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COAL MATERIALS HANDLING—CLASSIFIER EVALUATION

Quarterly Progress Report for Period October—December 1980

By
Reed S. C. Rogers

Work Performed Under Contract No. AC21-80MC14266

Kennedy Van Saun Corporation
Danville, Pennsylvania

U. S. DEPARTMENT OF ENERGY

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QUARTERLY PROGRESS REPORT

FOR THE PERIOD

OCTOBER - DECEMBER 1980

DR. REED S.C. ROGERS

KENNEDY VAN SAUN CORPORATION

DANVILLE, PA 17821

PREPARED FOR THE UNITED STATES

DEPARTMENT OF ENERGY

UNDER CONTRACT NO. DE-AC21-80MC14266

SUMMARY

This is the first Quarterly Progress Report for DOE Contract No. DE-AC21-80MC14266, "Coal Materials Handling Classifier Evaluation". It covers the period 1 October - 31 December 1980.

The project is divided into seven Tasks which can be grouped into three general phases of work. These general phases of work are a Preparation Phase, a Testing and Data Reduction Phase and a Reporting Phase. A last task, Task VIII, involves maintenance of DOE owned test equipment used during the project. Work during this project period has centered on the Preparation Phase and the following progress has been made.

One hundred tons of the study coal (Western Kentucky No. 9) has been ordered and is to be delivered to KVS in mid-January. All drawings required for fabrication of the Hukki centrifugal classifier have been completed; drawings for the ductwork are nearing completion. The first draft of the project Program Plan Manual has been completed and is included here as an appendix. The classifier evaluation procedures has been developed including a laboratory procedure for subsieve size analysis.

During the next quarter work will continue on the Preparation Phase, including receipt and preparation of the study coal and fabrication of the centrifugal classifier and ductwork. In addition, it is anticipated that roughly one-third of the required testing and data reduction will be completed.

ACKNOWLEDGEMENTS

This report was prepared by the Project Manager. However, the contents represent the contributions of many other individuals. In particular,

for DOE: Robert L. Gall, Technical Project Officer

for KVS: Ilse G. Pruefer, Contract Manager

Kenneth L. Gardner, Director, Engineering and Technology

James J. Wilver, Manager, Testing Facilities

Ari M. Hukki, Research Engineer

Karen J. Kniss, Research Analyst

for PSU: Peter T. Luckie, Project Associate

TABLE OF CONTENTS

INTRODUCTION

One of the most important industrial applications of classifiers is in closed circuit grinding systems. The primary function of a grinding device obviously is to produce a finer material from a coarser material. Standing alone, i.e., in open circuit, the grinding device at steady-state produces a fine material from a coarse material at a coarse material feed rate that equals the fine material product rate. When a classifier is coupled with the grinding device (thus closing the circuit) the coarse stream is returned to the grinding device and the fine stream becomes the product stream of the grinding circuit. Under these conditions the actual steady-state feed rate to the grinding device itself will be higher than the circuit feed and product rates.

There are many advantages in operating a grinding device in closed circuit. For example, if the grinding machine is a retention device; i.e., there is a holdup of material within the mill such that the mean grinding time is given by this holdup weight divided by the feed rate, then at a constant holdup weight a finer product will be produced by decreasing the feed rate. By closing the circuit with a classifier the feed rate need not necessarily be reduced since coarse material is being recycled for further grinding. In this way it would be possible to produce a given fineness of grind, e.g., 95% passing 140 mesh, at a significantly higher rate in closed circuit than in open circuit. Since the energy to operate the grinding device is essentially constant the specific grinding energy (KWH/ton) is reduced. Also, as demonstrated in the work performed under DOE Contract No. EX-76-C-01-2475, closed circuit grinding can result in better control of the size distribution of the circuit product, i.e., a more closely sized circuit product. That is, while both open and closed circuit grinding might produce 95% passing 140 mesh, the closed circuit product might analyze 30% passing 400 mesh versus 50% passing 400 mesh from the open circuit device.

The desire and need to reduce energy requirements is, of course, the first and foremost reason for seeking a better understanding of the role of classification in closed circuit coal grinding. A better understanding of classifiers typically used in conjunction with coal grinding circuits would result in the ability to better utilize energies expended in coal grinding. In addition, the ability to better control the product size distribution is of major importance to many new processes being introduced to our energy conscious economy. Such processes include coal-oil mixture production, the production of coal-water slurries of pipelines, coal gasification and the production of solvent refined coal. All of these processes call for the use of pumpable and high concentrate slurries. In all cases the product size distribution has a direct effect on the pumpability and percent by weight solids concentration that is reasonably attainable.

Recognizing the need for a better technical understanding of classifiers used in coal grinding, the United States Department of Energy and the Kennedy Van Saun Corporation conceived the present project to evaluate various classifiers currently being used in air swept coal grinding systems. The classifiers under consideration include a twin cone classifier, an expansion chamber type (vari-mesh) classifier and a new centrifugal classifier recently introduced by Hukki. The objectives of this evaluation are to compare the efficiency of the classifier designs with respect to their affect on closed circuit grinding system performance and to provide data that will allow a preliminary evaluation of classifier design with respect to coal separation on the basis of sulfur and ash content.

THE PROGRAM

The project program is broken down into seven tasks that are grouped into three general phases of work: a Preparation Phase, a Testing and Data Reduction Phase and a Reporting Phase. Progress made on these phases of work during the present reporting period is described in the following.

Preparation Phase

The Preparation Phase is comprised of four tasks. These are

- Task I. Coal Acquisition and Preparation
- Task II. Classifier Fabrication
- Task III. Facility Preparation
- Task IV. Test Planning and Development of Analysis Methodologies

Progress:

Task I. One hundred tons of the Western Kentucky No. 9 study coal has been ordered. The delivery date for this coal is mid-January 1981. The coal will be prepared as needed during the Testing and Data Reduction Phase of work.

Task II. Drawings necessary for fabrication of the Hukki Centrifugal Classifier have been completed. Metlmax Corporation of Lewistown, PA have been contacted and have agreed to fabricate the classifier.

Task III. Drawings necessary for ductwork fabrication are nearing completion. As with the centrifugal classifier, ductwork will be fabricated at Metlmax Corporation.

Task IV. The first draft of the Program Plan Manual has been written and is included here as an appendix. The reader will find the Manual to be a stand alone document which describes the Program Plan in detail and allows an updating of technical progress during the Testing and Data Reduction Phase of work. During this reporting period the classifier evaluation procedures have been developed including a laboratory method for subsieve size analysis. The following describes the evaluation procedures; the subsieve size analysis methods have been reported but are also included here.

Classifier Evaluation Procedure

The recommended methodology[1] for evaluating classifier performance is to calculate the fractional coarse recoveries and then plot these values against size, thereby generating a size selectivity curve, an independent measure of effectiveness. The fractional coarse recoveries are calculated as

$$r(x) = \frac{\text{amount of material of size x in the coarse stream}}{\text{amount of material of size x in the feed stream}}$$

Since material of size x cannot be measured, it is necessary to measure material between size x and x+dx. If the quantity dx is sufficiently small, the resulting values can be treated as point values. If dx is larger, the resulting values are interval values. Typically, interval values are calculated for size ratios, i.e., $(x+dx)/x$, equal to $\sqrt[4]{2}$ or $\sqrt{2}$, the latter being a maximum value. The resulting interval values are plotted against "size". Since they are interval values, it doesn't matter whether they are plotted against x+dx, x or some mean value, $x+dx<\bar{x}<x$, as long as the plotting method is consistent. The plotted values can be connected to produce a continuous curve which in turn can be employed to characterize the classification[2].

Data Analysis Techniques

Fitting Size Selectivity Functions

In order to develop a more consistent pattern for evaluation, it is often convenient to fit the values to a functional form, the size selectivity function. Also, with such a function, the size selectivity values can be readily recreated. The suggested method for fitting the fractional recoveries to the size selectivity function is by a weighted least squares criterion, i.e.,

$$\Sigma\, w(x_i)\left[s(x_i)-r(x_i)\right]^2 = \text{minimum}$$

The weighting values, $w(x_i)$, employed have included 1.0 (i.e., no weighting) and the quantity, $m(x_i)/\left[s(x_i)(1-s(x_i))\right]$, where $m(x_i)$ is the fraction of material of size x_i in the feed to the classifier.

A suggested form for the size selectivity function[2] is

$$s(x_i) = (1-a)c(\kappa,d_{50};x_i) + a$$

or

$$(1-s(x_i)) = (1-a)(1-c(\kappa,d_{50};x_i))$$

where a, κ and d_{50} are characterizing parameters. Numerous functional forms have been suggested for the two parameter function, $c(\kappa,d_{50};x_i)$[2]. During this reporting quarter, various functional forms -

- Lynch's model
- Rosin-Rammler
- Log normal
- Logistic

have been under study, with and without weighting.

