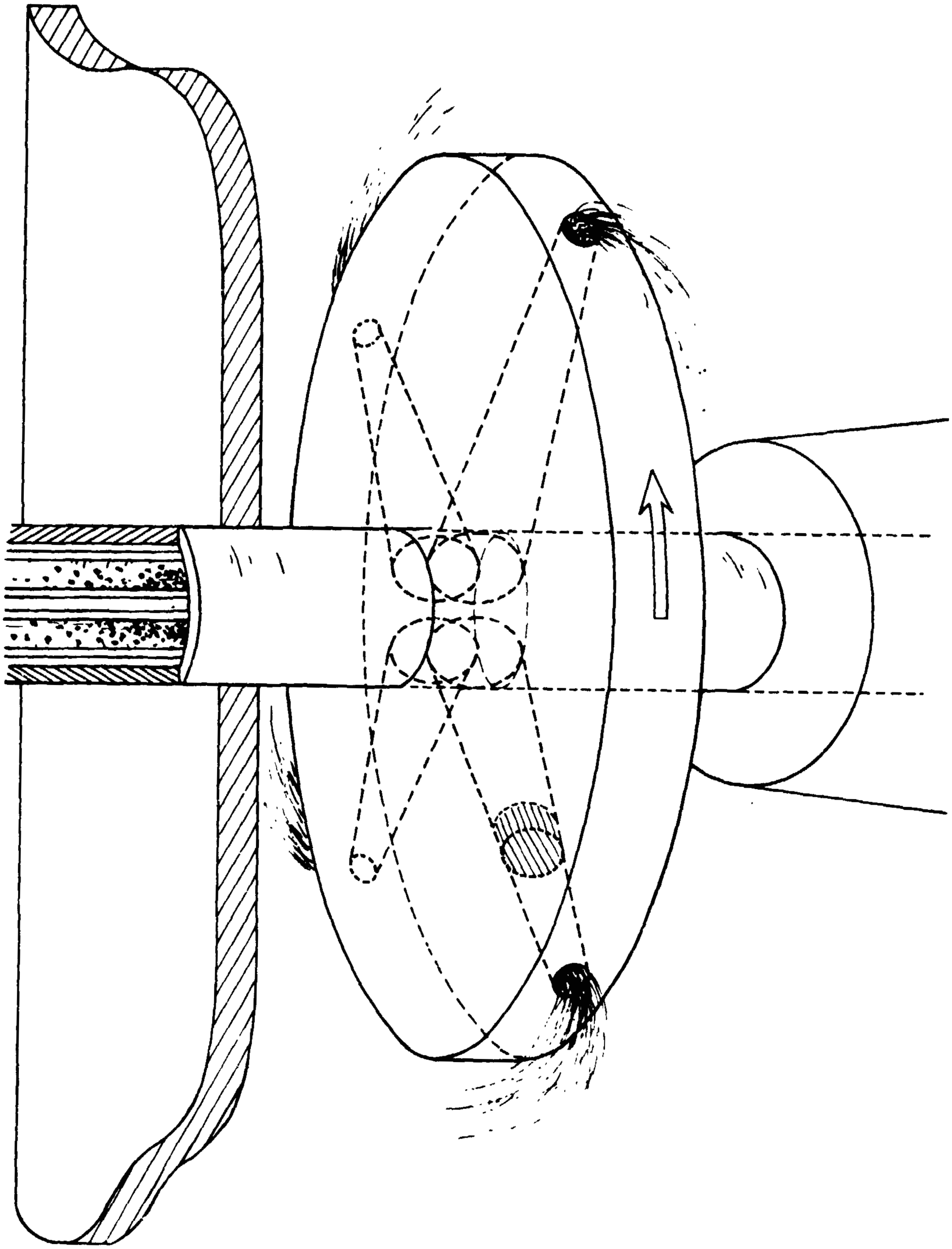
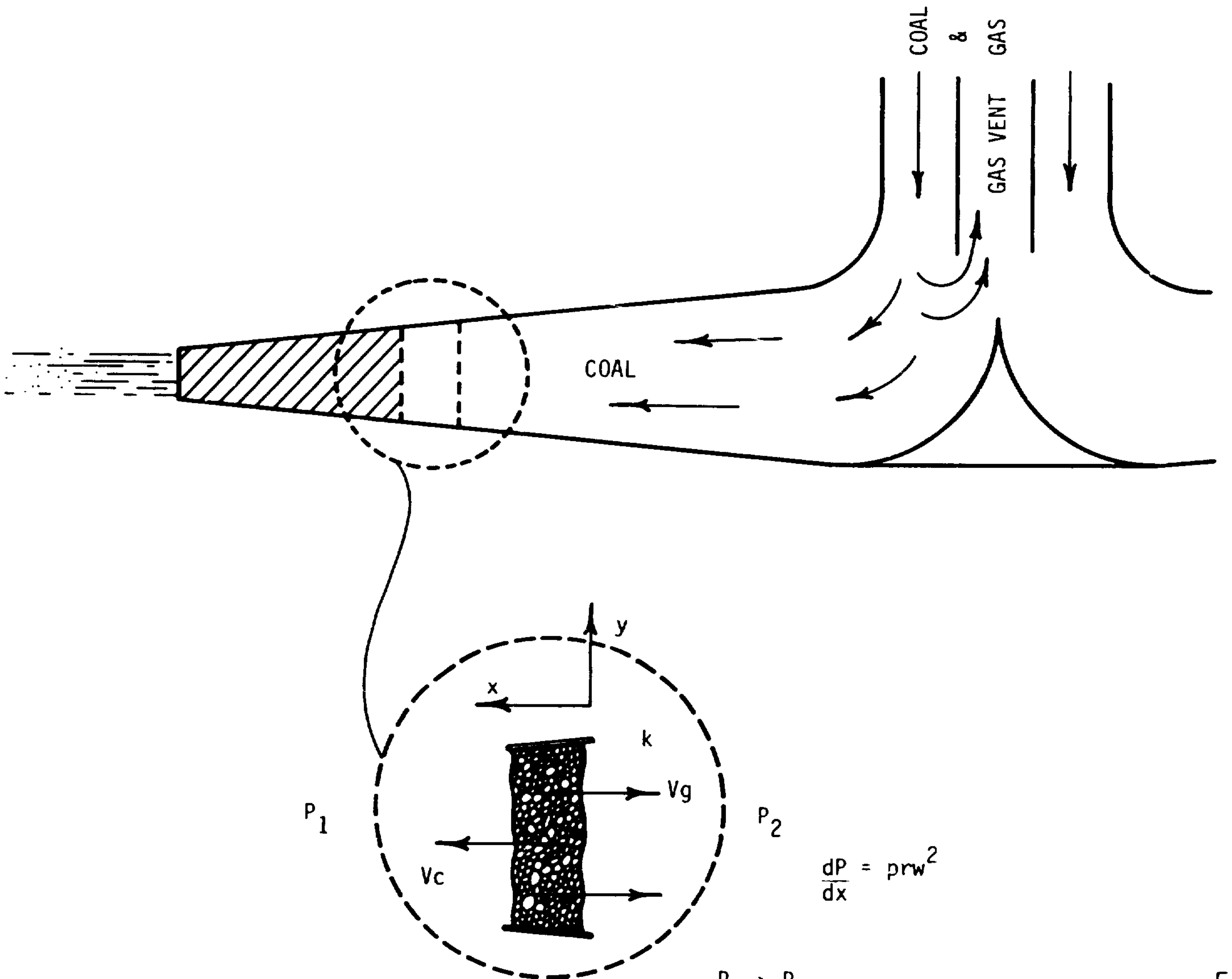


