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# BABCOCK & WILCOX'S EXPERIENCE WITH TWO-PHASE FLOW MIXTURES OF COAL AND GAS

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## ABSTRACT

This paper describes The Babcock & Wilcox (B&W) Company's general background in conveying crushed and pulverized materials but more specifically addresses the transport and feeding of pulverized coal at moderate pressures in dilute phase.

Based on B&W's background, two pulverized coal injection systems were designed, installed and placed in operation on blast furnaces and have an accumulated operating time of over 15 years. The larger and newer system was placed in operation in 1973 and has achieved essentially 100% availability. This system is capable of injecting 33 tons of coal per hour and operating at pressures up to 95 psig.

## INTRODUCTION

Conveying a material pneumatically from one place to another has been done for many years and industry has relied on pneumatic transport for grain, cement, wood chips, and coal. In general, the conveying of most materials presents no great difficulty to those knowledgeable in the art. However, certain processes, for example the firing of pulverized coal boilers, require steady non-pulsing feed. Developing technologies such as coal gasification, fluidized bed combustion, and magneto-hydrodynamics, require that pulverized or crushed coal be transported, split into equal flow streams, and fed into the process at high pressure in a controlled manner.

The Babcock & Wilcox Company has been designing and supplying systems for conveying and feeding pulverized and crushed coal for many decades. The following describes some of the Company's background and developmental work in this area.

## PULVERIZED COAL FIRING OF BOILERS

Pulverized coal has been used as boiler fuel since the 1920's. In this application pulverized coal infers that the coal has been milled until 70 weight percent will pass through a 200 mesh seive. Two principal systems — the bin system and the direct fired system — have been used for processing, distributing, and burning pulverized coal in power plants.

The bin system (see Figure 1) consists of two steps:

1. Coal preparation and storage
2. Coal transport and injection

From Figure 1 it can be seen that raw coal from a bunker is fed by gravity through a feeder to a pulverizer with a single outlet. In the mill, the coal is simultaneously pulverized and dried. Hot air to dry the coal and transport it out of the pulverizer is provided by a fan and an air heater. The temperature of this air may be as hot as 650° F depending on surface moisture. The pulverized coal leaving the pulverizer is separated from the conveying air in a mechanical dust collector where 90 to 95 percent of the coal is collected and discharged by gravity into a storage bin. The remaining 5 to 10 percent is recovered in bag filterhouses, and the clean moisture-laden air is vented to the atmosphere.

From storage, the pulverized coal is generally conveyed by pneumatic transport through pipelines to utilization bins sometimes as far as 5,000 feet from the point of preparation. For this phase of pneumatic transport of the coal, a differential pitch screw pump is often provided. The coal in the transport line is then distributed through a system of two-way valves to any number of bins. From the utilization bins the coal is picked up in an air stream and transported and fired into the boiler furnace as required.

In the direct fired system (see Figure 2), raw coal is fed to the pulverizer where it is dried as well as pulverized. The primary air fan provides hot air from the boiler air heater to the pulverizer for drying and conveying the coal to the boiler furnace. Each pulverizer has multiple outlet lines with each line feeding a burner. The velocity in the pulverizer discharge pipes must be sufficiently high to prevent settling of coal which may lead to burner line fires. At the burners, the air-coal mixture must be uniform and the velocity suitable for stable combustion.

## CRUSHED COAL FIRING OF BOILERS

Crushed coal (1/4" x O) is used as the fuel for the B&W cyclone furnace. Preparation of coal for burning in a cyclone furnace consists of crushing the coal to about 1/4-inch top size. In some plants, this crushing is done in a crusher, which discharges coal directly into the cyclone furnace with primary air. This is called the direct fired system (see Figures 3 and 4) and a feeder and a crusher are required for each cyclone furnace. This arrangement is advantageous when there is limited plant space or there is an existing coal handling facility.

In other plants, coal is crushed to size before it is delivered to the main bunkers. This is called the indirect system. Economics generally favor the indirect system because it permits more efficient use of larger and fewer crushers.

When burning lignite or other high moisture coals, the direct fired, predrying, bypass system (Figure 5) is used. This is a variation of the direct fired system described above and incorporates a mechanical dust collector between the crusher and the cyclone furnace. Hot drying air is added to the raw coal before the mixture enters the crusher. Mechanical dust collectors separate the crushed coal from the moisture laden drying air leaving the crusher and the drying air is then vented into the secondary boiler furnace. The venting of this moisture laden air to the boiler secondary furnace instead of the cyclone furnace helps to maintain maximum temperature in the cyclone with improved performance and slag tapping characteristics. Hot primary air conveys the crushed coal from the exit of the mechanical dust collector to the cyclones. The pressure drop of the air passing through a cyclone is in the range of 20 to 40 in. wg; thus, the pressure at the coal inlet to the conveying line may be 50 to 70 in. wg.

In 1966, tests were carried out at B&W's Alliance Research Center to investigate transport and distribution of 1/4" x O crushed coal by dense phase from a fluidized feed tank. Coal to air ratios ranged from 30 to 173 lb. coal/lb air and pressures at the feed tank varied from 30 to 58 psig. Heavy pulsations and some pluggage were experienced in many runs due to both the inability to uniformly fluidize a material consisting of a wide range of particle sizes (100:1) and to nonuniform distribution of the various size fractions throughout the bed of coal in the feed tank. Several successful runs were conducted but there was insufficient investigation of the test conditions which made these runs different from the ones with pulsations.

## DENSE PHASE TRANSPORT OF PULVERIZED COAL

In addition to conveying pulverized coal to steam generators at low pressures (less than 2 psig.), B&W has also designed and built systems to convey pulverized coal at pressures up to 95 psig.

The Company began to look at systems which could be utilized to inject pulverized coal into blast furnaces as a supplementary fuel in the early 1950's. In order to fire pulverized coal into a blast furnace, the coal must be divided into many streams, each stream going to a tuyere

An attempt to split the coal flow from one pipe into many smaller ones was made by using a horizontal distributor (see Figure 6) similar to the coal distributing equipment being used on several zinc-fuming furnaces since 1942. However, tests indicated that the degree of unbalance between individual transport lines was greater than desired.

As a result of the unsatisfactory performance encountered in the tests made on the horizontal distributor, a new distributor was designed; model tested; and based on the model test results, built and tested in full scale. The vertical distributor, (see Figure 7) after some modifications, performed satisfactorily at coal to air ratios from 33 lb. coal per lb. air to 1 lb. coal per lb. air and system pressures up to 40 psig.

Tests were also conducted at the Company's Alliance Research Center for transporting pulverized coal through 1 1/2 and 2 1/2 inch pipe at various coal rates, velocities, and pressures up to 40 psig.

The information and design data provided by the above tests led to the design and construction of the pulverized coal injection system installed on Armco Steel's Bellefonte blast furnace at Ashland, Kentucky.

## DESCRIPTION OF THE BELLEFONTE PULVERIZED COAL INJECTION SYSTEM

The pulverized coal injection system used in conjunction with the Bellefonte furnace (see Figure 8) was the first of its kind to be operated in the industry. It was placed into commercial operation in 1966 and is still operating today. This system is designed to inject up to 25 tons of pulverized coal per hour through the furnace's sixteen tuyeres.

Raw coal is stored in two storage bins on top of the pulverizer building. Starting at this point, the coal is handled by two parallel and independent systems, each of which supplies pulverized coal to eight of the sixteen furnace tuyeres. Coal from the storage bins is conveyed into lock hoppers (two for each parallel system) where the pressure is increased to 55 psig. The raw coal is then fed to the pulverizer where the coal is dried and pulverized. It is then conveyed in a light phase coal-air mixture to a cyclone separator at the blast furnace. The coal which is separated in the cyclone passes through a rotary valve, is re-entrained in injection air and the dilute phase mixture is delivered to a vertical bottle distributor where it is divided into eight streams. Individual coal transport lines run from the distributor bottle to eight adjacent tuyeres.

## DESCRIPTION OF THE AMANDA PULVERIZED COAL INJECTION SYSTEM

A larger second generation pulverized coal injection system has been in service since June, 1973 on Armco's Amanda blast furnace. This system, which is the largest in commercial operation in the United States, can feed a maximum of 33 tons of pulverized coal per hour to the blast furnace. Presently the blast furnace operates at between 25 and 30 psig. However, the pulverized coal injection system was designed for 40 psig operation at the blast furnace for future conditions.

The Amanda furnace's pulverized coal injection system (see Figure 9) is divided into three subsystems, namely:

1) Raw Coal Storage and Pulverization
2) Pulverized Coal Storage and Pressurization
3) Pulverized Coal Transport and Distribution

### 1) Raw Coal Storage and Pulverization System

This is a relatively conventional bin-type coal pulverizing system operating at atmospheric pressure. There are two raw coal bunkers, two raw coal feeders, two B&W air-swept pulverizers and two sets of peripheral equipment including primary air fans, pulverizer air heaters, cyclone separators and bag filters. The pulverized coal from the cyclone separators and bag filters discharge into one pulverized coal reservoir tank, which operates at atmospheric pressure. Each path is completely independent of the other so an outage of one will not shut down the entire system.