Fitting a Paucity of Data

When there are relatively small particles in the fine stream, it is difficult to obtain size analyses fine enough to cover the size range necessary to determine fractional recovery values for the lower portion of the size selectivity curve. For such a case, the classifier feed size consist is the only data that can be extrapolated with minimum error. Instead of calculating the fractional recovery, the fine recovery is calculated; i.e.,

$$R(x) = \frac{\text{amount of material of size x or less in the fine stream}}{\text{amount of material of size x or less in the feed stream}}$$

Again, this data is fitted to a functional form by a weighted least square criterion; i.e. -

$$\Sigma\ w(x_i)\left[\gamma(x_i)-R(x_i)\right]^2 = \text{minimum}$$

The functional form to be fitted is

$$\gamma(x_i) = \frac{(1-a)\ \sum_{j=N}^{i} (1-c(\kappa,d_{50};x_j))p(x_j)}{\sum_{j=n}^{i} p(x_j)}$$

where n represents the number of measured size intervals and N represents the number of measured and extrapolated. The resulting characteristic parameters obtained by fitting fractional recoveries and total recoveries are being compared.

1. A.I.Ch.E., "Classifier Equipment Testing and Evaluation Procedure", (1980).
2. Luckie, P. T. and L. G. Austin, "Technique for Derivation of Selectivity Functions from Experimental Data, 10th IMPC, London, (1973).

Fine Coal Size Analysis Procedure

The technique chosen to analyze the fine coal samples involves basically three steps. First the coal is screened conventionally using U.S. standard sieves down to 400 mesh employing wet screening on the 270 x 400 mesh fraction. The minus 400 mesh coal is then sampled and further analyzed using the Andreason pipet sedimentation technique and the Coulter Counter. The Andreason pipet is used as the standard against which the Coulter Counter is compared. For every Andreason run approximately ten Coulter runs are performed since a complete Andreason analysis requires approximately sixteen hours while a Coulter analysis requires only a few minutes.

Sieving

Objective

To size any of the plus 400 mesh coal using standard sieve sizes by dry screening the plus 270 mesh material and wet screening the 270 x 400 mesh.

Procedure

A 50 gm sample of coal is placed on the top sieve of a set of sieves. The sieves are then placed into a Rotap for 10 minutes then removed and deblinded. The screens are replaced into the Rotap for another 15 minutes then removed and rechecked for blinding. If no blinding is present, the dry screening is complete.

The 270 x 400 mesh coal is then removed and wet screened using a wetting agent such as Tergitol NPX to wet the surface of the coal in order to prevent the coal from agglomerating. The minus 400 mesh coal from the wet screening is combined with the minus 400 mesh coal from dry screened and saved for further analysis.

Coulter Counter

Objective

The purpose of using the Coulter Counter is to analyze the sub-sieve (minus 400 M) coal. It has the advantage of being a preferred method of analyzing fine coal since the coal particles are rapidly and automatically counted. The disadvantage of this method is that at the lowest end of the analysis range, the counter cannot detect the particles. Thus a steeper size distribution results since no approximately minus 1 micron particles are detected. The Andreason pipet is used to determine the minus 1 micron material in order to correct this error.

Background

When suspended fine particles, in an electrolyte solution, are passed through a small orifice, the passage of each particle displaces fluid thus increasing the effective electrical resistance of the orifice. If electrodes are placed on either side of the orifice, a voltage pulse can be generated as each particle passes. Furthermore, the change in resistance and consequently the size of the voltage pulse are roughly proportional to the particle volume. The Coulter Counter sorts these pulses and classifies them into 18 channels displaying a volume percent for each channel.

Procedure

A small sample of the minus 400 mesh coal is dispersed into a solution such as Tergitol NPX. The dispersed sample is then added to the electrolyte solution until a sufficient concentration is obtained. The particles are then counted.

After counting, the volume percent in each channel is recorded. The results are then plotted as the cumulative volume percent passing versus the corresponding size of each channel.

Andreason Pipet

Objective

The purpose of using the Andreason pipet is to analyze the sub-sieve particles, using this analysis as the standard to check the Coulter Counter results.

Background

The rate at which fine particles settle under gravity is given for spheres, by Stokes' Law:

$$V_t = \frac{(\rho_p-\rho_F)gd^2}{18\eta}$$

where V_t is the terminal velocity of a particle of diameter d, ρ_p and ρ_F are the densities of the particle and the fluid respectively, g is the acceleration due to gravity and η is the viscosity of the fluid. Thus, the time t taken for a particle of size d to settle a distance h is given by:

$$T = \frac{18\eta h}{(\rho_p-\rho_F)gd^2}$$

After time T, a sample of suspension taken from a distance h below the surface will contain no particles of diameter than d.

By sampling a suspension at a known depth for a series of time intervals and determining the total solids content of each sample, the particle size distribution of the material can be evaluated. This is the principle of the Andreason Pipet.

Procedure

Five grams of the minus 400 M coal is dispersed in water using a dispersant such as Tergitol NPX. The dispersed solution is then added to the pipet and the pipet volume is brought up to the starting line on the pipet (~550 cc) using the dispersant. The pipet contents are mixed by shaking it for several minutes to insure complete mixing. As soon as the shaking stops, a 10 cc sample is withdrawn. Subsequent samples are then withdrawn with the time of withdrawal being noted for each sample. A time sequence of - initial time, 1 minute, 2 minutes, 4 minutes, 8 minutes, 16 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, 8 hours and 16 hours is used so that the determined data points are spaced evenly when plotted on a log-log plot. The times chosen, though, are not crucial so as long as the withdrawal time is noted.

After withdrawing the samples into preweighed pans, they are dried and weighed. A blank is also checked to determine the weight of the dispersant. The weight of the sample is calculated by subtracting the pan weight and dispersant weight. From these values the weight percent can be calculated while the size can be calculated using Stokes' Law as previously stated.

Results

The following results were obtained for sizing a coal sample by employing the sieving/Andreason pipet/Coulter Counter procedure previously outlined.

Sieving Results (Dry):

Size	Cumulative % Passing
140 mesh	100.0
200 M	76.03
270 M	62.91
400 M	45.67

Sieving Results (Wet):

Size	Direct Weight %
-400 mesh (Dry)	45.67
-400 mesh (Wet)	45.75

Since the difference is only 0.08% this coal sample did not have to be wet sieved.

Andreason Pipet Results:

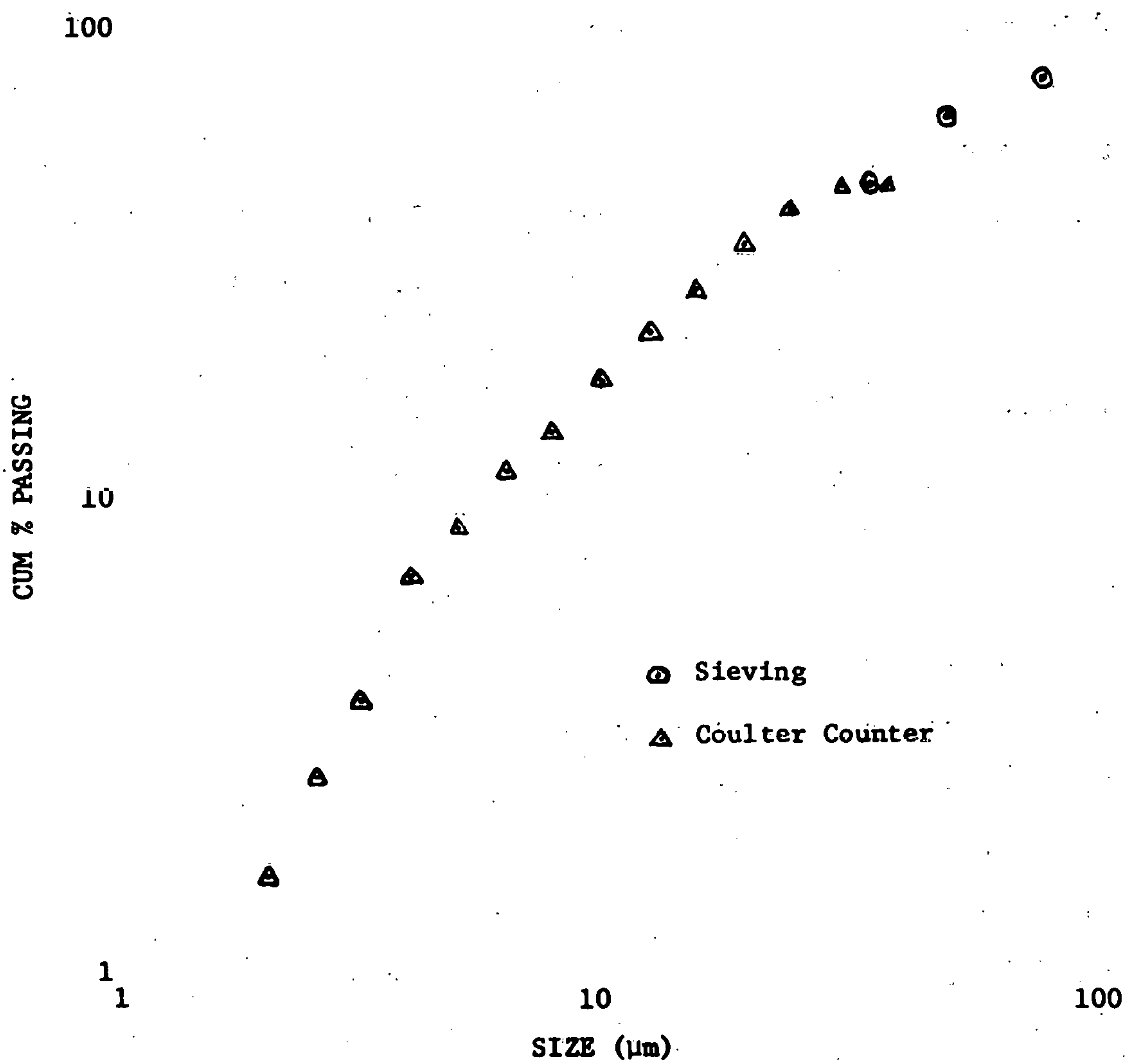
Size (μm)	Cumulative % Passing
192.7	100.0
95.88	97.45
72.74	98.37
54.81	96.83
38.84	93.77
27.32	48.72
19.82	24.72
13.89	18.39
9.58	14.20
6.78	11.34
4.79	10.62
2.72	13.18