Figure 5. Schematic Representation of the Centrifugal Feeder Rotor



$$\frac{dP}{dx} = \rho r w^2$$

$P_1 > P_2$

$Vc = Vg$

$$\frac{dP}{dx} = -kv$$

$$K = f(ls)\left[f_1 \frac{1-E}{E^2} \frac{M}{dp^2} + f_2 \frac{1-E^2}{E^3} \frac{P_2}{dp}\right]$$

Figure 6. Operating Principle of Centrifugal Feeder

3.4 Coal Plug Feeder

The coal plug feeder concept also uses the coal itself to create a pressure seal. In figure 7 a reciprocating screw feeder configuration is illustrated. Other configurations are also possible. The operation of the machine is depicted in figure 8. In the top view a feed stroke has been completed. In the middle view a new charge of coal is fed into the barrel of machine by the rotation of the feed screw as the plunger mechanism retracts. In the bottom view, the plunger reciprocates forward creating a new briquette to add to the series of briquettes formed in previous cycles. With successive cycles briquettes are formed and pushed progressively into the receiver. The briquettes do not form an absolute seal but rather a low permeability plug.

Functionally, the coal plug concept is a batch type feeder, which seals with compacted coal. The coal is transported with positive displacement mechanical action and metering is controlled by cycle rate. The coal plug concept gives a very simple feeder configuration. However, the concept has very high power requirements and potentially severe wear rate problems The feeder is suitable for feeding pulverized coal to entrained bed gasifiers. This application requires that means be provided to break up the briquettes in the high pressure receiver.

3.5 Phase I Summary

In table 3, a relative comparison of the four FMA feeder concepts is presented. The Phase I recommended concepts are compared in terms of feed pressure capability, feed size, application, and feed cycle. Development work following the Phase I effort indicates that the linear pocket feeder may be suitable for pressures to 1,000 psi or higher.