### 2) Pulverized Coal Storage and Pressurization System

The pulverized coal in the reservoir tank is fluidized with inert gas at atmospheric pressure and transported to the three feed tanks. The inert gas is produced in a gas generator which burns natural gas in air. The inert gas is dried, compressed, and supplies both the reservoir tank and the pressurized feed tanks. During operation the coal feed tanks are loaded cyclically. While one tank is emptying, one is being filled and one is on standby fully loaded and pressurized to the prevailing feeding pressure to assure continuity of feed to the blast furnace. Load cells supporting each feed tank measure the weight of coal added to or transported from each tank. When a feed tank that is being charged with pulverized coal becomes full, a ball cock between the reservoir tank and feed tank is closed and the tank is pressurized with inert gas. At the proper time, the ball cock between the feed tank and transport line is opened and the fluidized pulverized coal flows from the feed tank to the blast furnace at a rate of flow that is controlled by the inert gas pressure in the feed tank.

As the feeding tank empties, the load cells measure the change in weight of the tank. When the tank reaches minimum weight (low coal level), the ball cock on the next tank, which is full of coal, opens and the ball cock on the first feed tank closes. The pressure in the tank which has just emptied is reduced to atmospheric pressure and the tank is then ready for filling from the reservoir tank. The Amanda system is designed to operate with only two tanks. To assure system reliability a spare feed tank is provided and all three are kept in operation, which increases the probability that the spare will function properly when needed. If a tank malfunctions, it is taken out of service and the system transferred to the next tank automatically.

Except for some automatically actuated valves, the pulverized coal storage and pressurization system is comprised entirely of static equipment. Material flow through the storage and pressurization system is by gravity.

### 3) Pulverized Coal Transport and Distribution System

The pulverized coal transport and distribution system is a completely static pipeline system which conveys the coal pneumatically from the feed tanks to the furnace area and distributes it among the tuyeres.

The transport of pulverized coal to the blast furnace which is located 340 feet from the coal preparation and pressurization system is accomplished by the addition of a small quantity of compressed air to the coal stream leaving the feed tank. A distributor (see Figures 10 and 11) is located at the far end of the 340 feet transport line. The coal-air mixture is divided into 24 streams with each line supplying one blast furnace tuyere.

The rate at which coal is injected into the furnace is normally a function of hot metal output. Therefore, it is logical to make the injection rate proportional to the blast furnace wind rate since this factor is indicative of furnace productivity.

The injection rate is a function of the differential pressure across the transport and distribution system and the density of the coal-air mixture. However, only the system pressure drop is varied to control the injection rate as the density of the coal-air mixture is held constant. Since the blast furnace operates at constant pressure, the feed rate is determined by controlling feed tank pressure. The density of the mixture is controlled so that the system is always in a stable mode of transport. This is accomplished by controlling the transport air rate.

A simple parallel control assigns a specific system pressure drop and air flow to each desired injection rate. Deviations from the proper relation between the desired injection rate and the controlled variables are nullified by a corrective vernier derived from the actual injection rate.

The actual injection rate is determined by differentiating the weight signals from the feed tank load cells to obtain the rate at which each tank is changing weight. An electromechanical auctioneer that receives its actuating intelligence from the feed tank sequence control always picks the rate signal from the discharging feed tank for control purposes.

## TWO — PHASE FLOW FUNDAMENTALS

B&W's approach to understanding two phase flow characteristics is based on a combination of theory and testing. The phenomena of gas-solids flow are studied by postulating theoretical relationships and then either confirming or modifying these relationships based on experimental data. This approach is superior to the empirical methods that are normally employed and can be used for extrapolation with greater confidence.

To properly understand and design a two-phase system, it is essential to be able to develop slip velocity and performance diagrams for both horizontal and vertical flow. The slip velocity is used to calculate the static head or suspension losses, and the losses which result from the frictional resistance between the coal-air mixture and the pipe wall. The performance curve relates pressure loss (exclusive of shock and acceleration losses), superficial gas velocity, spatial density and pipe diameter, and is used to establish regions of stable and unstable transport.

### Pressure Drop in Vertical Section

The total pressure drop of a gas solids system consists of the following components:

1) Static head or suspension losses
2) Frictional losses
3) Losses associated with solid accelerations, bends, expansions, etc.

### 1.) Static Head or Suspension Losses

The slip velocity diagram is essential in predicting static head or suspension losses. A general slip velocity diagram for a vertical flow system is shown in Figure 12. This shows a plot of slip velocity versus pressure gradient for a given particle size. The slip velocity is assumed to be related to the superficial gas velocity and the true particle velocity by:

$$\frac{V_d}{e} = \frac{V_o}{e} - V_s \qquad (1)$$

where

$V_d$ = Rate of slip between fluid and particle assemblage defined as the approach velocity uncorrected for voidage, ft/sec

e = volume fraction of voids in a bed of particles, dimensionless

$V_s$ = average solids velocity, ft/sec

For a transport system, $V_s$ may be calculated as follows:

$$V_s = \frac{R}{\rho f} = \frac{R}{\rho_s \ (1\text{-}e)} \qquad (2)$$

where

R = Solid feed rate, lb/(ft$^2$) (sec)

$\rho f$ = Dispersed density of solids, lb/ft$^3$

$\rho_s$ = True particle density, lb/ft$^3$

With reference to Figure 12, line OQ represents the relationship between pressure gradient and slip velocity when a fluid is passed through a bed of particles in which the particles are supported by direct contact with each other and the retaining wall. Whether the bed is moving or in a static condition, the same result is obtainable provided the material in each case is in a similar state of particle arrangement and relative velocity. Under these conditions, the total pressure drop across the bed increases with the velocity of the fluid as shown in Figure 12, but the length, L, of the bed corresponding to a given amount of the solid phase remains constant.

As the fluid velocity through a fixed bed is increased, a point Q is reached at which the particles begin to rearrange themselves into a more open packing. This condition is called the point of quiescence. The particles will yield much more readily to any external force. A further increase in the fluid velocity will result in an increase in the total pressure drop, $\Delta P$, and in the bed length, L, due to expansion. The approximate net result is operation along the vertical line QF until point F is reached. The latter condition may be called the point of incipient fluidization, at which the weight of the particles is completely borne by the air stream. The individual particles now possess freedom of motion, and the bed behaves like a "boiling" liquid.

Full fluidization is attained at Point F. As the velocity in the system is increased from $V_f$ to $V_\infty$, the value of $\Delta P/L$ decreases, however, $\Delta P$ remains essentially constant because of a corresponding decrease in stream density. In pneumatic conveying we are interested in velocities shown between $V_f$ and $V_\infty$ on Figure 12. The curve between points B and C represents the region of dense phase transport or fluidized bed operation. In this area the pressure gradient is described by:

$$\Delta P/L = (\rho_s - \rho) \quad (1 - e) \tag{3}$$

At the point (C, $V_\infty$), the superficial fluid velocity exceeds the settling velocity of all the particles in the bed. The curve then passes through a maximum at (A, $V_M$). A region of instability exists between points C and A along the F, $V_\infty$ curve; here pulsations may occur in a pneumatic system. Finally, the pressure gradient becomes zero at the terminal settling velocity of a single particle in an infinite fluid.

Means for predicting curve F, $V_\infty$ are provided by the following relationships (4) and (5):

C = f (Re), a relationship between a modified drag coefficient and a modified Reynolds number which coincides with the well-known resistance curve for spheres settling in an infinite fluid (see Figure 13). (4)

$$V_d = V_c\left[\frac{1 + KNV_c \times 10^6}{135\, e}\right]$$

, an empirical relationship representing data on gas fluidization (see Figure 14) (5)

where

$$C = (C_o)(Y)$$

$$C_o = \left[\frac{4}{3}\ \frac{g\, \varnothing s\, D_p\, (\Delta P/L)}{\rho V_c^2 (1 - e)}\right]\left[\frac{2}{K_v (K_v + 1)}\right]$$

$$Y = Y'' + (Y' - Y'') \sin \frac{24}{CRe}\ \frac{\pi}{2}$$

$$Y'' = \frac{1}{1 + \frac{9.65}{k}(1 - e)}$$

$$Y' = \frac{1}{1 + \frac{9.65}{k}(1 - e) - \frac{14.83}{k}(1 - e)^2}$$

$$Re = \frac{Re_p}{K_v}$$

$$Re_p = \frac{\varnothing s\, D_p\, V_c\, \rho}{\mu}$$

$$K_v = \frac{1}{1 - 1.107\,(1 - e)^{2/3}}$$

$$K = \frac{\rho \mu^3}{\left[g\rho\, (\rho s - \rho)\, \mu\right]^{4/3}}$$

$$N = \frac{1 - e}{\frac{\pi}{6}\, D_p^3}$$

$Y$ = Generalized dispersion factor as defined above, dimensionless

$k$ = Ratio of specific heats, $C_p/C_v$, dimensionless

$\varnothing_s$ = Carman's shape factor for securing the specific surface of non-spherical particles

$D_p$ = Diameter of sphere of the same volume as that of the particle, ft

$V_c$ = Calculated fluid velocity relative to the particle for gas fluidized bed assuming the validity of Figure 13

$\rho$ = Density of fluid, lb/ft$^3$

$K$ = A dimensional factor

$N$ = Particle concentration, number /ft$^3$

Trial and error is now required in the solution of equations (4) and (5).

**2.) Frictional Losses**

The pressure drop due to wall friction can be determined empirically by starting with the usual friction factor versus Reynold's number correlation, and the Fanning equation by using the viscosity of the air and the density of the mixture.

$$Re_t = \frac{DG}{\mu}(1 + L_x) \quad (6)$$

$$\left(\frac{\Delta P}{L}\right)_{fs} = \frac{4f}{D}\;\frac{G^2}{2\rho_f g}(1 + L_x)^2 \quad (7)$$

$$\rho_f = \frac{\dfrac{R}{V_o - V_d}}{1 + \dfrac{R}{\rho_s(V_o - V_d)}} \quad (8)$$

$Re_t$ = Pipeline Reynolds Number = $\frac{DG}{\mu}$, dimensionless

D = Inside diameter of transport line, ft.