The analysis indicates that basically all the coal is less than approximately 40 microns which seems reasonable since minus 400 mesh caol was used. However, the steepness of the size consist is unusual. This unusual result may be due to the coal being one of variable density which in turn would affect the size according to Stokes' Law. Testing is continuing to refine this technique.

Coulter Counter Results:

Channel	Size (μm)	Cumulative % Passing
16	>50.48	100.0
15	50.48-40.07	99.7
14	40.07-31.80	98.6
13	31.80-25.24	88.6
12	25.24-20.03	74.5
11	20.03-15.90	61.1
10	15.90-12.62	48.5
9	12.62-10.02	38.7
8	10.02- 7.95	30.2
7	7.95- 6.31	24.8
6	6.31- 5.01	19.0
5	5.01- 3.98	14.9
4	3.98- 3.16	8.2
3	3.16- 2.51	5.6
2	2.51- 1.99	3.5
1	<1.99	1.7

The Coulter Counter results give a smooth size distribution except that at the lower end, the distribution steepens. This is caused by the non-detection of the minus 1 micron particles. A good Andreason result is required in order to correct this. Also, since the Coulter Counter detects by size not specific gravity, this might explain why the Coulter gave a smooth result and the Andreason did not. A graph of the screening results and Coulter Counter results are given on the next page. The data was not corrected because of the problems with the Andreason pipet.



Size distribution data from sieving and Coulter Counter analysis

Testing and Data Reduction Phase

This phase of work is broken into two tasks. These are

Task V. Testing

Task VI. Data Reduction

Progress:

Task V. Since work under this Task is not scheduled to begin until late January 1981, no progress can be reported.

Task VI. Since work under this Task is not scheduled to begin until early February 1981, no progress can be reported.

Reporting Phase

This phase of work is comprised of a single task:

Task VII. Reporting

Progress:

Task VII. Monthly and quarterly report schedules are being met as required.

FACILITY MAINTENANCE

The last task, Task VIII. Maintenance of the Facility, is proceeding as required. It is noted that a formal Property Management System was required by the Project Property Administrator, Mr. Peter Rusinko. KVS has submitted this document to Mr. Rusinko. However, due to the modest dollar value of the DOE owned equipment in use for this project and the costs to be incurred in carrying out the reporting requirements as set forth by DOE Handbook PR-002/R1, KVS has requested a waiver of the formal Property Management System Procedure. No problems have been encountered with the operation or maintenance of DOE owned equipment.

CRITICAL ITEMS

There are no actual or anticipated critical items to report.

APPENDIX

This appendix is a first draft of the Project Program Plan Manual submitted to the Technical Project Officer.

PROGRAM PLAN MANUAL

FOR

COAL MATERIALS HANDLING - CLASSIFIER EVALUATION

U. S. DOE CONTRACT NO. DE-AC21-80MC14266

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Table of Contents

1. INTRODUCTION

In a previous study supported by the U.S. Department of Energy and conducted by the Kennedy Van Saun Corporation (DOE Contract No. DE-AC21-76MC02475) a number of coal grinding devices and circuits were investigated. As a part of this work, the twin cone and vari-mesh pneumatic classifiers were coupled with a ball mill for studies of air-swept dry coal grinding. At the time of this study, the Hukki centrifugal pneumatic classifier was strictly a gravity fed device, thereby making its direct application to air-swept coal grinding systems impractical. More recently, however, the Hukki classifier has been adapted for use in systems where the classifier feed is air entrained.

Based on studies conducted by Hukki there is evidence to show that the Hukki classifier might well be an excellent classifier for dry coal grinding applications. In fact, the classifier is presently being used in an industrial coal grinding circuit in Finland. In light of these recent developments, the present program was initiated, the objective being to evaluate the Hukki centrifugal classifier as a classifier for fine coal. Under this program, the classifier will first be evaluated in the stand alone (open circuit) condition using an air-swept ball mill to prepare the classifier feed. This will be done to study the effect of feed rate, feed size consist, fluid/solid ratio and adjustable settings of the classifier on overall classifier performance. Then, comparative, closed circuit testing of the Hukki, twin cone and vari-mesh classifiers will be conducted utilizing the air-swept ball mill as the comminutor. The test work will be evaluated based on size selectivity and the reduction of specific grinding energy.

In order to provide both DOE and KVS personnel an easy updating of progress and findings during the course of this effort, the present Program Plan Manual has been developed. The contents of the manual includes, for the benefit of readers unfamiliar with coal grinding and classification, a discussion of classification concepts (including the role of classifiers in size reduction systems) and a description of the classifiers to be tested. This is followed by an outline of the program plan, including the test program, data analysis procedures and the format for reporting test data. The test facilities and equipment, including control functions and safety devices, are also described. The remainder (and bulk) of the Manual is devoted to the actual description of each test to be conducted during the program. This information is presented in the form of a two page report for each test which can be inserted in the Manual as test results become available. In addition to these reports, ASTM sulfur and ash analyses will be performed on various classifier product samples in order to allow a preliminary analysis of classifier performance with respect to the separation of the coal on the basis of sulfur and ash content. These test data, generated at a commercial laboratory, will be included in the Manual as Appendix C.

2. CLASSIFICATION CONCEPTS

Classification is a term assigned to non-screening processes which split particles in a fluid stream, usually air or water, on the basis of their "size", into two streams - one containing coarse particles; one containing fine particles. The device which does the partitioning is termed the classifier.

Within the classifier the fluid is always moving. The actual partitioning of the particles is achieved by combining gravitational (including centrifugal), inertial and drag forces into a series of separating mechanisms. Classifier designers take advantage of the fact that in a medium small particles fall at a slower rate than large particles; that larger particles are acted on with a greater force in a cyclonic flow than small particles; that smaller particles can change their direction of flow more easily than larger particles; that large particles require a higher conveying velocity than small particles; or that the probability of collision with a rotary blade is higher for a large particle than it is for a small particle. The designer then proceeds to design the classifier so that there is a minimum of mutual interference among the particles in the classification zone.

It is assumed that size is the only characteristic that varies among the particles and hence only size influences the trajectories of the particles. A measure of particle trajectories would be the residence time of particles within the classifier. It is expected that because of the various gravitational and inertial forces acting on particles in a classifier, the residence time for smaller particles would be longer than that for larger particles. Obviously, other characteristics such as specific gravity or shape effect the trajectory of a particle but only in a minor manner if they are the same for all particles in the population. If there is a characteristic among the particles which varies and influences the trajectory such as specific gravity then the partitioning is termed sorting, not classifying. If the feed is a mixture of material with different specific gravities then each type of material must be treated individually when predicting the classifier performance.

One of the most important industrial applications of classifiers is in closed circuit grinding systems. The function of a grinding device obviously is to produce a finer material from a coarser material. Standing alone; i.e. in open circuit, the grinding device at steady-state produces a fine material from a coarse material at a coarse material feed rate that equals the fine material product rate. When a classifier is coupled with the grinding device (thus closing the circuit) the coarse stream is returned to the grinding device and the fine stream becomes the product stream of the grinding circuit. Under these conditions the actual steady-state feed rate to the grinding device itself will be higher than the circuit feed and product rates.

There are many advantages to operating grinding devices in closed circuit. For example, if the grinding machine is a retention device; i.e., there is a holdup of material within the mill such that the mean grinding time is given by this holdup weight divided by the feed rate, then at a constant holdup weight a finer product will be produced by decreasing the feed rate. By closing the circuit with a classifier the feed rate need not necessarily be reduced since coarse material is being recycled for further grinding. In this way it would be possible to produce a given fineness of grind, e.g., 95% passing 140 mesh, at a significantly higher rate in closed circuit than in open circuit. Since the energy to operate the grinding device is essentially constant the specific grinding energy; i.e., KWH/ton is reduced. Closed circuit grinding also produces a steeper product size distribution. That is, while both open and closed circuit grinding might produce 95% passing 140 mesh, the closed circuit product might analyze 30% passing 400 mesh versus 50% passing 400 mesh from the open circuit device. This is an important advantage in many industrial applications, e.g., in the preparation of coal for combustion, gasification and liquefaction processes. The practical constraints of closed circuit grinding are classifier efficiency (discussed later) and the capacity of the grinding device; at high classifier coarse stream product rates the actual feed to the grinding device can be several hundred percent higher than the circuit feed and product rates.