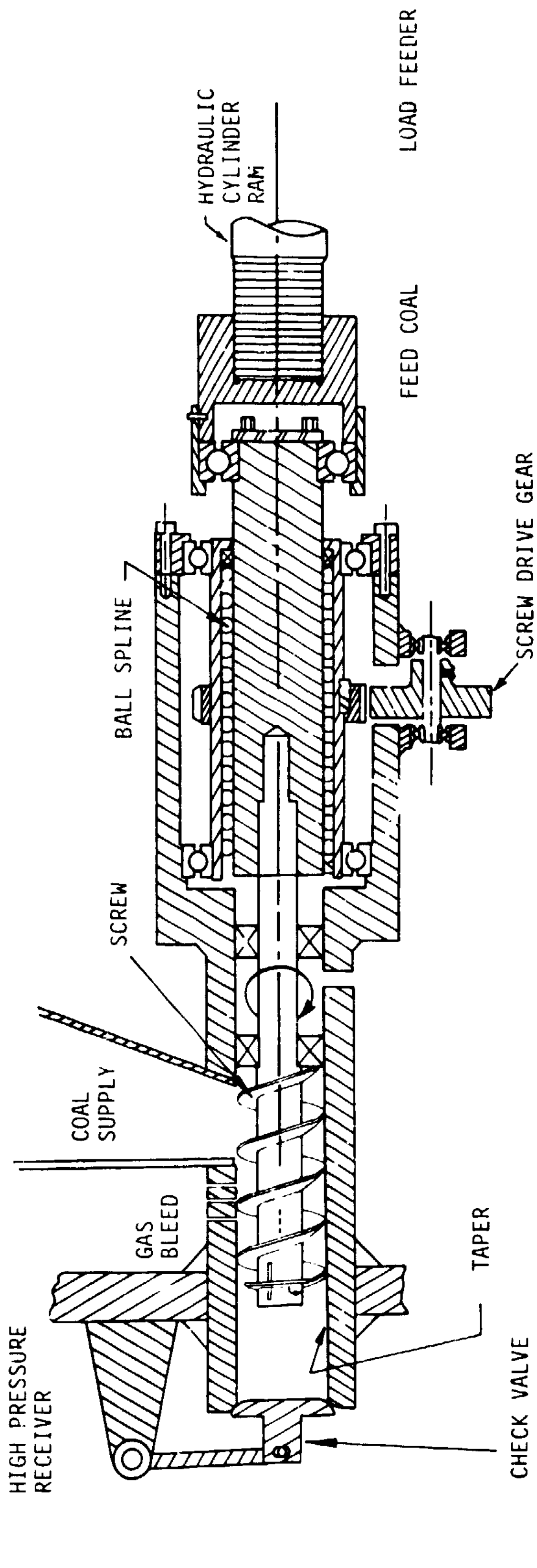


Figure 7. Cross Section of a Reciprocating Screw Coal Plug Feeder

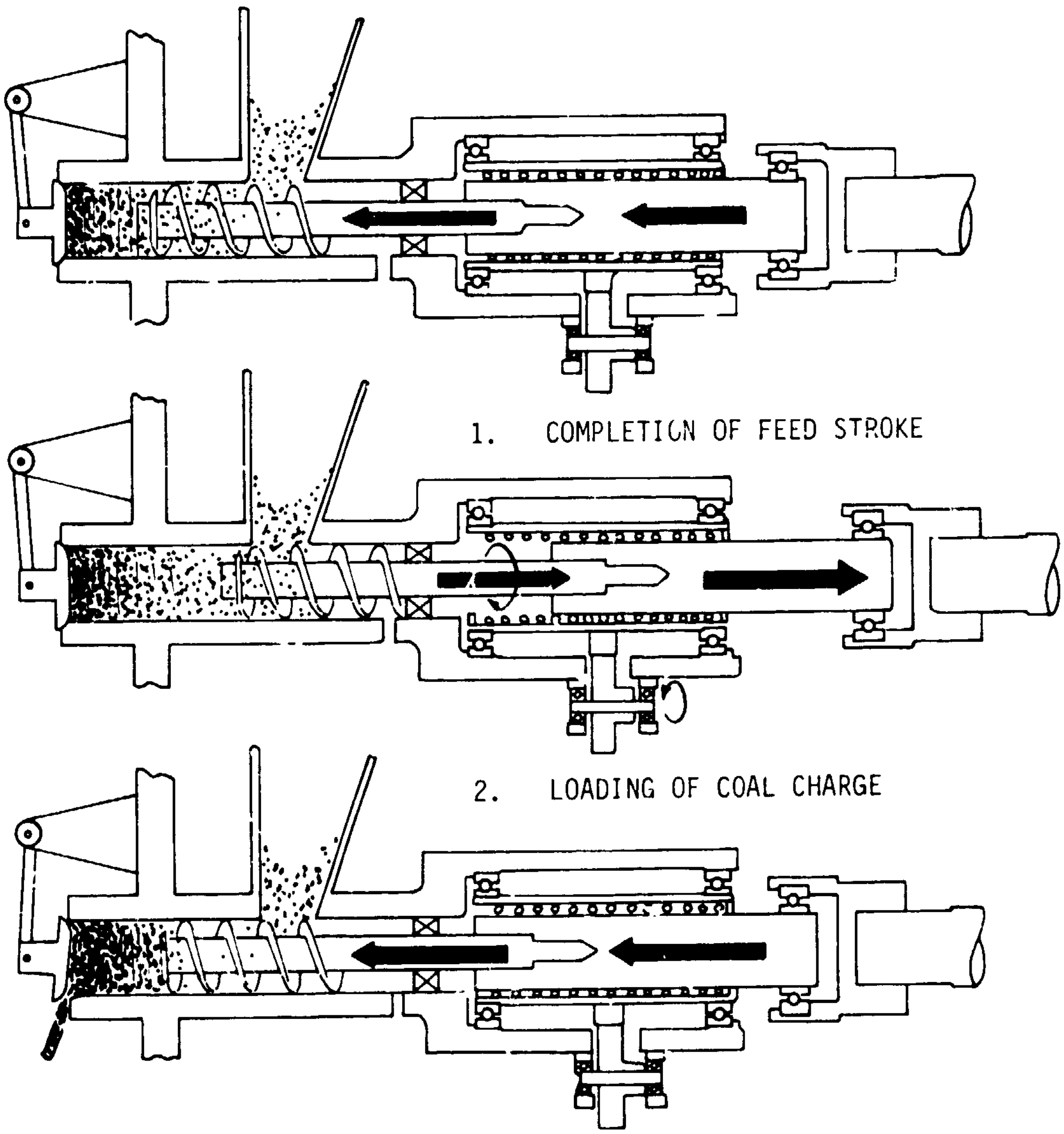


Figure 8. Operating Cycle of a Reciprocating Screw Coal Plug Feeder

Table 3. Comparison of Foster-Miller Coal Feeder Concepts

Features	Centrifugal Feeder	Fluidized Piston Feeder	Coal Plug Feeder	Linear Pocket Feeder
Feed Pressure Differential (Maximum)	1000 psi	1,500 psi +	1,000 - 1,500 psi	500 psi
Feed Size	Fine*	Medium-Fine	Fine	Coarse-Fine
Application	Entrained Bed	Entrained Bed Fluidized Bed	Entrained Bed	All
Feed Cycle	Continuous	Intermittent	Intermittent	Continuous

* The feed pressure differential performance of the centrifugal feeder will decrease as feed size increases.

4. Phase II Results

The Phase II program effort is essentially the hardware evaluation of the concepts developed in Phase I. In conducting this phase two scaling steps have been carried out. Bench scale models of all four concepts were designed, built and tested. Following this work, pilot plant scale prototypes of three of the four concepts have been designed and built and are now under test.

4.1 Bench Scale Testing

The bench scale testing will be discussed only briefly in this paper. Details of the bench scale test program are presented in reference 2. The bench scale centrifugal feeder model was used to perform coal flow studies and to determine if the required outlet limited (full sprue) flow mode could be achieved. This flow condition is necessary if the device is to be capable of sealing against pressure. For the piston feeder development a glass model of the feeder was built and tested to study possible development problems. A full scale, two flight, sealing section model for the linear pocket feeder was developed to test leakage rates and drive forces. For the plug feeder, a small bench scale apparatus was tested to determine leakage, plug stability, driving forces, compaction forces required etc. At the conclusion of the bench scale testing, essentially all four concepts were deemed to be technically feasible. However, because of funding limitations, it was necessary to eliminate one of the four feeder concepts. The plug feeder concept development was suspended. Basically, the considerations influencing this decision included the high power requirements of the device, the lack of flexibility in end use, and duplication of effort with respect to other feeder development programs being conducted. It should be noted that in the bench scale testing, the plug feeder apparatus was able to feed reliably against pressures to 1200 psi with a stable plug and with very low leakage rates. The leakage rates were, in fact, substantially less than lock hopper venting losses under comparable conditions.

4.2 Prototype Testing

Prototype feeders have been designed, built, and are now being tested for the centrifugal, piston, and linear pocket concepts. The prototype hardware is described and test results to date are discussed below.

4.2.1 Centrifugal Feeder Prototype

Testing of the centrifugal feeder prototype was initiated in mid November 1976. The test facility is illustrated in figure 9. The feeder rotor is located within the domed head of the large vessel on the left side of the support structure. The coal supply runs down a fluidized standpipe from a weigh hopper on the roof of the test facility. The weigh hopper is not visible in the photograph. The specifications for the prototype feeder are given in Table 4. The 200 psi limit for the prototype feeder was selected as being sufficient to prove the validity of the concept while keeping testing costs and component lead times to reasonable figures.

Table 4. Prototype Centrifugal Feeder Specifications

Parameter	Value
Feed Rate	Up to 1 ton per hour
Pressure Differential	Up to 200 psi
Speed	2000 RPM (nominal) 3000 RPM (maximum)
Rotor Diameter	24 inches
Downcomer Diameter	3 inches
Sprue Outlet Diameter	Up to 0.5 inches
Sprue Inlet Diameter	Up to 2.5 inches
Coal Size	70 percent through 200 mesh
Coal Moisture	1.5 percent (presently in use)