G = Gas flow rate, lb/(ft$^2$) (sec)

$\mu$ = Viscosity of fluid, lb/(ft) (sec)

$L_x$ = Solid to gas loading, lb/lb

$(\Delta P/L)_{fs}$ = Pressure gradient component due to frictional resistance of the mixture with the pipe wall, lb/ft$^3$

f = Fanning friction factor, dimensionless

g = Local acceleration due to gravity = 32.17 ft/(sec)$^2$

$V_o$ = Superficial fluid velocity, ft/sec

Equations (6) and (7) are usually adequate for normal engineering applications at low solid to gas loading; but at high loadings the actual pressure drops could be 30 to 40% lower than predicted. Therefore, to improve their accuracy, it is valid to use a linear function of solids loading in correcting the mass rate term. Equations (6) and (7) may then be rewritten as:

$$Re_t = \frac{DG}{\mu}(1 + aL_x) \quad (9)$$

$$\left(\frac{\Delta P}{L}\right)_{fs} = \frac{4f}{D}\;\frac{G^2}{2\rho_f g}(1 + aL_x)^2 \quad (10)$$

where

a = Dimensionless correction constant applied to solids loading in the modified Fanning relationships for two-phase flow.

**3.) Acceleration and Shock Losses**

Pressure drop across bends and other fittings have been extensively studied for one phase flow. A correlation relating the bend losses for two-phase flow to single-phase flow was developed by B&W.

A similar procedure was then used to obtain pressure drops through other types of fittings.

## Pressure Drop in Horizontal Sections

Means for the prediction of slip velocities for horizontal flow could not be found in the literature and was therefore developed by the Company from tests performed at the Alliance Research Center. These tests also identified regions of stable and unstable flow.

## Performance Diagram

The total line loss is defined by means of the following relationship:

$$(\Delta P/L)_{LL} = M\rho_f + (\Delta P/L)_{fs} \quad (11)$$

where

$$m = \frac{(\Delta P/L)h}{\rho_f}$$, lb force/lb mass

$(\Delta P/L)h$ = Pressure gradient component due to slip between the gas and solid phases in horizontal flow, lb/ft$^3$

The first term accounts for the "suspension" losses while the second term relates to the wall friction whose value was already defined (Equation 10) so that:

$$\left(\frac{\Delta P}{L}\right)_{LL} = m\rho_f + \left(\frac{4f}{D}\right)\left(\frac{G^2}{2g\rho_f}\right)(1 + aL_x)^2 \quad (12)$$

The pressure drop equation derived for line losses (static head and friction) forms the basis for predicting system performance. The performance diagram shown on Figure 15, is typical of those which can be developed quantitatively for pulverized coal. For a fixed pipe diameter, such a diagram shows the relationship between the pressure gradient (line losses only) and superficial gas velocities for parameters of different coal feed rates, $W_1$, $W_2$, and $W_3$.

Starting on the upper left part of the diagram, the pressure gradient decreases with gas velocity. This results from the coal dispersion becoming more dilute, resulting in lower "suspension" losses; but as the velocity increases to higher values, the term which describes the friction of solids against the wall begins to prevail and the curves pass through a minimum. For dilute and light phase transport there is a minimum velocity below which the solids begin to settle in horizontal flow. This velocity is the saltation velocity and is shown by the dotted curve on Figure 15. Also, as the solid loading increases, particles begin to settle out and the system may be expected to exhibit flow instability. In dense phase flow, on the other hand, smooth operation is possible below the saltation velocity because the relative low voidage hinders particle separation and the solids remain in a dispersed condition. But pluggage may take place in dense phase transport if the velocity drops below the minimum velocity required for smooth flow.

Three other curves are also superimposed on Figure 15. These are lines of constant density and pertain to the spatial concentration ($\rho_f$) of the solids dispersed inside the pipeline. A high value of spatial concentration is shown at A $lb/ft^3$, an intermediate value at B $lb/ft^3$, and a relatively low value at C $lb/ft^3$.

By means of these constant density lines and the saltation velocity curve we can separate the above chart into five different regions:

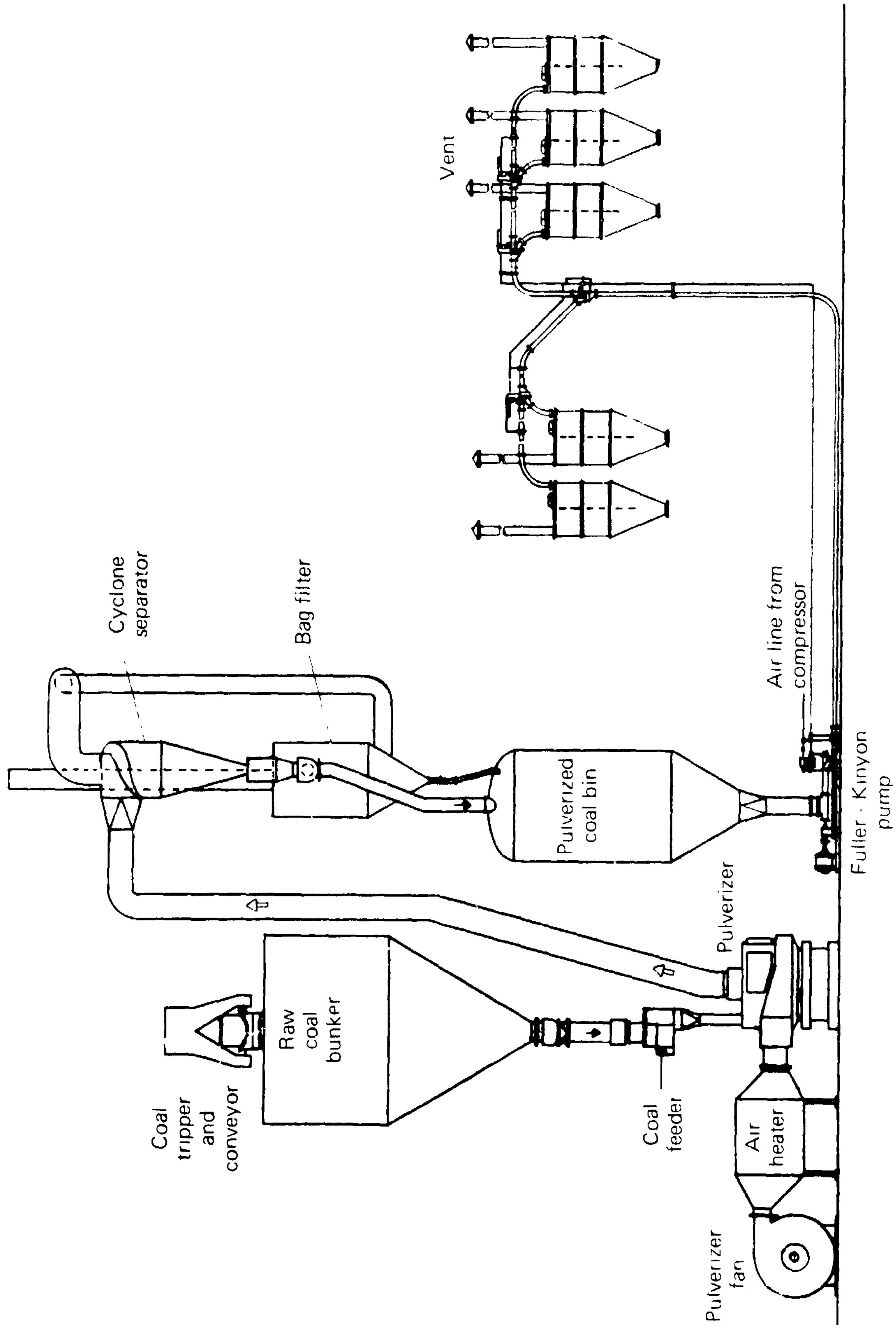
Region 1 — stable dense phase
Region 2 — unstable
Region 3 — unstable for horizontal flow
Region 4 — questionable
Region 5 — stable dilute phase

It should be recognized, however, that the apparent stability of Regions 1 and 5 may be upset by the interaction of other variables in the system such as feed tank internals, bends and distribution devices.

By using the techniques described, it is possible to identify the regions of instability which can exist in every pneumatic transport system. Also these regions may vary for different materials depending on the particle characteristics. B&W has defined these regions for a limited application. To be able to design systems capable of achieving smooth flow, and to satisfy the requirements which new processes demand, considerable research and development is needed.