Types of classification can be conveniently cataloged as in Figure 2.1.

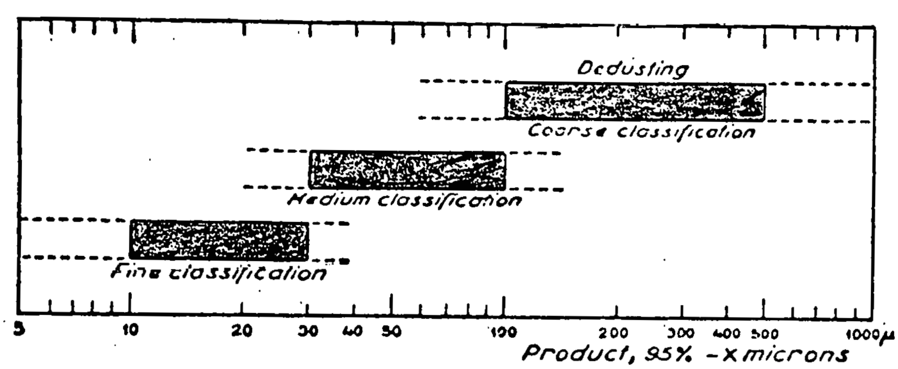


Figure 2.1 Types of Classification

Typically in classification, the product stream is usually not defined in terms of 100% passing a particular size since in order to guarantee 100% passing requires the production of a product stream much finer than actually needed. Hence, the product from the classifier is usually specified as 95% passing, 80% passing, etc.

The performance of a classifier is a function of the feed material, the operating conditions and classifier design. Feed material properties which influence performance include such things as size consist, specific gravity and rheological properties. Operating conditions include such things as fluid/solid ratio, energy input and feed rate. Classifier design factors would include type of classification, geometric configuration, settings of adjustable features and materials of construction. There are some obvious correlations between these factors. For example, the rheological properties of a fluid/solid stream are dependent not only on the material but also on the fluid/solid ratio. Not all of these factors are controllable; for any given system many are uncontrollable. Further, variation of the factors can give results that range from excellent to poor; e.g., a classifier which gives good results for cement classification (specific gravity ~ 3.0) may be unsuitable for coal classification (specific gravity ~ 1.4).

Due to the numerous variables which can affect classifier performance, evaluating classifier performance can be very involved. Ideally, if individual particles could be followed through a classifier and particles trajectories determined as a function of each of the cited variables, a detailed, predictive evaluation of classifier performance would be available. Since this is not possible at the present time, the size selcotivity concept is used.

Size selectivity is defined as the probability that particles of a particular size entering the classifier will report to the coarse classifier product stream. The AIChE Classifier Equipment Testing and Evaluation Committee (1) has determined that the size selectivity function (size selectivity vs. size) gives the most complete measure of classifier performance. In terms of size selectivity, the ideal efficient classifier would have selectivity values of unity for all sizes greater than a certain size (the cut size) and values of zero for all other sizes. As defined in the AIChE Committee's document (1) the cut size (denoted D_{50}) is the size whose selectivity value is 0.5.

Unfortunately, real classifiers are neither ideal nor 100 percent efficient. Real classifiers suffer from two types of inefficiencies that are reflected in the size selectivity function. One type is the apparent by-pass; some fraction of fine particles report to the coarse stream and some fraction of coarse particles report to the fine stream. In both cases the particles in question short circuit or by-pass the classifying mechanisms. The second type of inefficiency occurs because real classifiers are non-ideal. Because of such things as the inability to truly define size, the trajectory that a particular size and density of particle follows in a classifier is not always the same and therefore it may enter one or the other existing streams. Hence, the probability that a particle less than the cut size will report to the coarse stream is not necessarily zero. Instead the probability increases from zero for the smallest sizes of particles to unity for the larger particles. Figure 2.2 illustrates selectivity functions for ideal; ideal, inefficient; and non-ideal, inefficient classifiers. The fractions of by-passing material are given by a and b. For cases where there is particle by-passing, the selectivity curve given in Figure 2.2c would be corrected such that the corrected size selectivity values (termed classification values) would range from zero for the smallest sizes to unity for the large sizes. The cut size would be the size for which the corrected size selectivity value is 0.5. A measure of the deviation from ideal classification is given by the sharpness index, κ . The sharpness index is determined by dividing the size of particles having a corrected size selectivity of 0.25 by the size of particles having a corrected size value of 0.75. A sharpness index of unity indicates ideal classification; anything less than one indicates non-ideal classifications. Experience has shown (2) (3) (4) that selectivity values (and hence cut size, apparent by-pass and sharpness index) can be strongly dependent upon the various factors which influence classifier performance.

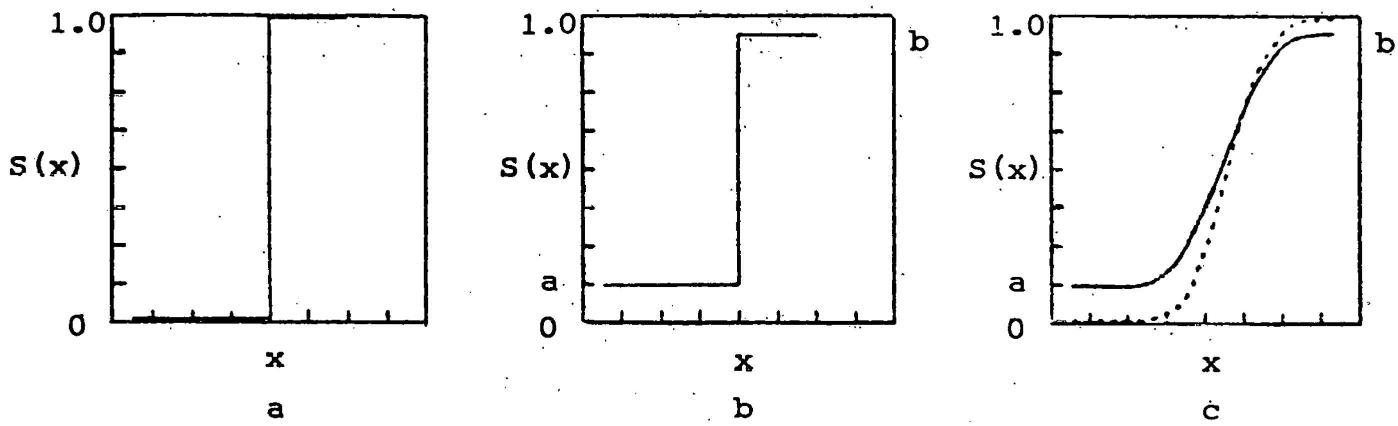


Figure 2.2 Selectivity curves for ideal (a), inefficient (b) and inefficient, non-ideal (c). The dashed line in (c) represents the corrected size selectivity curve (the classification curve).

Finally, since the development of single stage classifiers with performances far superior to current industrial devices may not be likely, an alternate approach is to accept the limitations of one stage classification and attempt to correct them by reclassification of the impure stream in a separate, independent step. It would be noted, however, that this can lead to practical problems; e.g., classification can cause a dilution of the solids in the fluid stream that might be unacceptable in down stream processing of the particulates in question. Hence, while this approach might be desirable for applications where the objective of the process is simply to size reduce the feed material, in most applications it is desirable to use an optimum single stage classifier.

3. AIR-SWEPT CLASSIFIERS FOR COAL

In light of the foregoing, it is seen that the production of fine coal through size reduction can be greatly enhanced by coupling the grinding device with a classifier and recycling the coarse classifier product stream for further grinding. In the previous study supported by the U.S. Department of Energy and conducted by the Kennedy Van Saun Corporation (DOE Contract No. DE-AC21-76MC02475) this was done for air-swept ball milling of dry coal using cone-type (twin cone) and expansion chamber-type (vari-mesh) classifiers. Both of these classifier designs are presently being utilized in industrial air-swept coal grinding systems.

At the time of this work, Hukki of Finland had developed a centrifugal, air-swept classifier that showed great promise for fine classification; however, the classifier was a gravity fed device and was therefore not used. More recently Hukki introduced an adaptation of the original device that allows for feed material that is air entrained. The air-entrained feed centrifugal classifier is being successfully used in an air-swept coal grinding system in Finland.

As seen in the following, these three classifier designs are physically dissimilar and employ different combinations of classifying mechanisms.

3.1 The Twin Cone Classifier

Figure 3.1 depicts what is probably the most popular type of air classifier design for air-swept coal grinding -- the twin cone classifier. The feed stream enters the outer cone and then passes through adjustable vanes into the inner cone. When the vanes are fully opened, the inner cone acts as an expansion chamber, increasing the amount of product while decreasing the overall fineness of the product. Turning the vanes towards the closed position causes the inner cone to act as a cyclone. The centrifugal action decreases the product output while increasing the overall fineness of the product. The coarse particles are directed to the bottom of the classifier and exit through a seal.