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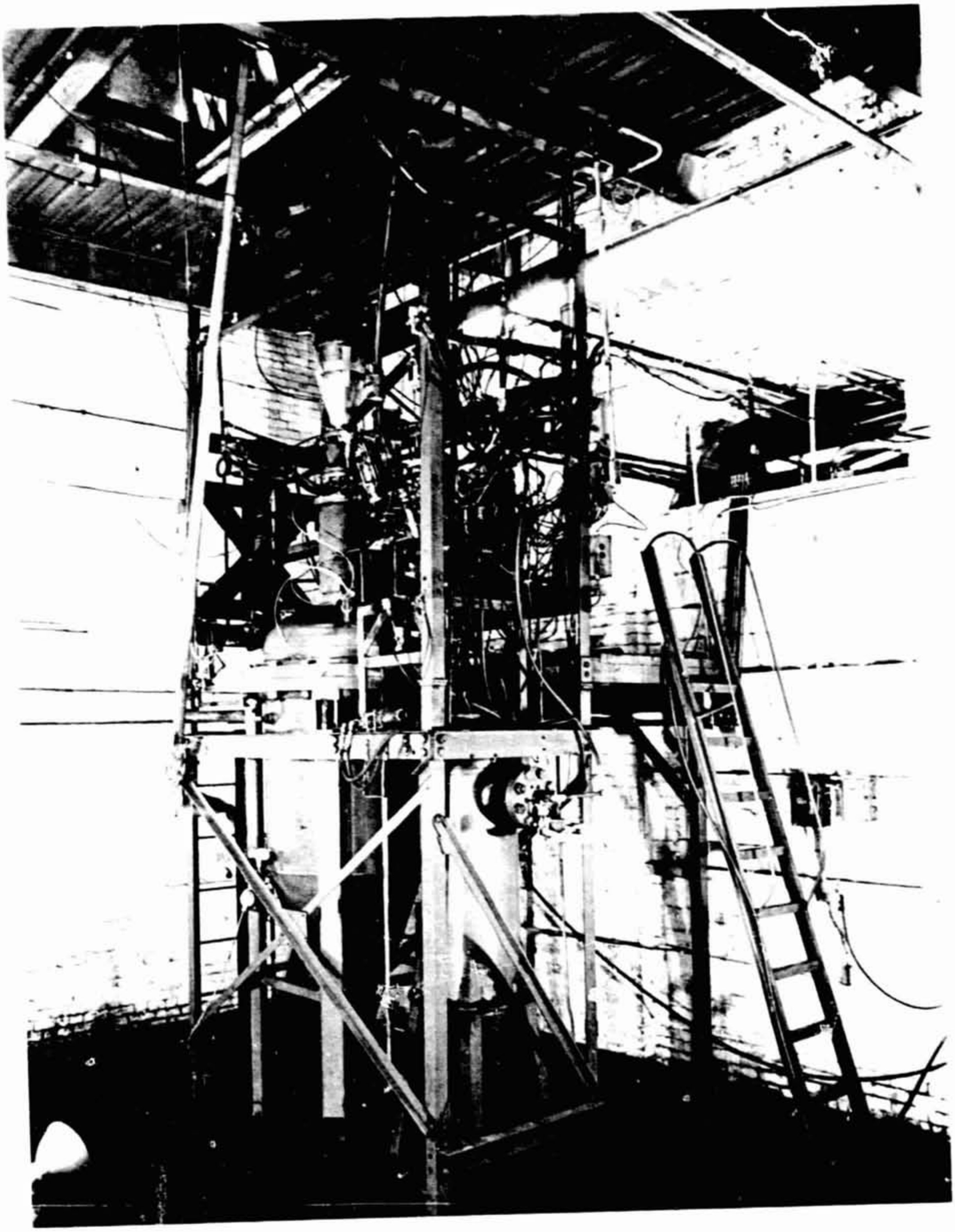

Figure 9. Prototype Feeder Test Facility

Testing of the prototype centrifugal feeder has progressed through two stages. In conjunction with the testing, an analytical study of the centrifugal feeder concept is being carried out. This study has been computerized to allow rapid comparisons between test results and the analytical model of feeder performance.

The first series of feeder tests were plagued by problems in maintaining reliable coal feed to the inlet of the centrifugal rotor. These problems have been overcome by relocating and fluidizing the coal supply plumbing. The results of the series A feeder tests are summarized in Table 5. These results indicated that the prototype feeder operated at high feed rates with little or no pressure differential (Run 2, Table 5) and that feed rates dropped off very rapidly as the pressure differential increased (Run 6).

The analytical model of feeder performance was revised substantially and a rationale was developed which explained the results achieved in the series A tests. Based on this rationale, detail changes were made in the centrifugal rotor design and a second series of tests were initiated. The results to date in the B series test program are presented in Figure 10. The test results correlate very well with the data derived from the analytical feeder model.

Figure 10 presents test results and theoretical predictions for two sets of sprues, one with a 1/4 inch outlet diameter and a set with .150 inch openings. Referring to Figure 10, the 1/4 inch set has achieved pressure differentials to about 40 psi with a feed rate of about one ton per hour. The .150 inch set has achieved pressure differentials to 185 psi at feed rates of approximately one quarter ton per hour. Further testing will involve one more sprue set designed to achieve the 200 psi pressure differentail and one ton per hour feed rate projected for the prototype.

Table 5. Summary of Centrifugal Feeder Test Results
Test Series A

Run No.	Sprue Outlet Diameter (In.)	Rotor Speed (RPM)	Receiver Vessel Pressure (PSI)	Flowrate (LB/HR)	Comments
1	0.5	2000	20	-	Material flow test with "Speedy Dry"
2	0.188	2000	--	12,000	Temporary fluidization in rotor hub
3	0.5	2000	4	-	No sealing beyond 4 psi
4	0.375	2000	11	-	Break in coal delivery to hub. Coal seal breaks when pressure still building up
5	0.375	550	25	2,400	Coal fluidized in feed hopper, feed lines and rotor hub
6	0.375	1500	75	-	No discernable coal flow
7	0.375	2700	25	1,600	One sprue operational. Large foreign particle in the other

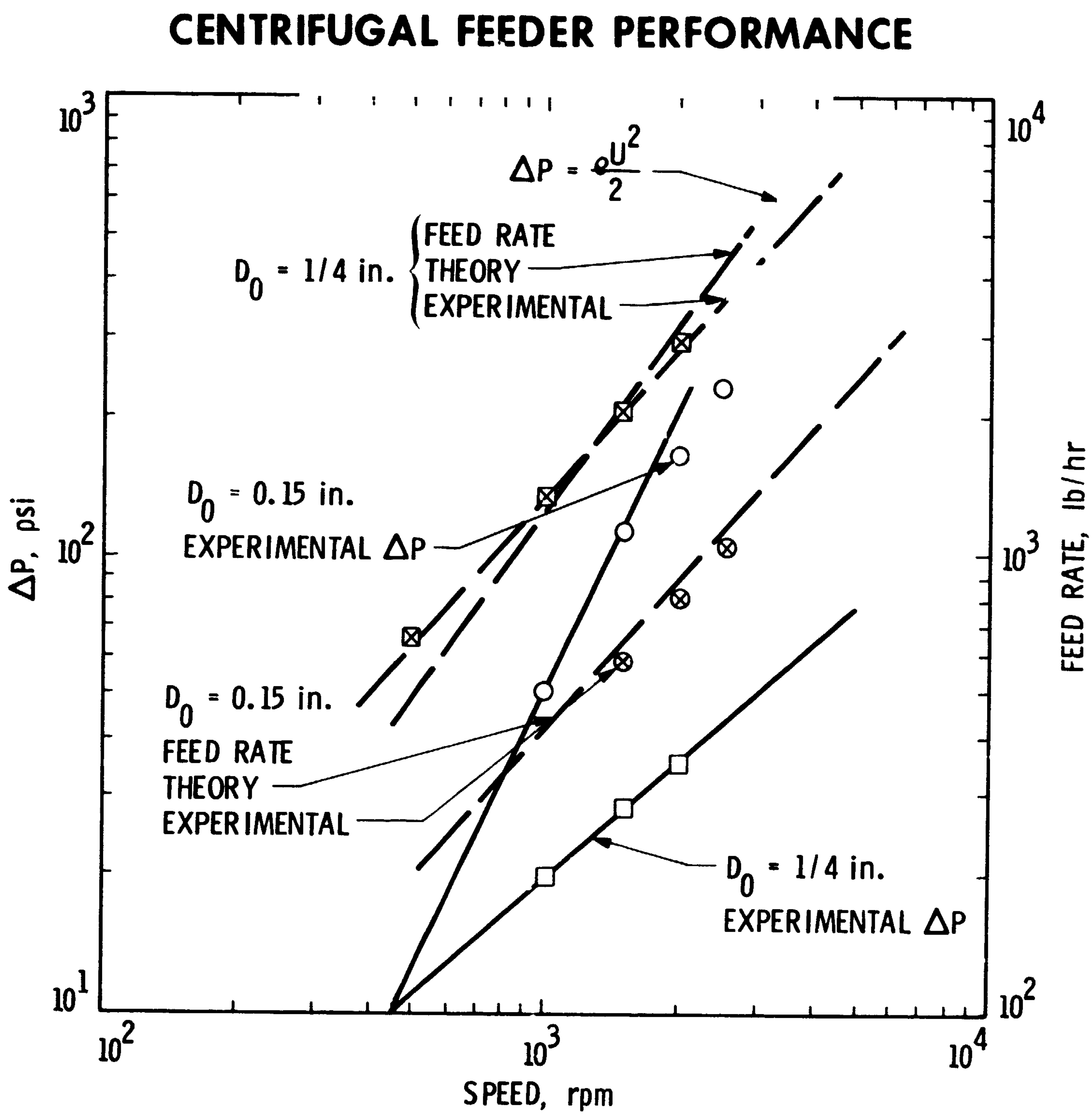

Figure 10. Prototype Centrifugal Feeder Test Results (Series B)