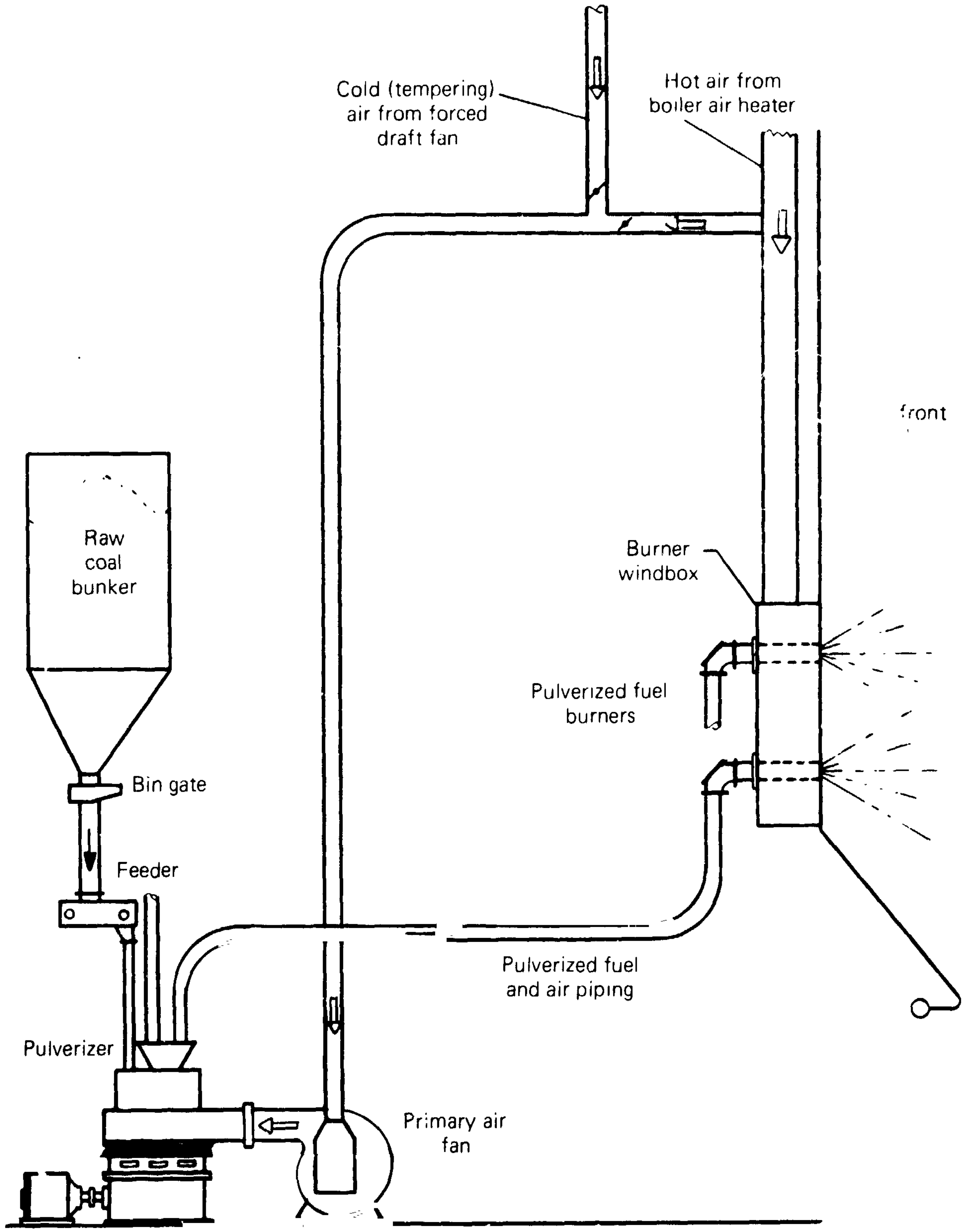
## ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of the Industrial and Marine Division of the Company who sponsored most of the research work defining the characteristics of two phase flow mixtures of air and coal. However, particular recognition must be made of the work performed by W. C. Lapple of B&W's Alliance Research Center who should get the credit for the development of the slip velocity, and performance diagrams.