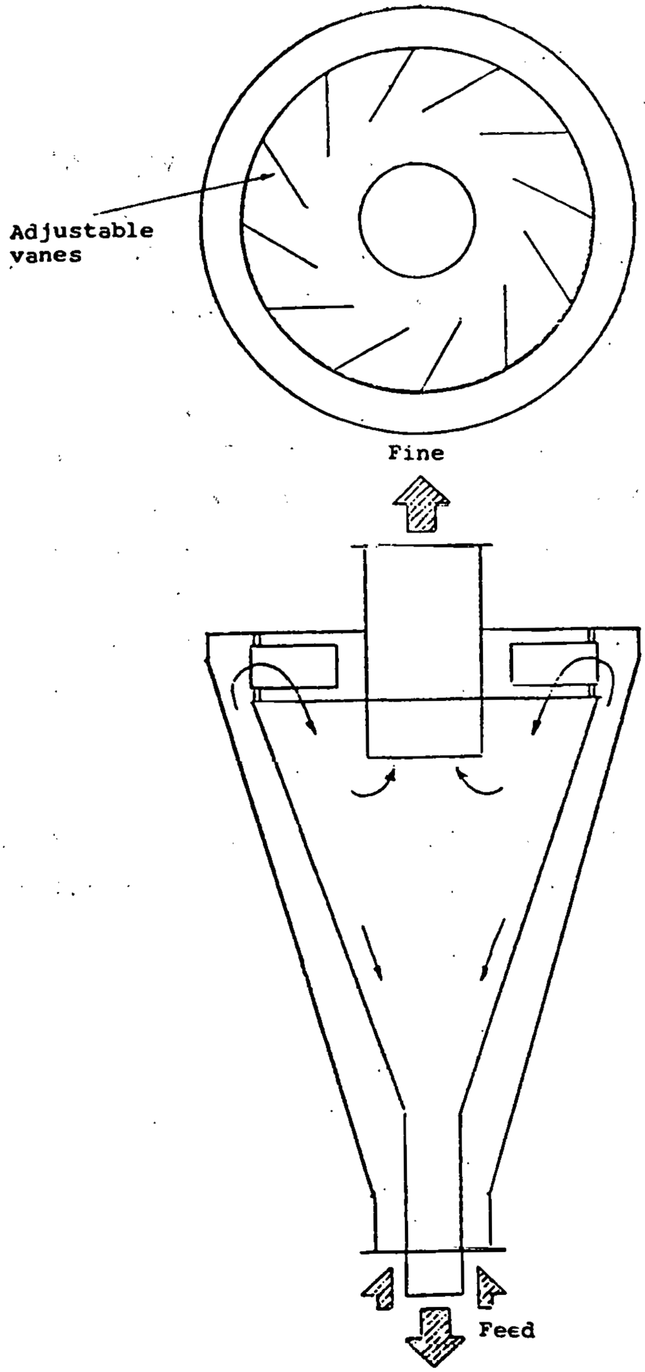


Figure 3.1 The Twin Cone Classifier

3.2 The Vari-Mesh Classifier

Figure 3.2 gives a cross-sectional view of the expansion chamber type, vari-mesh classifier. Solids are brought to the classifier in a gas stream flowing through a volute. The centrifugal action of the volute concentrates the solids to the outside as they leave the elbow. The gas is directed via adjustable gates down the right hand side where it recontacts the solids at several points, causing the particles to be swept outwards and upwards into the main expansion chamber. Particles that continue to fall or drop out in the expansion chamber exit through a seal at the bottom of the classifier.

The main expansion chamber is adjustable, thereby varying the product fineness. At the 100% open position the air conveying velocity is at a minimum thus yielding a finer product.

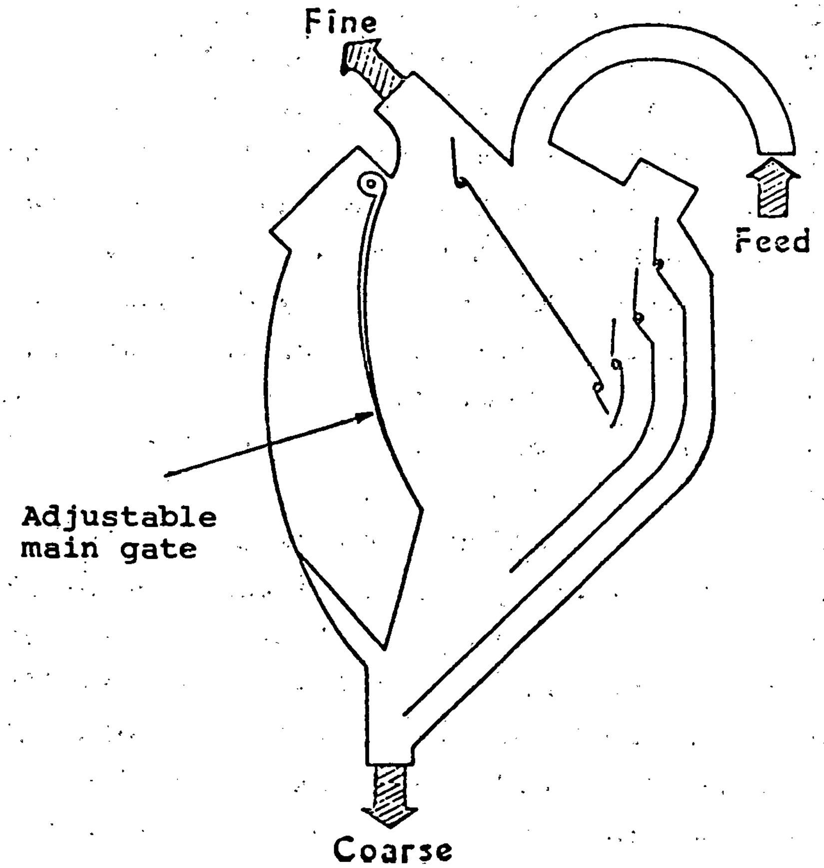


Figure 3.2 The Vari-Mesh Classifier

3.3 The Hukki Centrifugal Classifier

A new classifier design employed on an air-swept coal grinding system in Finland is shown in Figure 3.3. The feed stream enters through the volute, concentrating the solids to the outside as they leave the elbow. The stream is then split as it enters the classifier into an upper particle stream and a lower gas stream. The particle stream is forced downward as it enters the classifier. As the conveying velocity decreases the coarse particles fall to the bottom of the classifier. The gas stream passes through the coarse stream before it exits via a seal to remove any fine particles. The particle/gas stream is then directed upward into a centrifugal field. Adjusting the flow guide (A) such that its longest surface approaches a position parallel to the classifier entrance duct will cause more coarse material to enter the centrifugal field. The middling fraction is separated to the outer wall and returned back into the incoming particle stream. The fine stream is removed via the eccentrically placed exit pipe. Rotating the flow guide (B) towards the classifier wall will cause a large fraction of coarse particles to enter the fine stream.