4.2.2 Fluidized Piston Feeder Prototype

The piston feeder prototype is essentially similar to the concept illustrated in Figure 2. The most significant change in the prototype is the use of a double inlet valve. The inlet valve set has a coarse valve which performs the function of stopping the coal flow from the supply hopper and a fine valve which performs the gas sealing function. The specifications for the prototype feeder are presented in Table 6.

Table 6. Prototype Fluidized Piston Feeder Design Specifications

Parameter	Value
Feed Rate	1 ton per hour
Pressure Differential	1000 psi (1500 psi max.)
Feed Hopper Pressure	0-20 psi
Receiver Pressure	Up to 1500 psi
Coal Size	70 percent thru 200 mesh (1/4 x 0 max.)
Cylinder Diameter	4 inch
Stroke Length	Up to 8 inch

The performance which has been achieved to date with the prototype feeder is presented in Table 7 and Figure 11. The drop off in feed rate with increasing receiver pressure which is evident in Figure 11 is indicative of valve leakage problems. At lower pressure differential, the density of the material throughput has been above projections dropping off to below projections at higher differentials. A slight improvement in throughput occurs with increased supply hopper pressure. To date, the unit has fed at differentials up to 500 psi. Feed rate at this differential was approximately 200 pounds per hour. Development is continuing

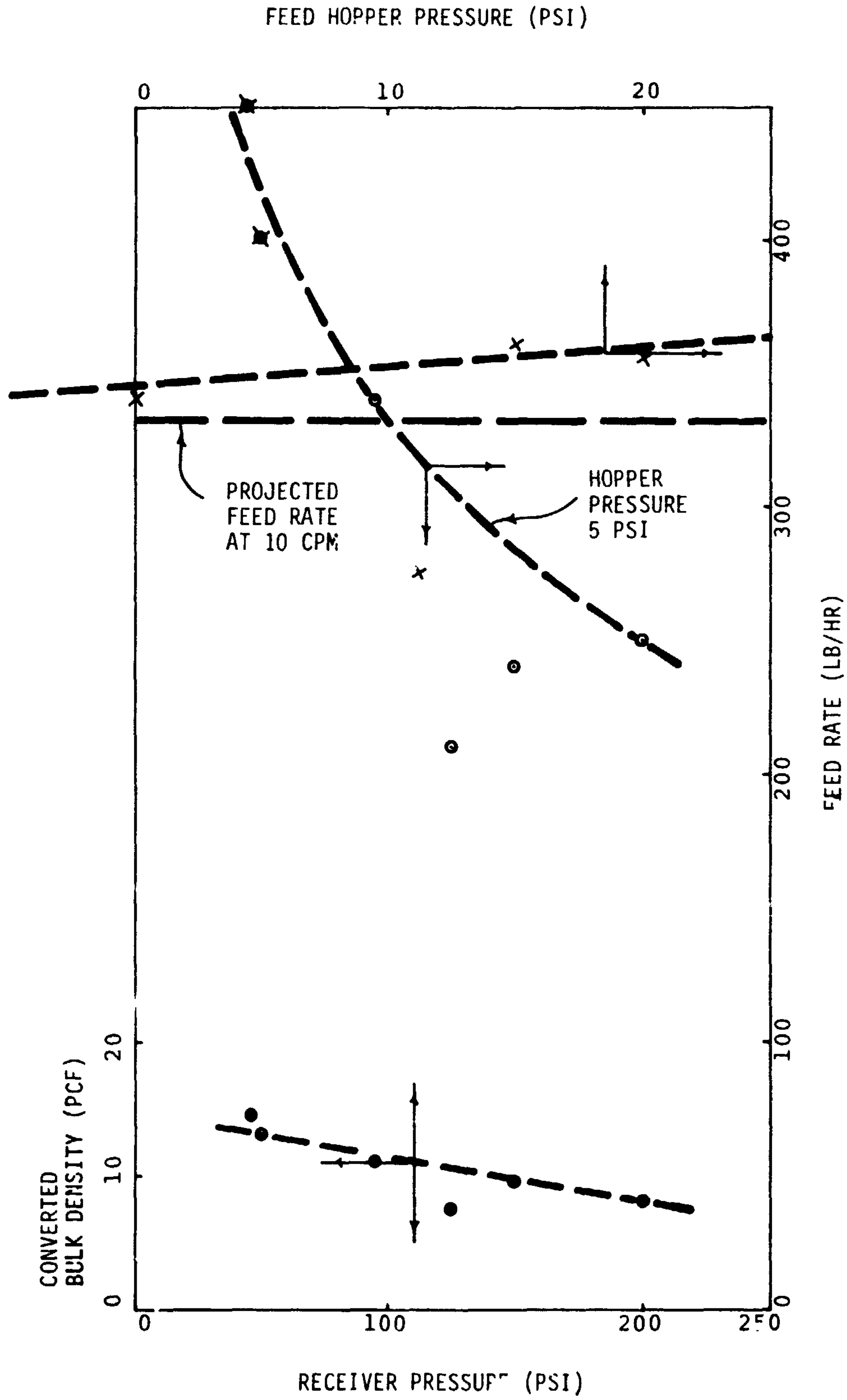

Figure 11. Prototype FP Feeder Performance

Table 7. Fluidized Piston Feeder: Typical Test Results

Run No.	Feed Hopper Press. (psi)	Line Fldzn. Press. (psi)	Valve Purge Press. (psi)	Cylinder Press. (psi)	Receiver Vessel Press. (psi)	Cycle Time (sec)	Run Time (min)	Feed Rate (lb/hr)	Estimated Feed Density (PCF)
Stroke Length: 8 inches									
1	5	10	40	80	45	6.7	12	450	14.5
2	10	10	40	85	45	10.0	12	265	12.72
3	15	-	60	80	50	6.7	12	360	11.61
4	20	-	60	80	50	6.7	13.5	356	11.47
5	10	10	50	140	95	6.8	8	323	10.5
6	5	-	60	150	125	7.04	12	210	7.09
7	7	10	60	180	145	6.8	7.5	304	9.75
8	5	10	60	250	200	6.8	6	250	8.16
Stroke Length: 6½ inches, intake valve modified.									
9	5	10	60	350	300	6.7	6	380	15.1
10	5	10	60	450	400	6.7	6	160	6.35
11	5	20	100	550	500	6.7	6	200	7.94

*Estimated feed density (converted density) refers to the mass of coal in the cylinder per unit cylinder volume. Please note that the maximum density possible is that of coal at minimum fluidization.

centered around improvement of valve performance. The piston feeder has also been modeled analytically. The computer model allows the effect of such variables as valve timing, cycle rate, and coal input density to be evaluated.