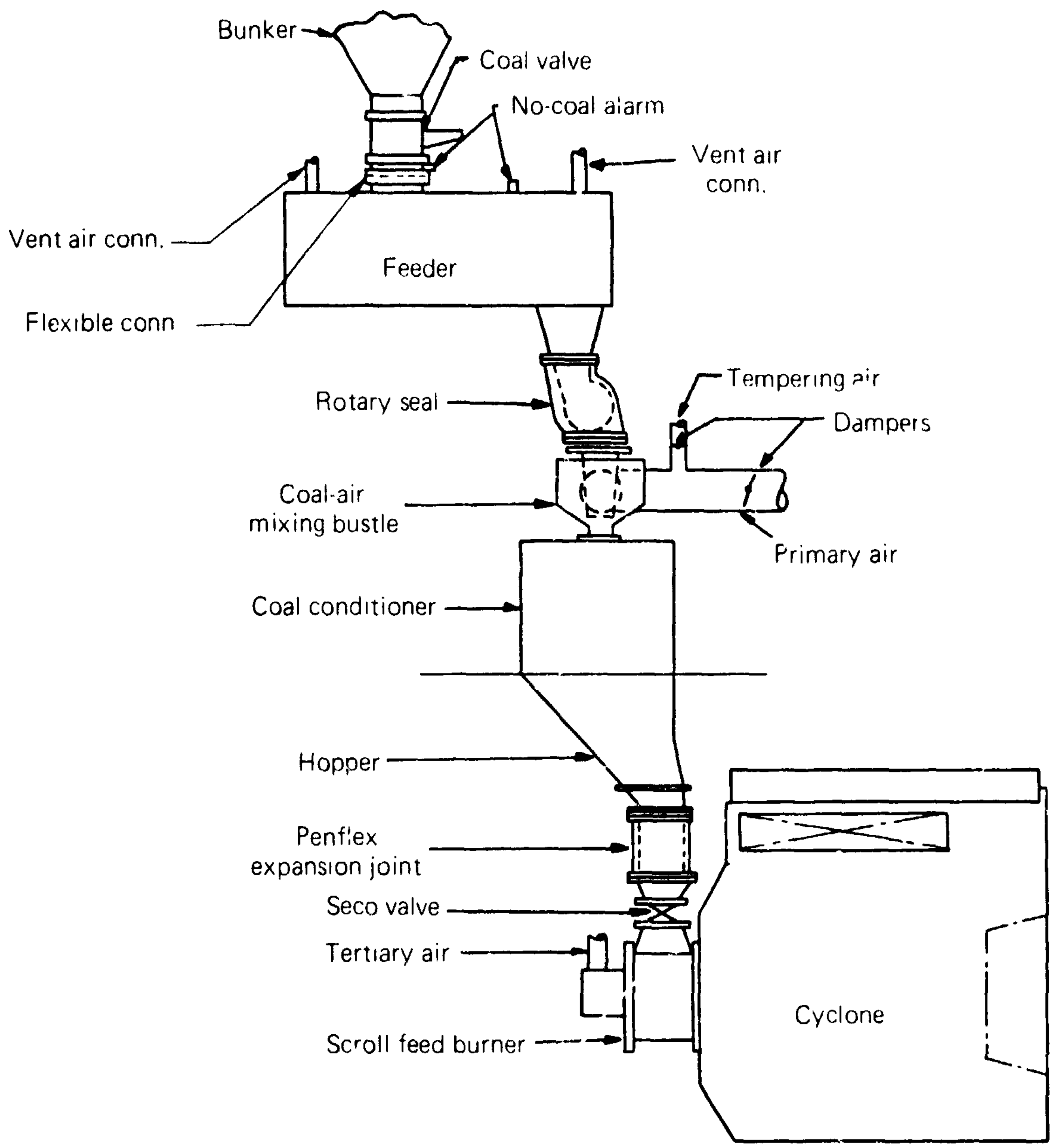

**Bin system**

Figure 1



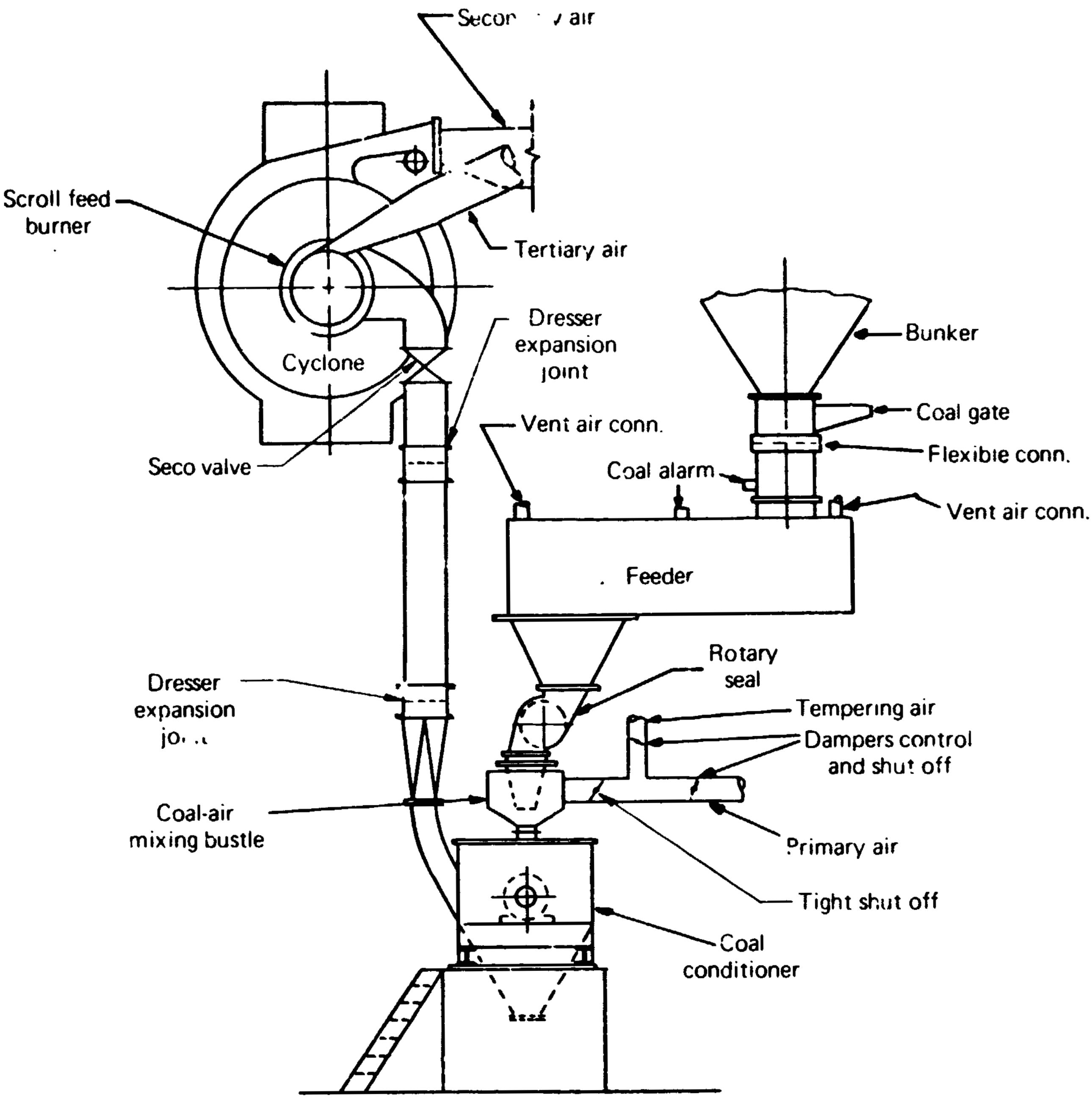

**Direct firing system**

Figure 2



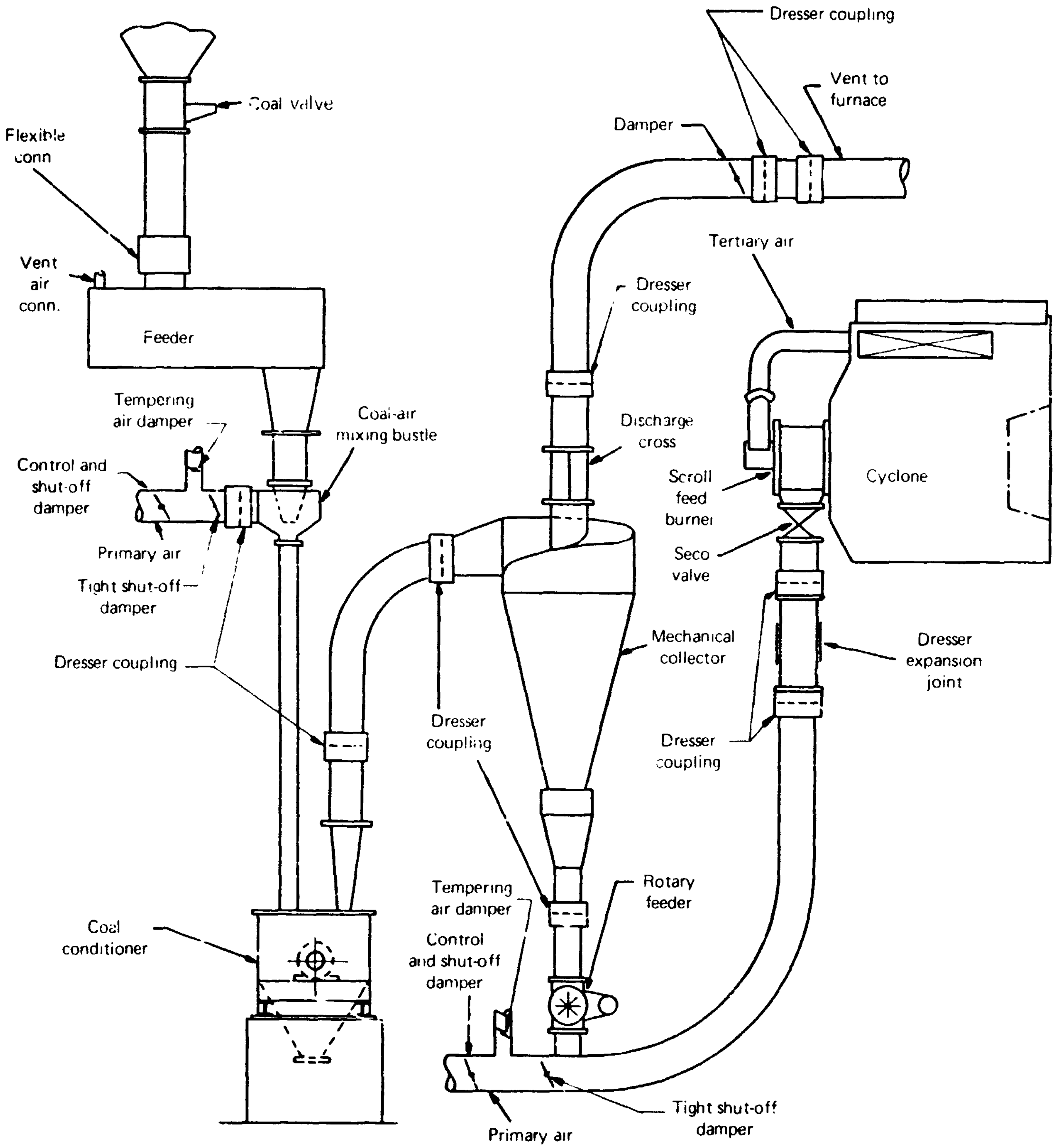

**Direct fired gravity system**

Figure 3