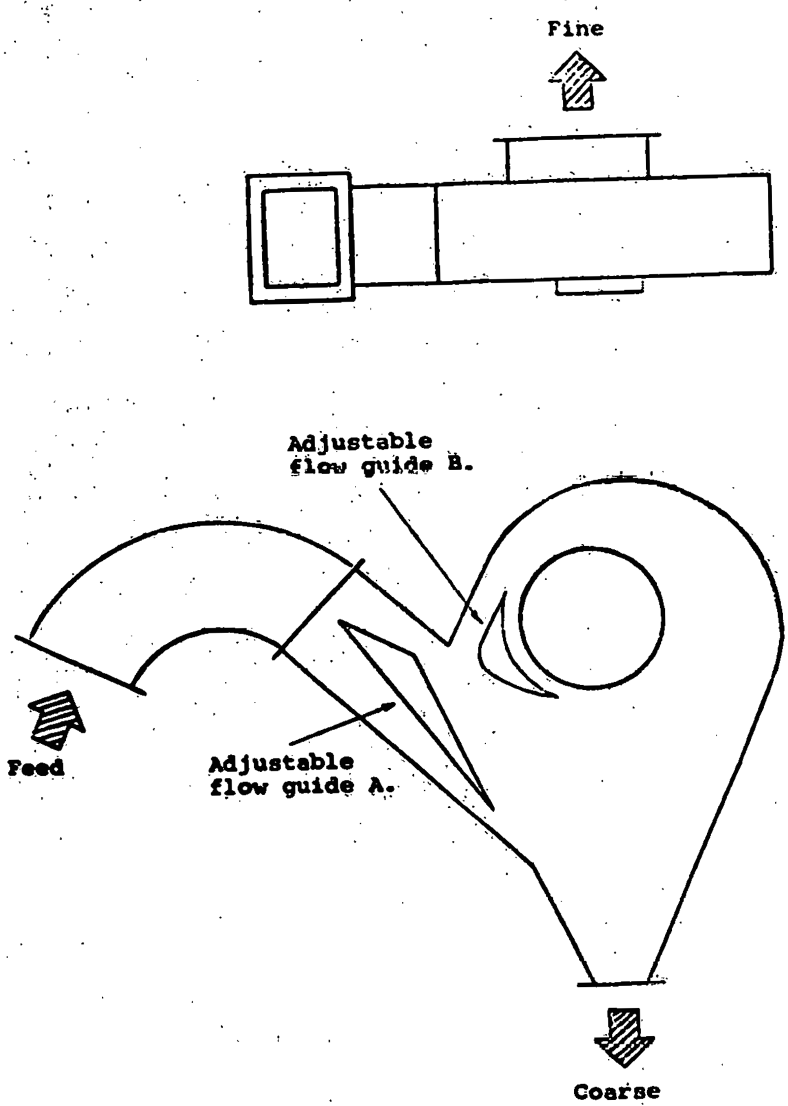


Figure 3.3 The Hukki Centrifugal Classifier

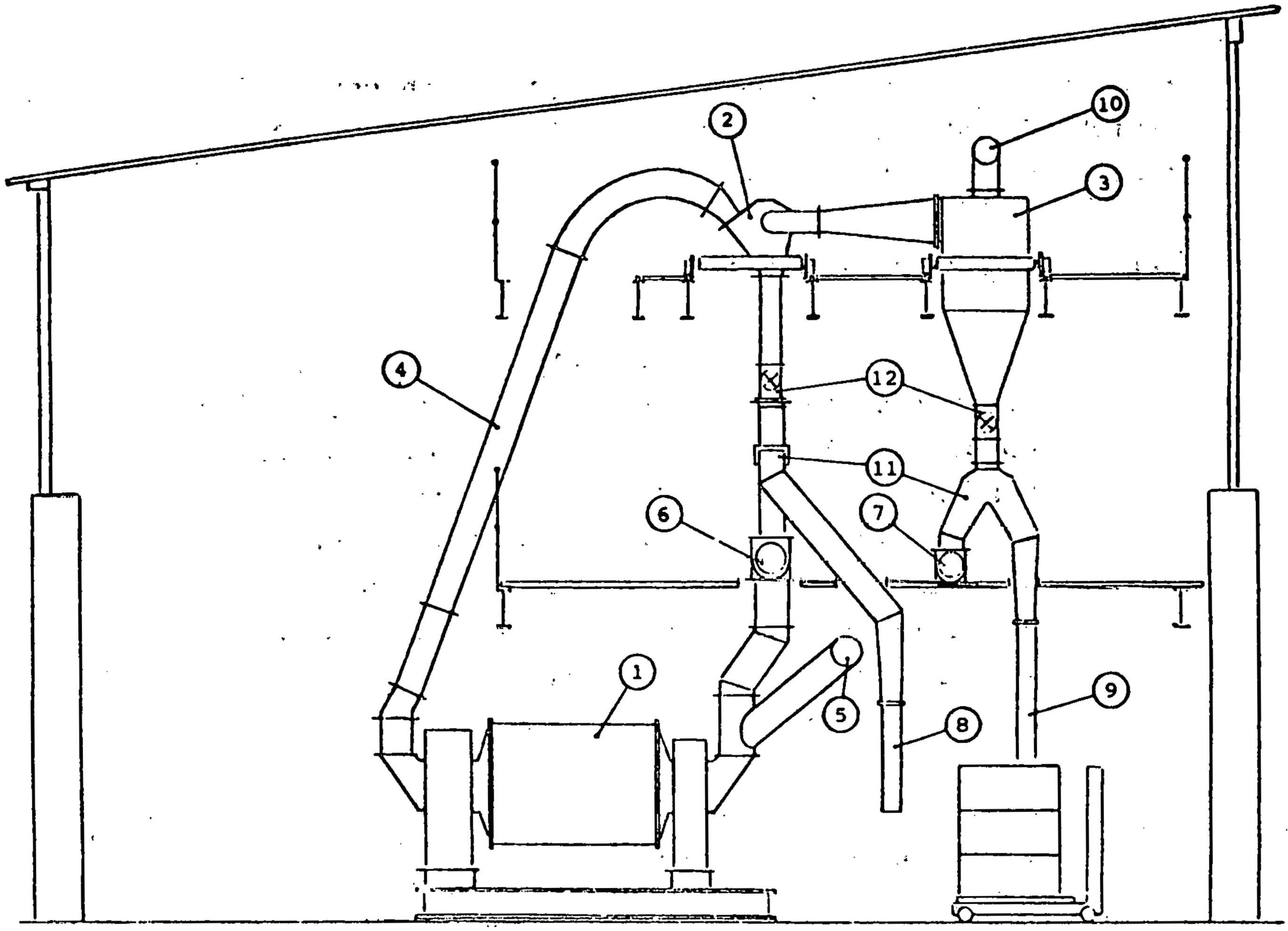
4. THE PROGRAM PLAN

The primary objectives of the present program are to evaluate the Hukki centrifugal classifier as a classifier for coal and to compare the effect of different classifier designs (centrifugal, twin-cone and vari-mesh) on air-swept coal grinding circuit performance. A secondary objective is to provide data to allow a preliminary evaluation of classifier design on the separation of coal with respect to sulfur and ash content. These objectives will be accomplished according to the following plan.

4.1 Testing

As a partial result of the previous DOE-KVS coal grinding research program, the KVS Test Plant includes the air-swept ball milling circuit seen in Figure 4.1. This circuit was designed to allow the incorporation of various classifiers with a minimum of adjustment to the circuit. The design also allows testing in the open circuit mode; hence, the operation of a classifier in the stand alone condition with the ball mill as a feed preparation device is also possible. Figure 4.1 shows a general layout of the circuit; the circuit configurations for actual tests required for the present program are given later. Also, a detailed description of each component of the circuit is presented in APPENDIX A - TEST FACILITIES.

In order to evaluate the Hukki centrifugal classifier as a classifier for coal, the classifier will be tested in the open circuit mode. This testing is geared toward evaluating classifier performance as a function of operating conditions and settings of the adjustable features. Comparative, closed circuit testing will



1. Unit 202, Air Swept Ball Mill
2. Classifier
3. Unit 204, Product Cyclone
4. Mill discharge, classifier inlet duct
5. Hot air inlet duct
6. Unit 106, Reversible Screw Conveyor for fresh feed and classifier rejects
7. Unit 209, Screw Conveyor for product
8. Classifier rejects duct: Closed Circuit-Closed Open Circuit - Open
9. Classifier product sample duct
10. Cyclone outlet - fan inlet duct
11. Unit 208, Diverter
12. Unit 211, Rotary Air Lock

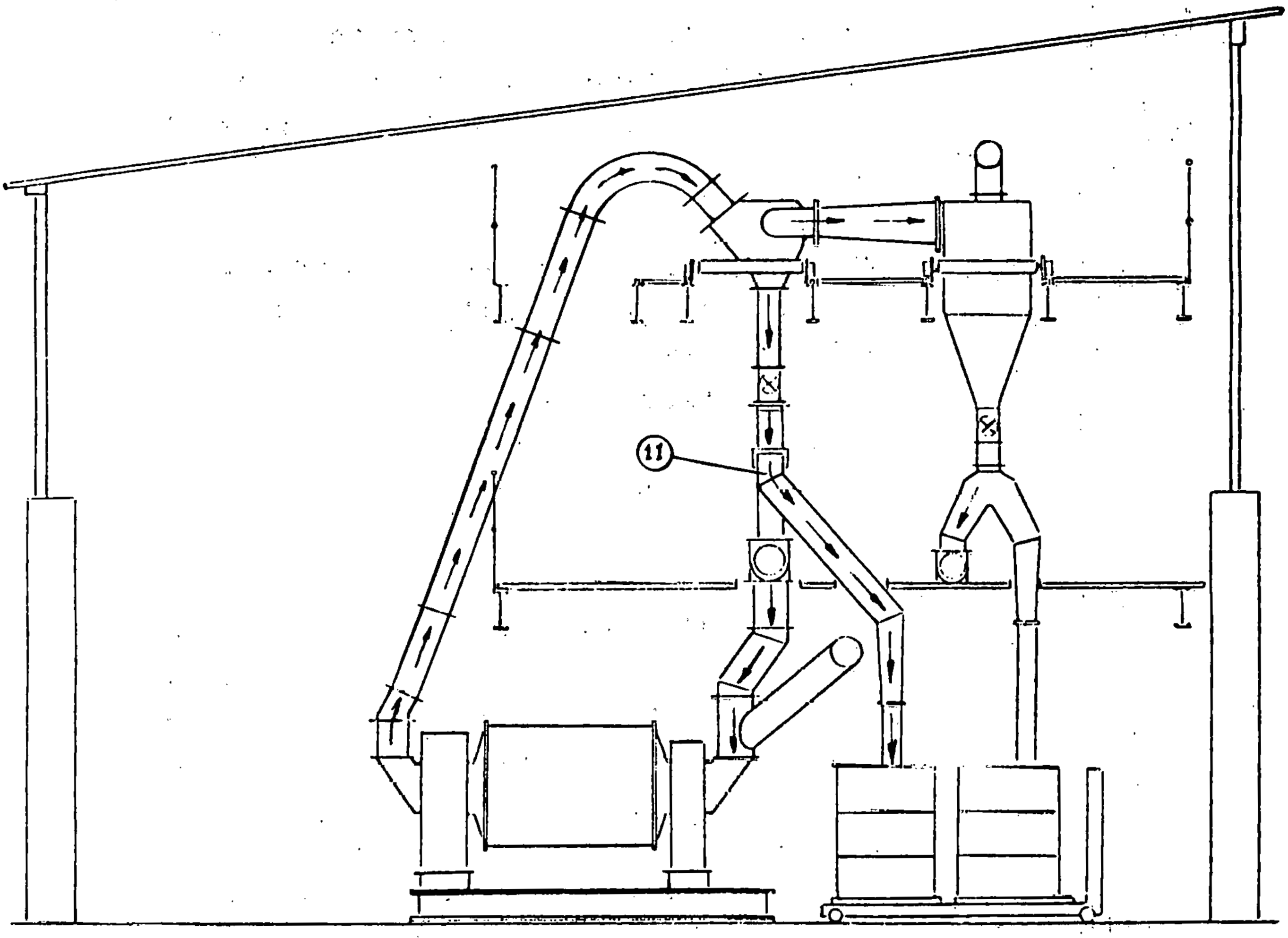
Figure 4.1 Diagram of Existing Air Swept Ball Mill Circuit then be performed using the centrifugal, twin cone and vari-mesh classifiers in turn. The testing required for this phase of the program is as follows.