4.2.3 Linear Pocket Feeder Prototype

The configuration of the linear pocket feeder prototype is illustrated in Figure 12. The feeder is 16 feet in length from sproket axle to sproket axle and about 18 feet in length overall. The prototype is functionally equivalent to the basic concept discussed earlier. The specifications for the prototype feeder are presented in Table 8. The details of the pistons or flights of the conveyor are illustrated in Figure 13. The alumina wear ring takes the brunt of the mechanical wear and forces involved in breaking and feeding the coal. The metal hook type sealing rings act as redundant seals.

Table 8. Design Specifications for the Linear Pocket Feeder Prototype

Parameter	Value
Flow Rate of Coal	0-5 tons per hour @ 2.5 feet per second 50 percent loading
Maximum Operating Pressure	500 psig
Diameter	3.5 inches
Coal Size	3/4 inch
Temperature	Ambient
Chain Speed	0-10 feet per second
Minimum Wear Life of Critical Components	8000 hours

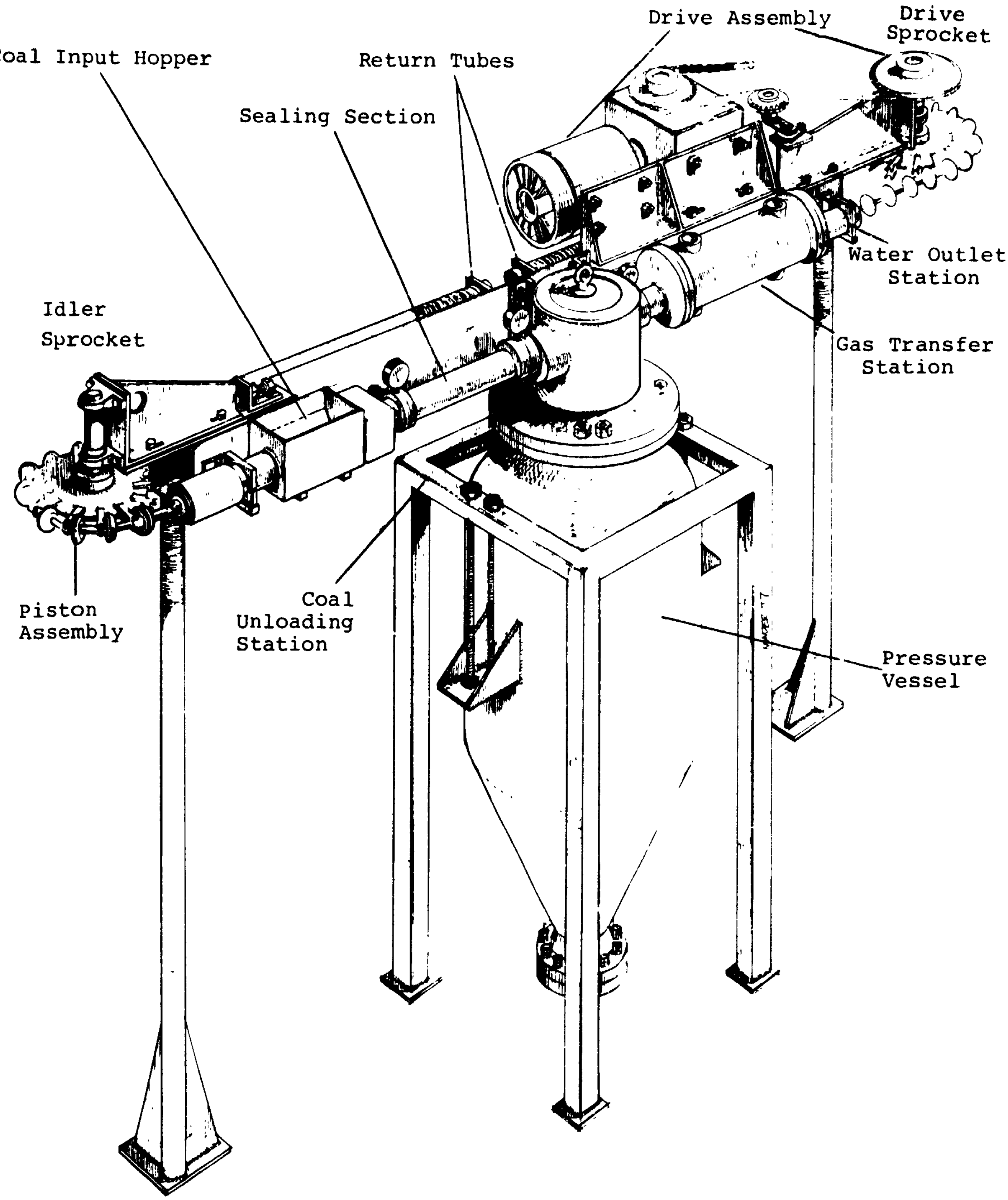

Figure 12. Prototype Linear Pocket Feeder (LFP) Presently Being Tested

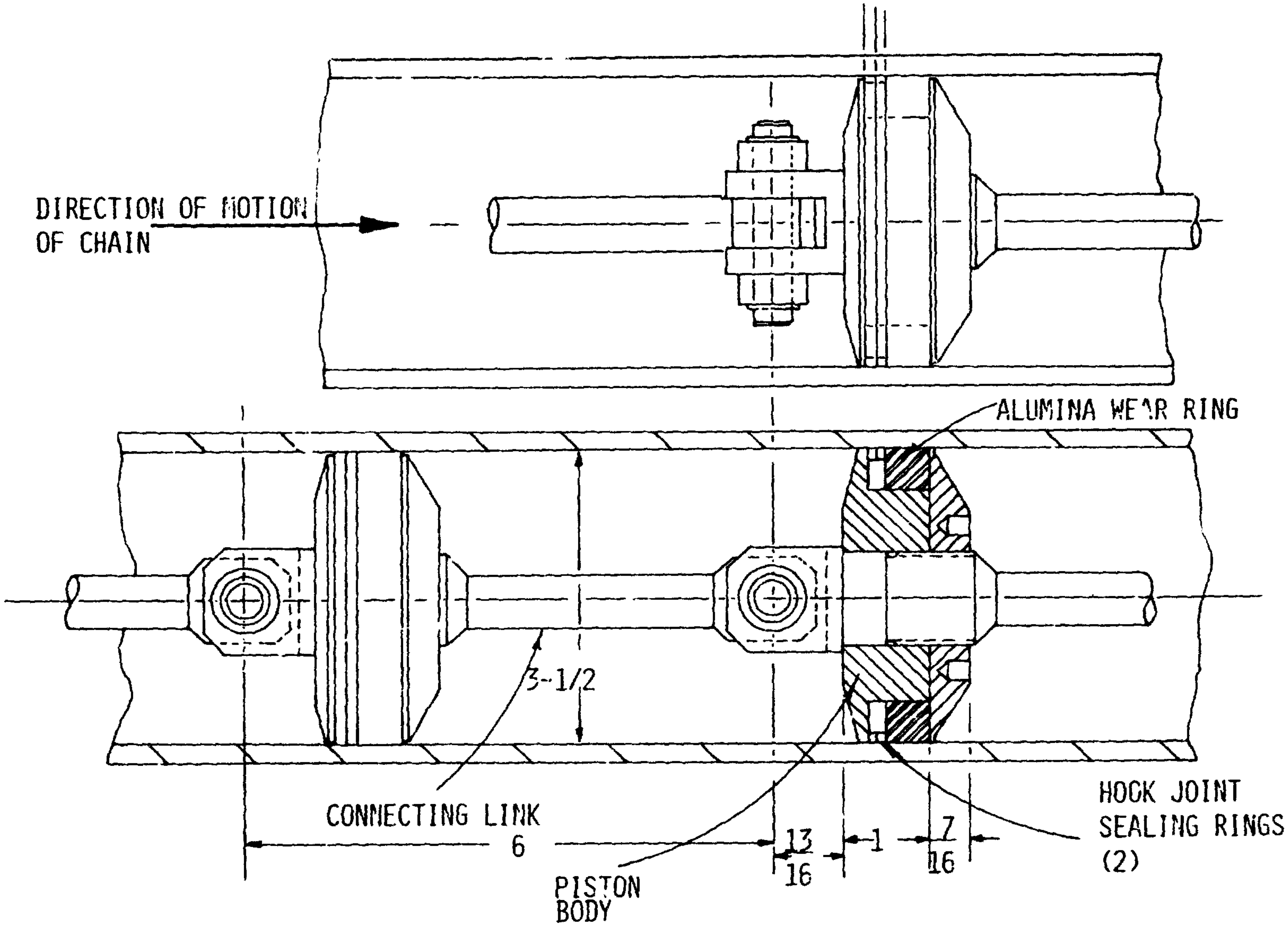

Figure 13. Linear Pocket Feeder Piston Details

At this time, the pressure vessel components of the linear pocket feeder have not been received, so testing to date has been limited to running coal without a pressure differential imposed on the device. In this testing, the feeder is operating with no significant problems. Line pulling force is about as predicted and coal feed has been fed against zero pressure differential. The feeder has been operated continuously for five hours, without coal, with no probelms being noted. Pressure testing of the feeder is scheduled for August 1977.