**Direct fired air I. . system**

Figure 4




**Direct fired, pre-drying by-pass system**

Figure 5

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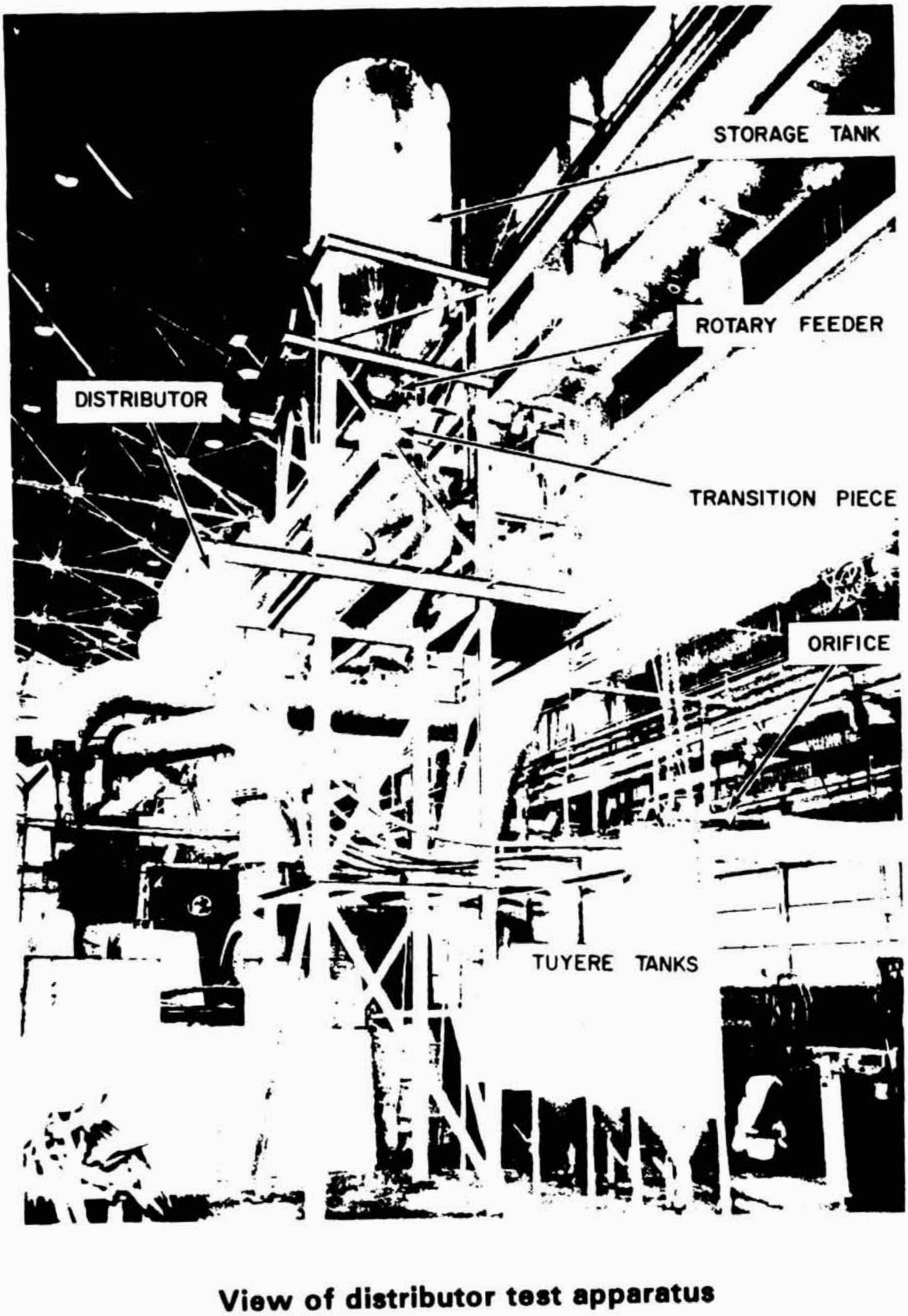
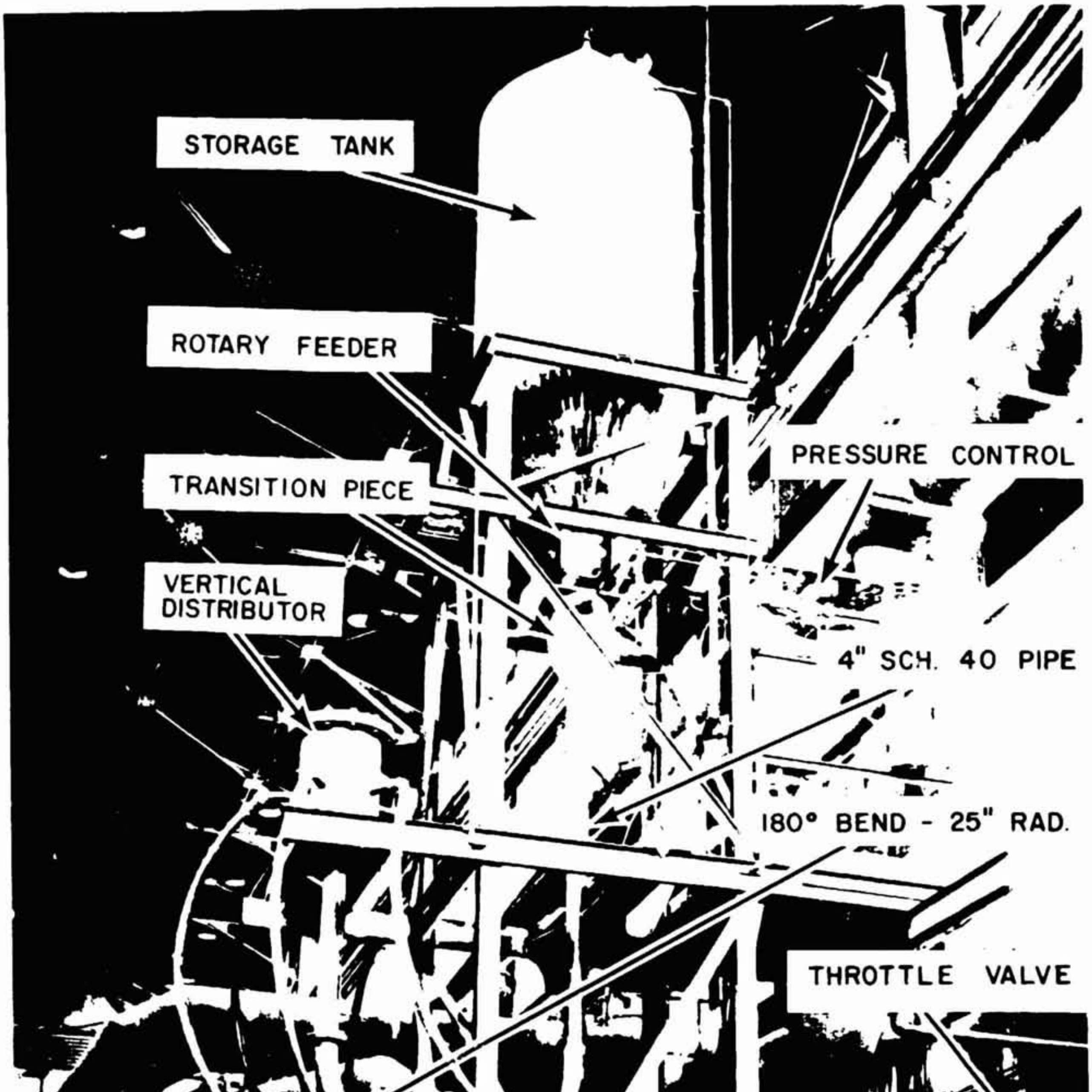