4.1.1 Centrifugal Classifier

The open circuit testing of the centrifugal classifier calls for the circuit configuration as seen in Figure 4.2. During these tests, the ball mill is used simply to prepare classifier feed material; therefore, the divertor numbered (11) is adjusted so that the classifier rejects duct remain open. In this portion of the program testing will be geared toward examining the effect of air flow rate, classifier settings and feed size consist on the classifier size selectivity function. The test variables will include

- one type of coal - Western Kentucky No. 9
- two coal sizes - 1-1/2" x 0" and 3/4" x 0" (ball mill feed)
- four air flow rates
- at each air flow rate and for each type of coal tested, the classifier settings will be adjusted to produce four different coarse/fine stream product rate ratios.

A total of 32 open circuit tests of the centrifugal classifier will be performed. At each test condition, air and coal flow rates and the settings of the classifier will be recorded. Samples of the circuit feed and classifier product streams will be taken for sieve analysis. ASTM sulfur and ash content de-



ARROWS INDICATE FLOW PATH FOR COAL

Figure 4.2 Circuit Configuration for Open Circuit Testing of the Hukki Centrifugal Classifier terminations (product samples only) and, for selected tests, subsieve size analysis (product samples only).

The closed circuit testing of the centrifugal classifier will be done using the circuit configuration seen in Figure 4.3. The test variables for this phase of the work will include

- one coal type - Western Kentucky No. 9
- two coal sizes - 1-1/2" x 0 and 3/4" x 0 (circuit feed)
- four air flow rates
- adjustments of the classifier settings such that four circuit circulating ratios are obtained.

A total of 32 closed circuit tests of the centrifugal classifier will be performed. At each test condition, air and coal flow rates and settings of the classifier will be recorded. Samples of the circuit feed and classifier product streams will be taken for sieve analysis, ASTM sulfur and ash content determinations (product stream only) and for selected tests, subsieve size analysis (product streams only).

4.1.2 Vari-mesh Classifier

The circuit configuration for closed circuit

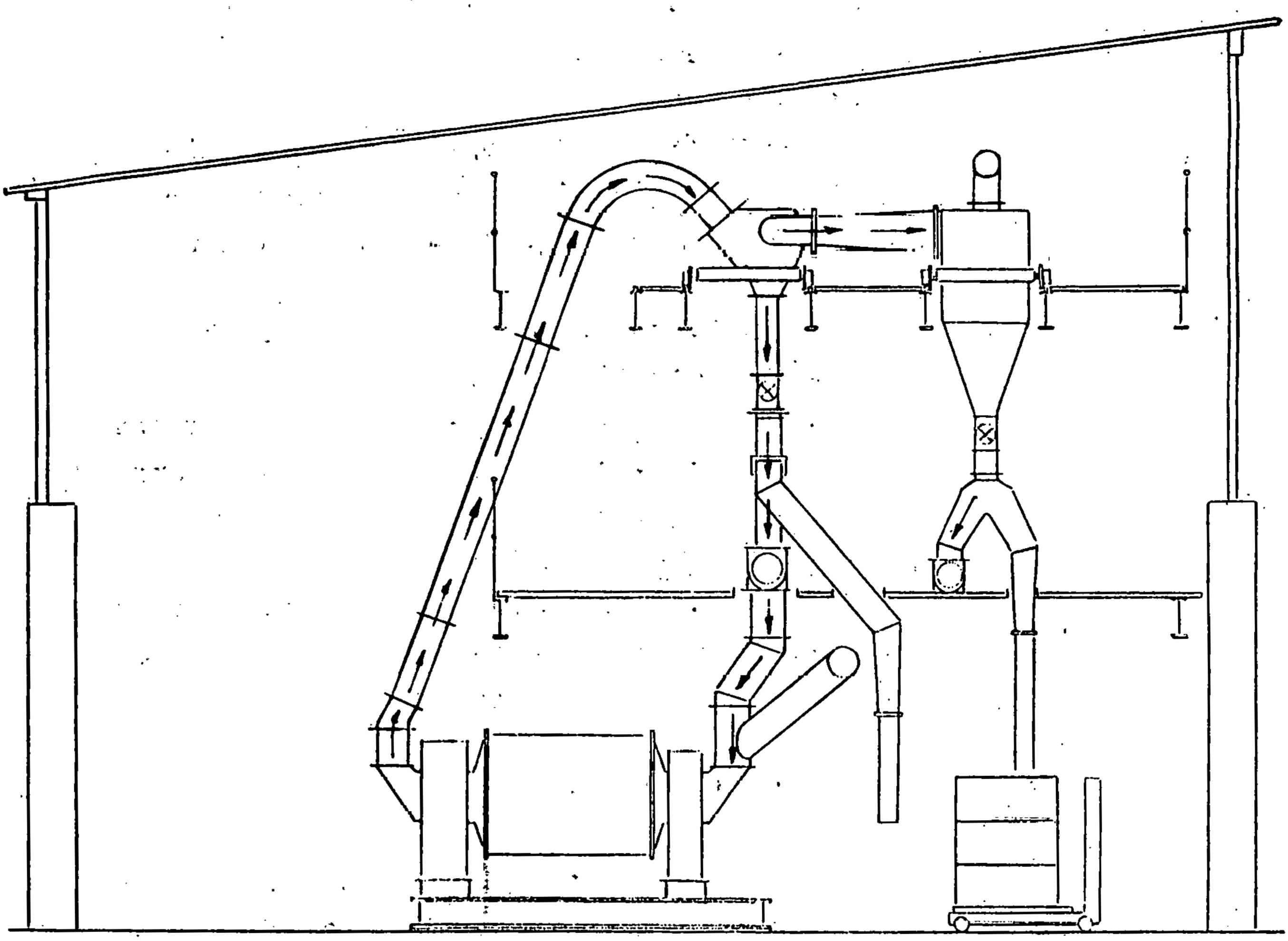


Figure 4.3 Circuit Configuration for Closed Circuit Testing of the Hukki Centrifugal Classifier

testing of the vari-mesh classifier is seen in Figure 4.4. The test variables will include