4.3 Phase II Summary

The remaining FMA feeder concepts are compared in Table 9. A consideration not noted in the table is the anticipated development time required for each of the feeder concepts. It is estimated that the linear pocket feeder can be developed for near term applications (approximately 1 to 3 years), the piston feeder for mid term applications (approximately 2 to 5 years), and the centrifugal feeder will probably require the most development (3 to 5 years plus).

Table 9. Comparison of Foster-Miller Coal Feeder Concepts

Features	Linear Pocket Feeder	Fluidized Piston Feeder	Centrifugal Feeder
Feed Pressure Differential (Maximum)	500 psi +	1,500 psi +	1000 psi
Feed Size	Coarse - Fine	Medium-Fine	Fine
Application	All	Entrained Bed Fluidized Bed	Entrained Bed
Feed Cycle	Continuous	Intermittent	Continuous

5. Future Development

In Figures 14 to 16, the three feeder concepts are depicted in a form suitable for field applications. The linear pocket feeder illustrated is a 3½ inch inside diameter unit suitable for feed rates to five tons per hour. In Figure 15 the fluidized piston feeder is illustrated as it would be constructed for field applications. The unit illustrated would have a cylinder diameter of 2.5 feet and stroke of 3.125 feet and would feed at the rate of 5 tons per hour with a cycle time of 36 seconds. The centrifugal feeder design of Figure 16 eliminates the pressure vessel receiver used for the prototype. The feeder head is enclosed in a case which could be plumbed to a gas feed line to the reactor. Coal is conveyed out of the case continuously and carried into the process. The design illustrated employs a 3 foot diameter head and would be suitable for flow rates of 3 to 5 tons per hour.