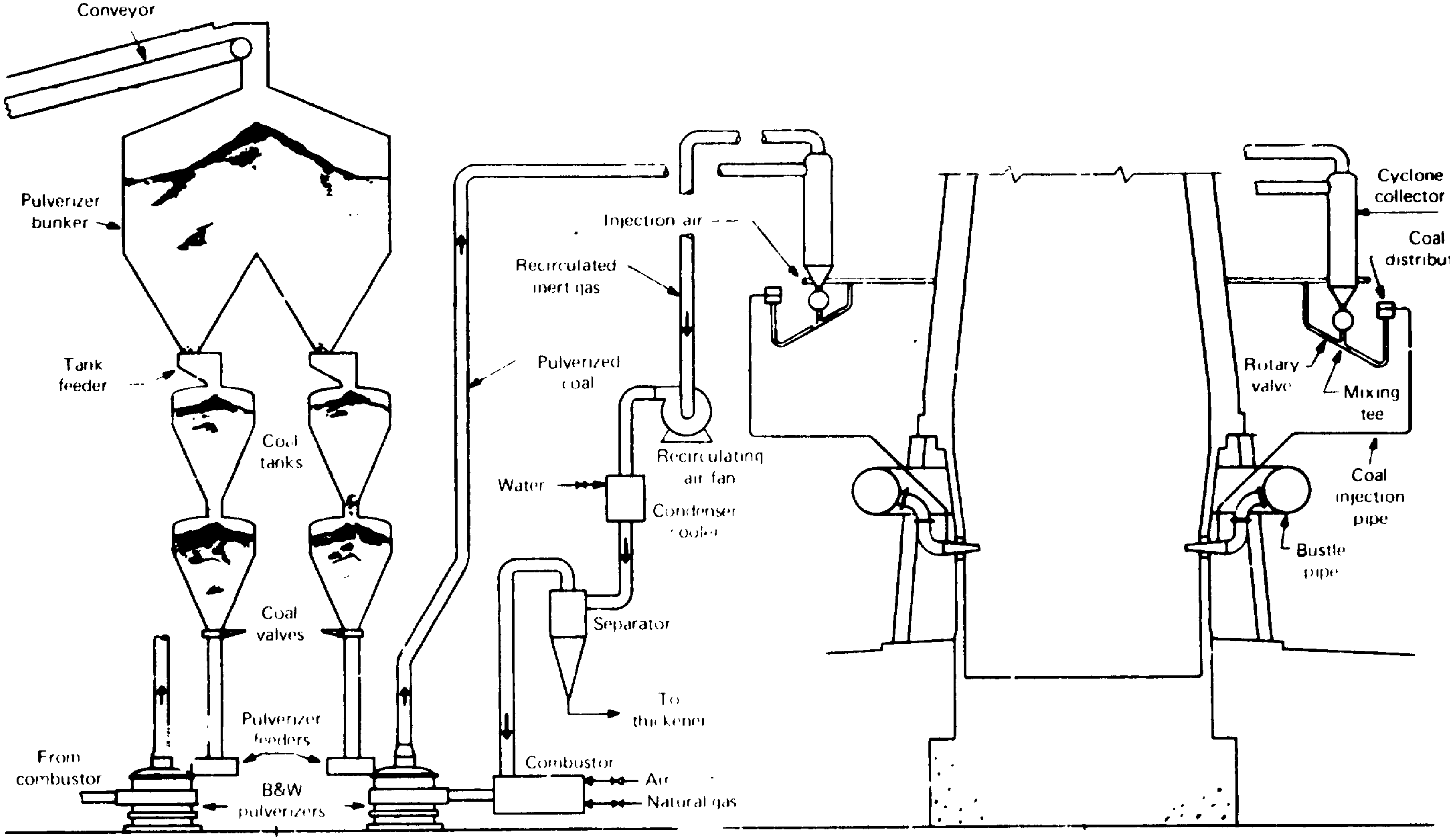

**View of distributor test apparatus**

Figure 6



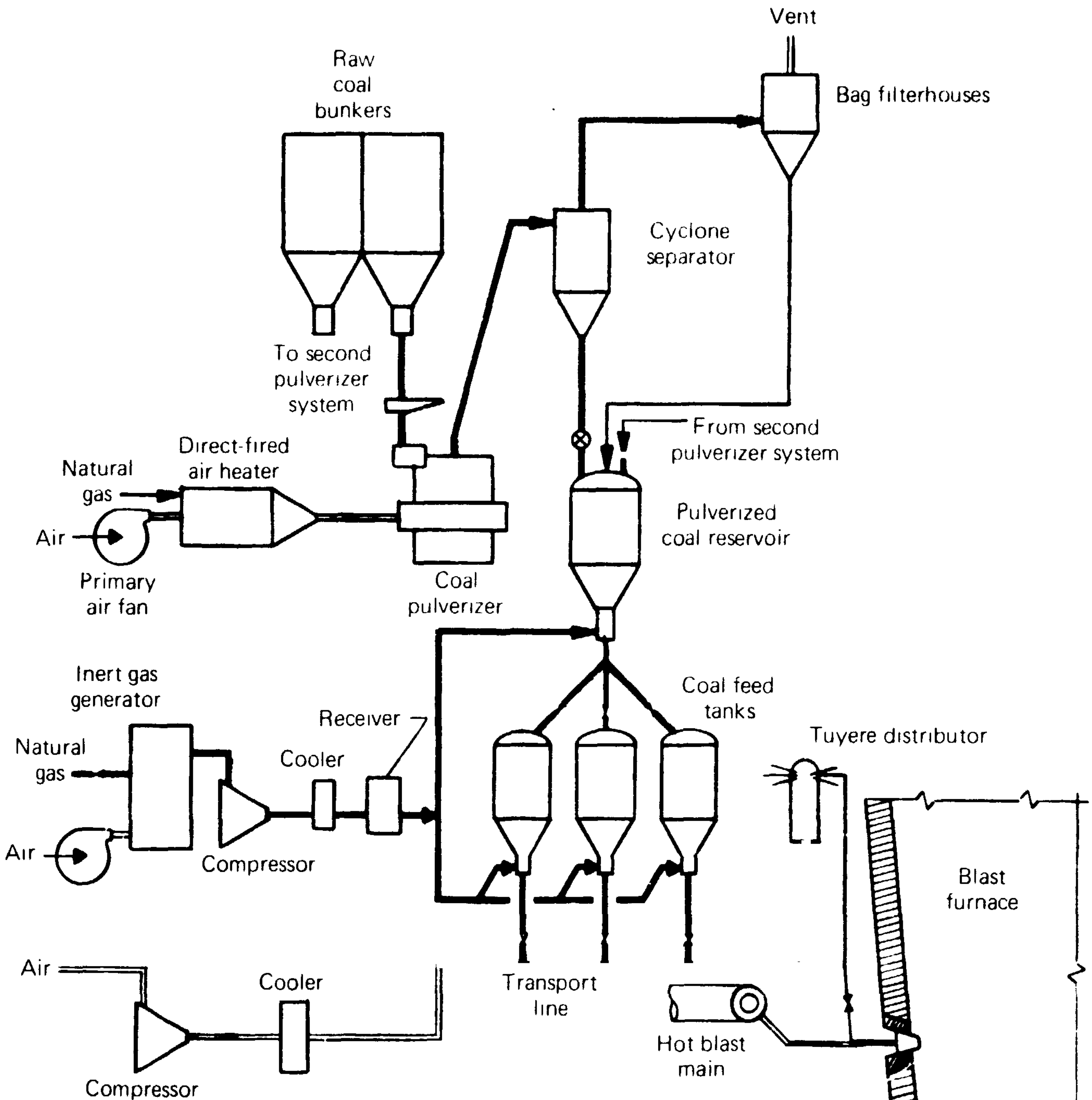

**View of coal distributor test apparatus**

Figure 7



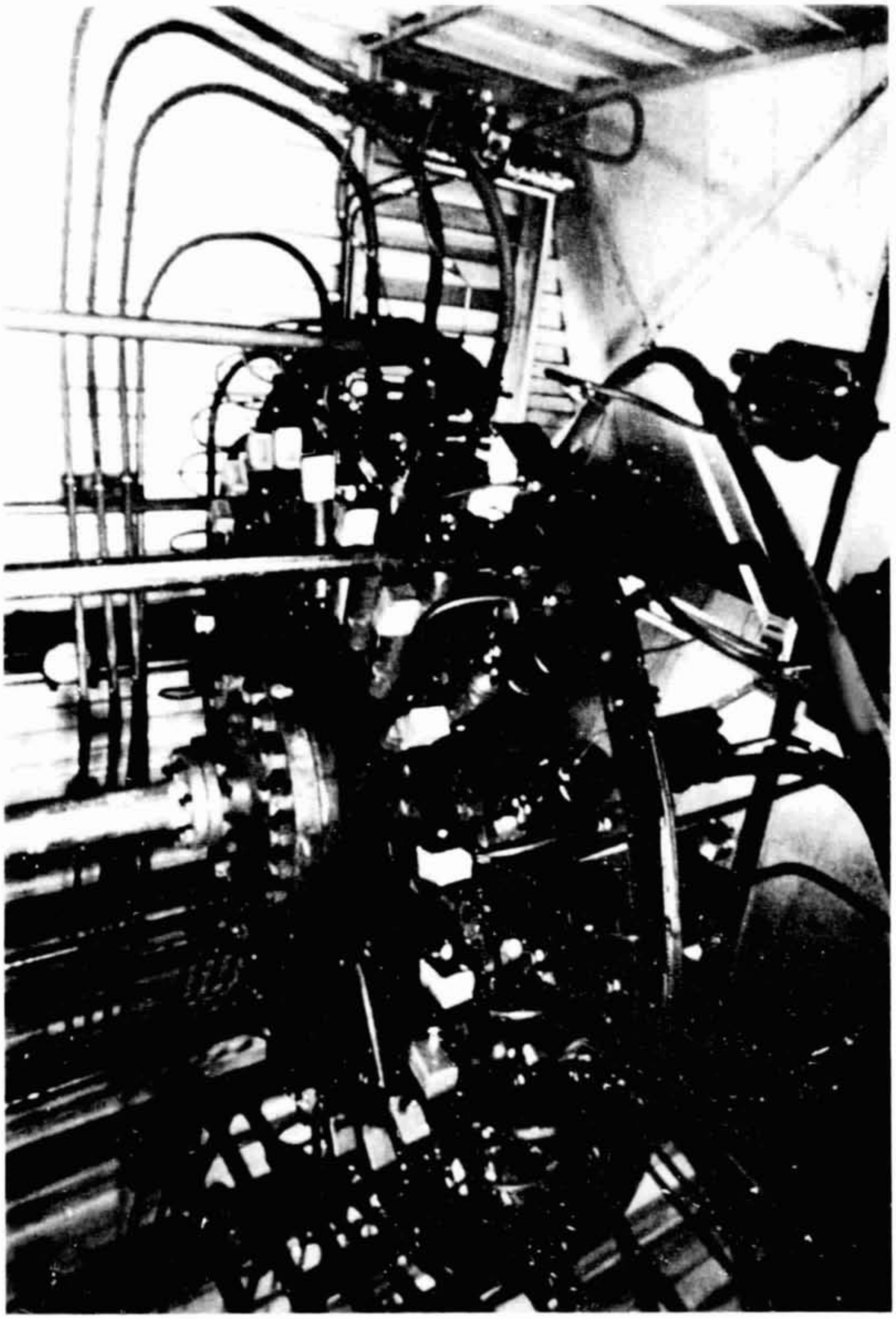

**Bellefonte's pulverized-coal-injection system**

Figure 8



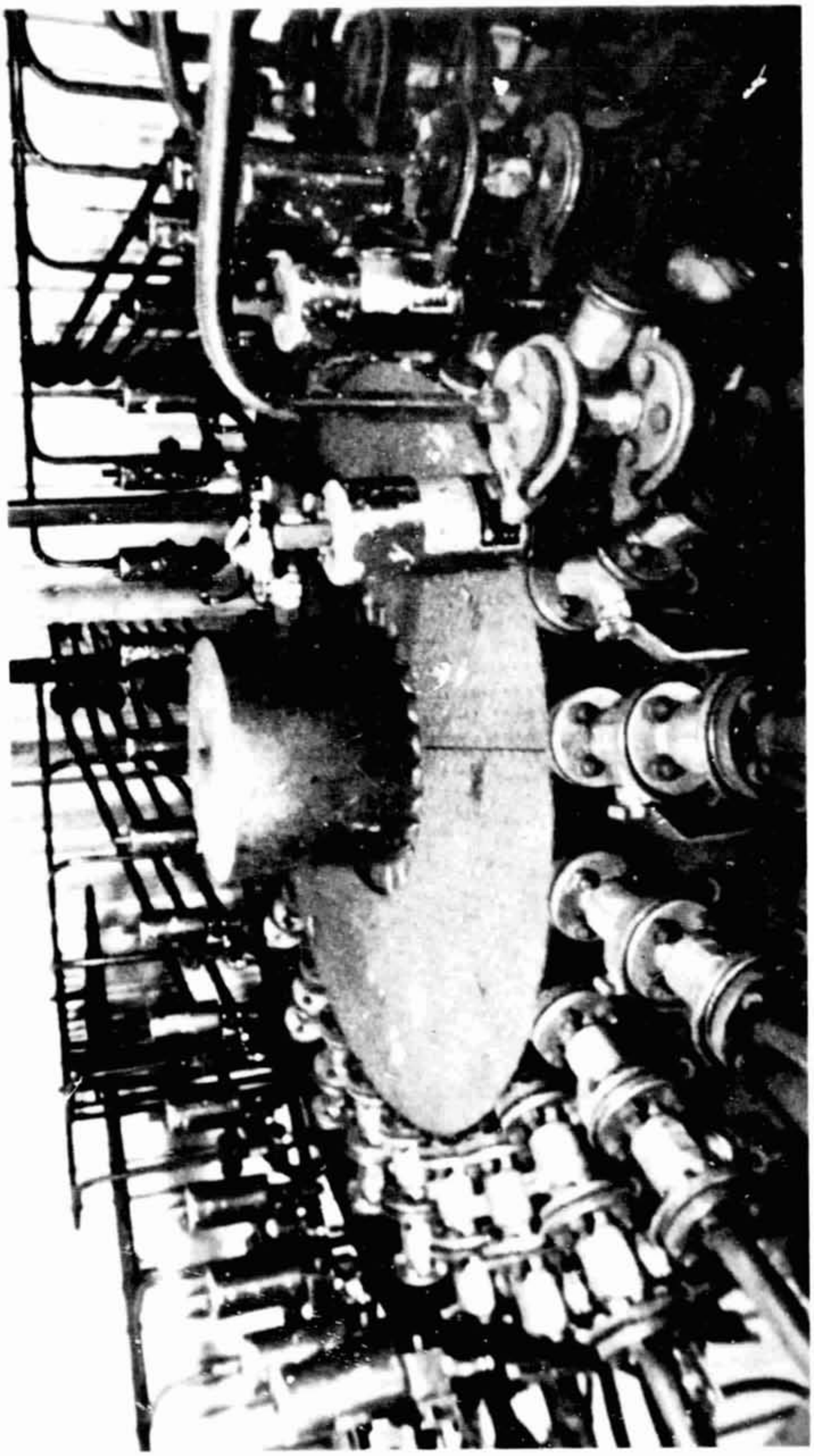

**Amanda's pulverized-coal-injection system**

Figure 9



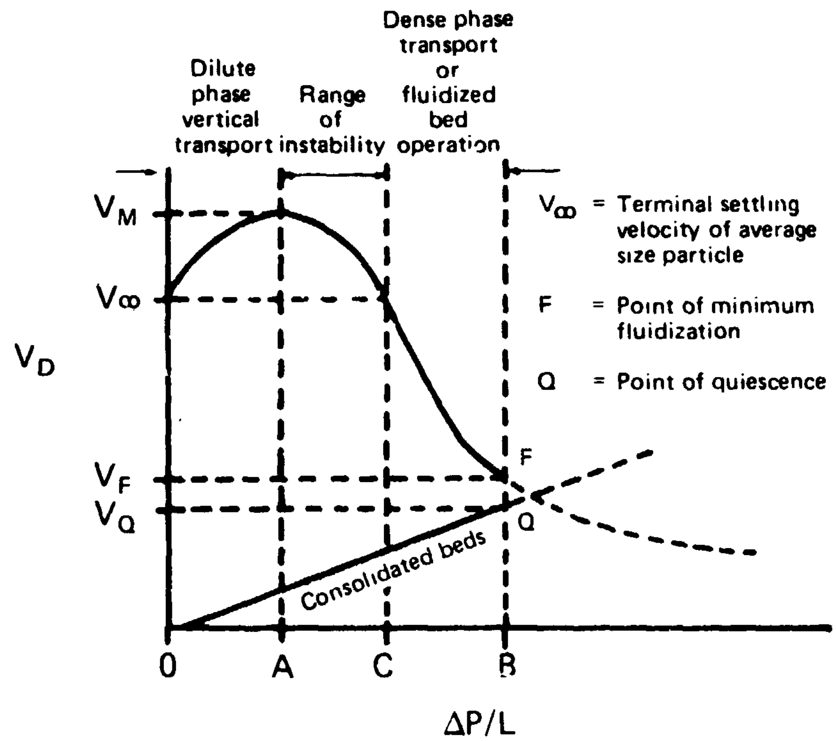
**Bottom of distributor bottle**

Figure 10