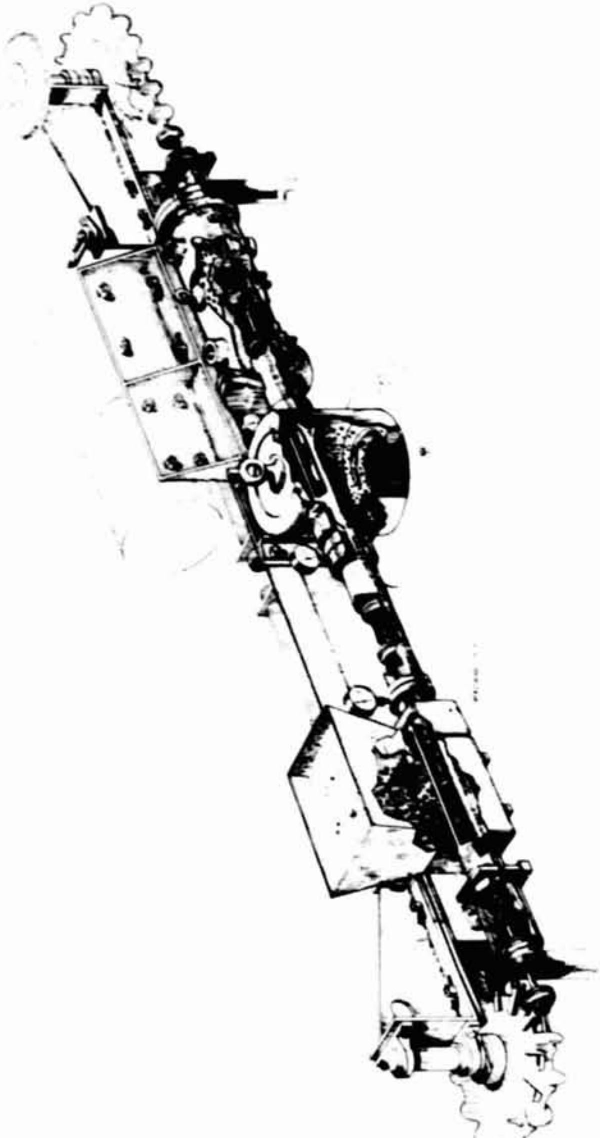

Figure 14. Linear Pocket Feeder

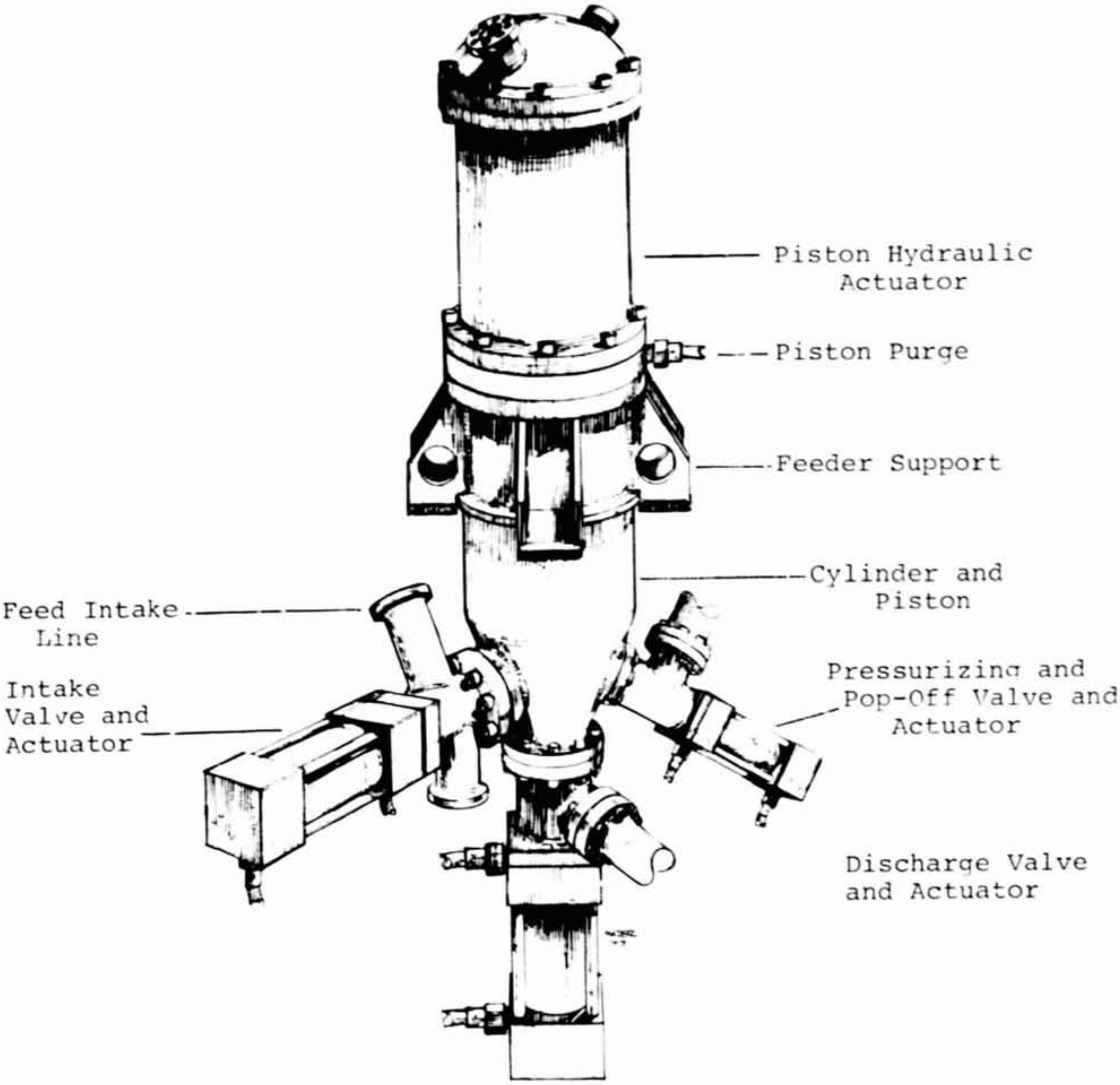

Figure 15. Fluidized Piston Feeder

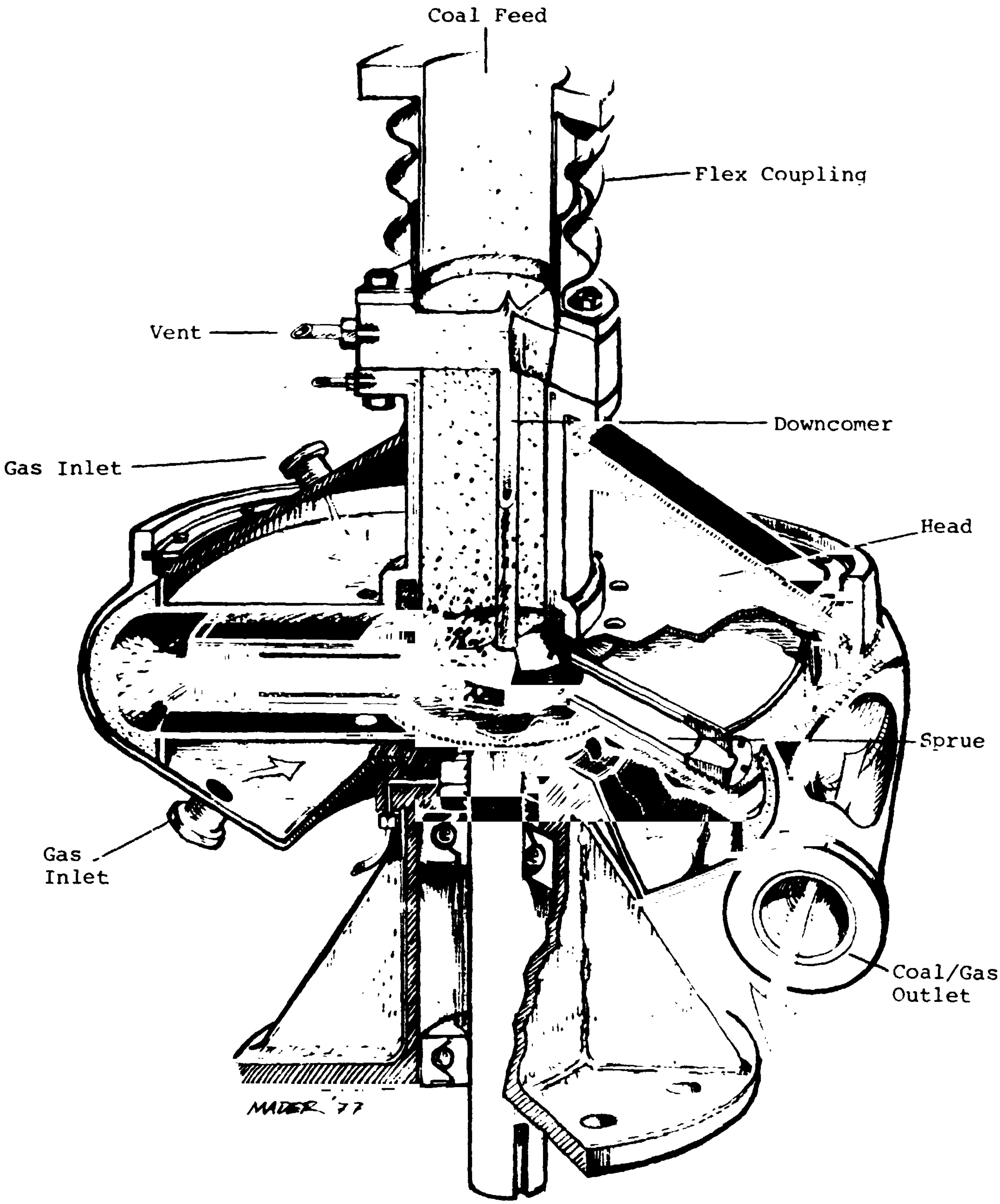

Figure 16. Centrifugal Feeder

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