**Top of distributor bottle**

Figure 11




**Slip velocity diagram for vertical flow system**

Figure 12

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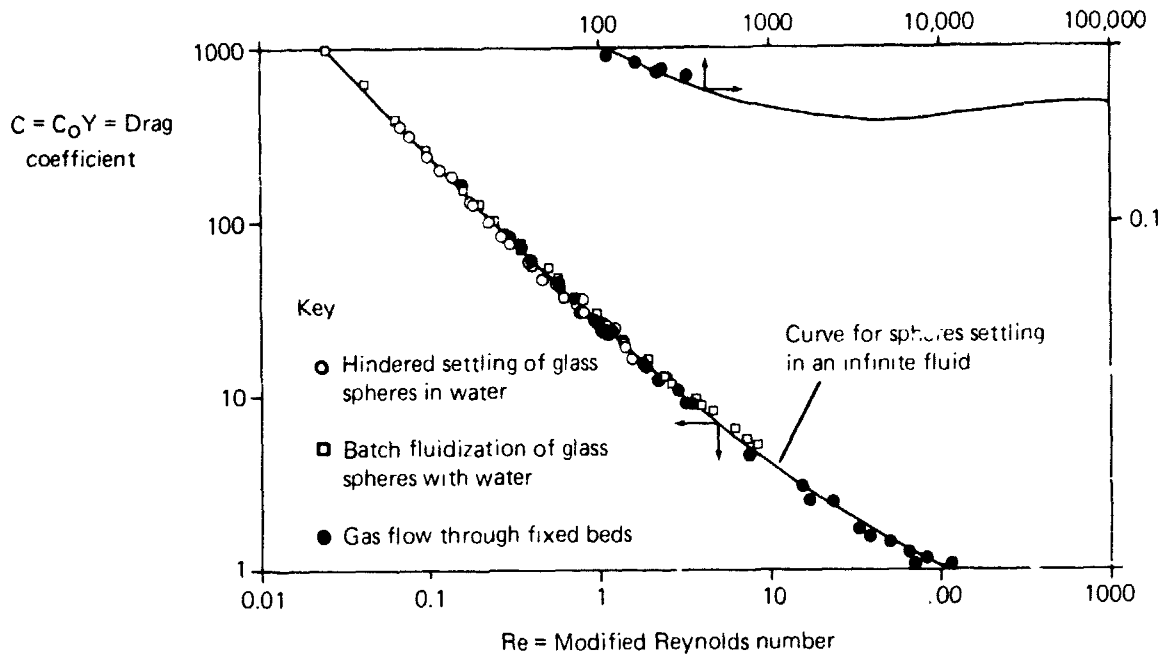
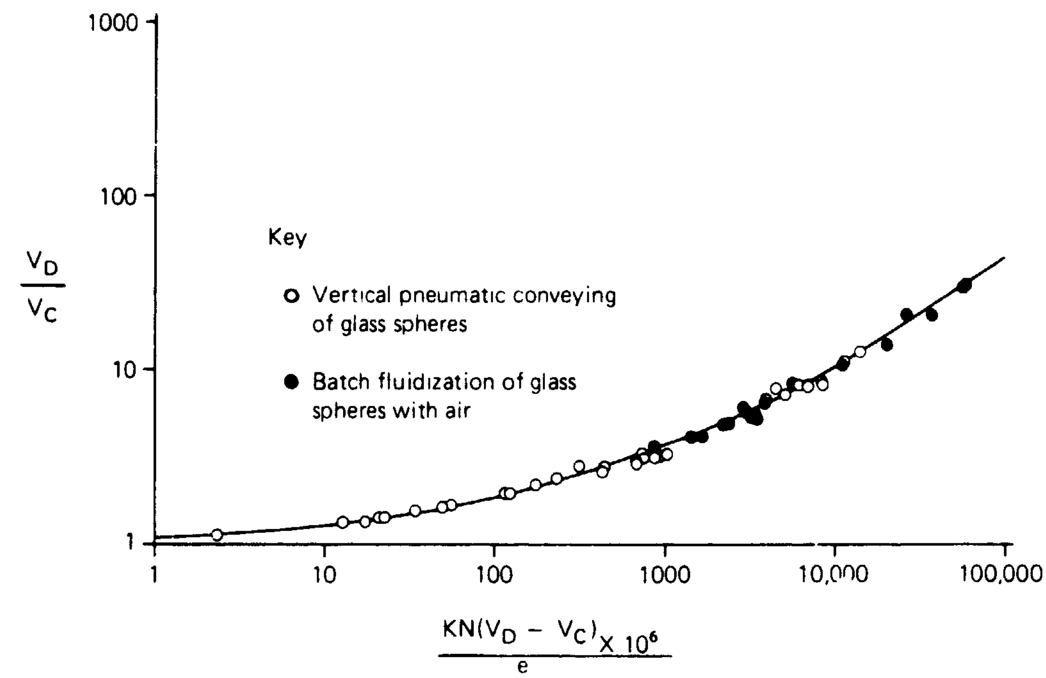


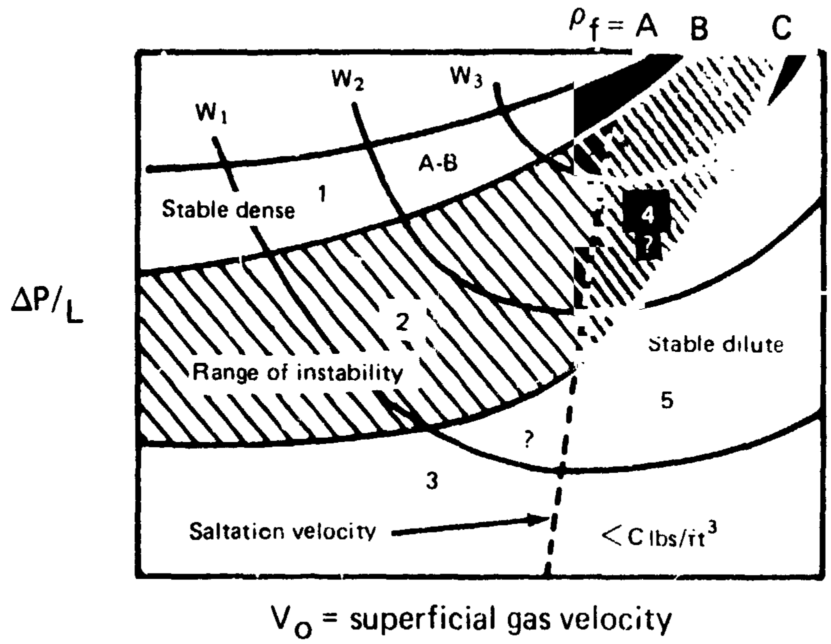

**Generalized correlation of data on flow of fluids through beds of granular solids**

Figure 13




**Generalized correlation of data on gas fluidization**

Figure 14




**Performance curve for pneumatic transport system**

Figure 15