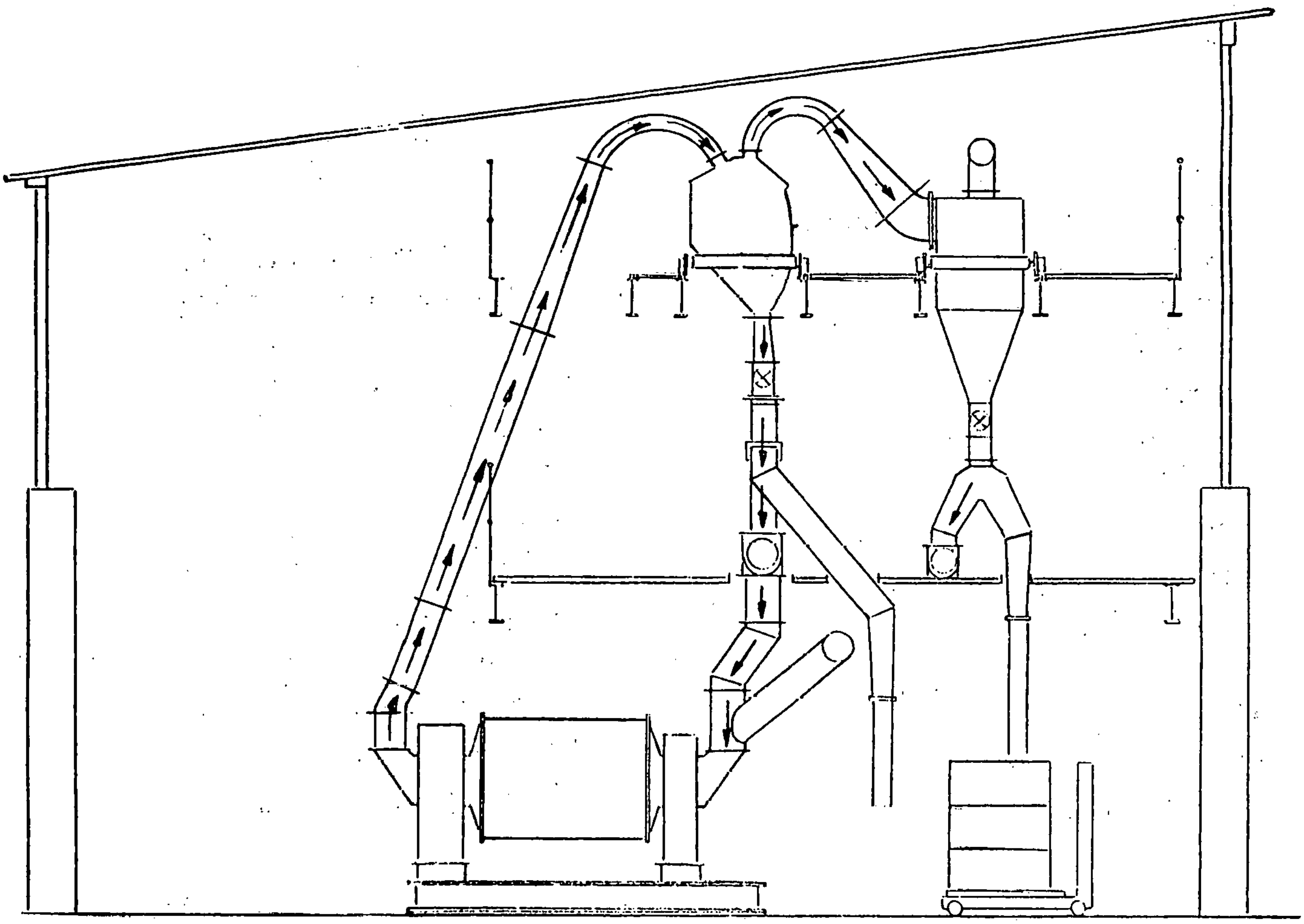
- one type of coal - Western Kentucky No. 9
- two coal sizes - 1-1/2" x 0 and 3/4" x 0 (circuit feed)
- four air flow rates
- two classifier width openings; the main gate of the classifier will be set at 50 percent and 100 percent width openings.

A total of 16 closed circuit tests of the vari-mesh classifier will be performed. At each test condition, air and coal flow rates and classifier width will be recorded. Samples of the circuit feed and classifier product streams will be taken for sieve analysis, ASTM sulfur and ash content (product samples only) and for selected tests, subsieve size analysis (product samples only).

4.1.3 Twin Cone Classifier

Figure 4.5 depicts the circuit configuration that will be used for closed circuit testing of the twin cone classifier. Test variables will include

- one type of coal - Western Kentucky No. 9
- two coal sizes - 1-1/2" x 0 and 3/4" x 0 (circuit feed)
- four air flow rates
- 25 percent and 50 percent open vane settings.



ARROWS INDICATE FLOW PATH FOR COAL

Figure 4.4 Circuit Configuration for Closed Circuit Testing of the Vari-Mesh Classifier

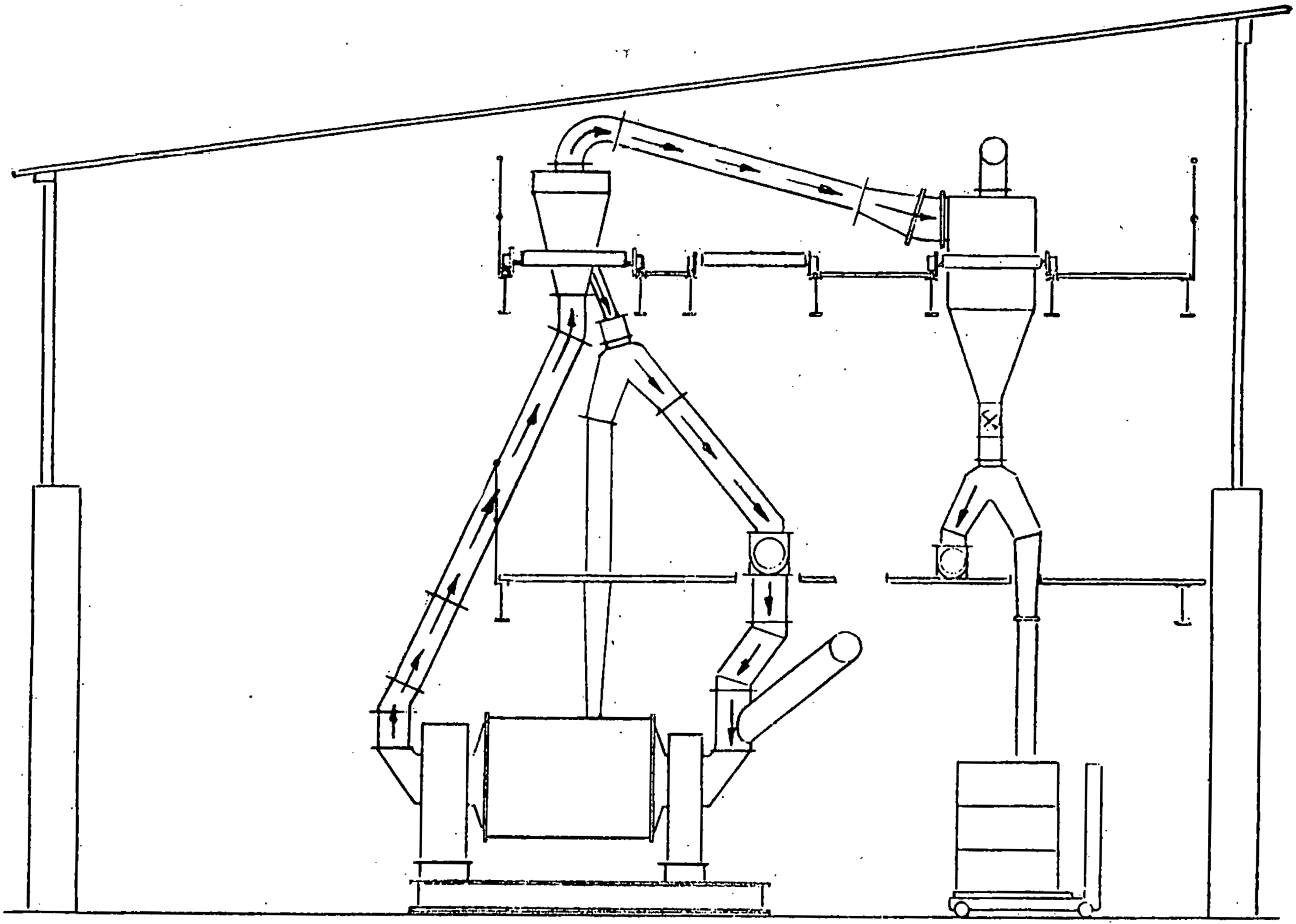

ARROWS INDICATE FLOW PATH FOR COAL

Figure 4.5 Circuit Configuration for Closed Circuit Testing of the Twin-Cone Classifier

A total of 16 closed circuit tests of the twin cone classifier will be performed. At each test condition, air and coal flow rates and classifier vane settings will be recorded. Samples of the circuit feed and classifier product streams will be taken for sieve analysis, ASTM sulfur and ash content determinations (product samples only) and, for selected tests, subsieve size analysis (product samples only).

4.1.4 Test Procedures

The actual procedure to be followed for a given test is comprised of the following steps.

1. After grinding circuit start-up, as described in APPENDIX A - TEST FACILITIES, the system is allowed to operate at the desired air flow rate and classifier settings.

   The circuit feed rate is adjusted manually until the mill holdup monitor (a sound level indicator) reports a constant reading; this indicates that the coal flow into and out of the mill is constant and therefore, steady-state conditions have been achieved. Experience has shown that the elapsed time between system start-up and the attaining of a steady-state operation can is on the order of two (2) to three (3) hours.

2. After the circuit has reached steady-state, samples of the circuit feed, classifier fine and coarse products and the dust collector product are taken. Samples from the fine product stream and from the dust collector are collected for five (5) minutes into fifty-five gallon containers. Classifier coarse product samples will be collected for fifteen (15) seconds (in order to prevent a "starving" of the mill feed for any length of time). In all cases, a minimum of two samples per stream are taken.

3. At the completion of testing at a given circuit condition, the circuit condition (flow rates, classifier settings, etc.) are changed to meet the requirements for the next test. The elapsed time between the completion of a test and the attainment of steady-state conditions for a subsequent test is roughly one (1) hour.

For tests on the centrifugal classifier in the stand alone condition, sampling of the coarse product stream will be conducted in the same fashion as that for the fine product and dust collector streams.

The Project Engineer and 2 technicians will be present during each test. The estimated manpower loading is 12 man-hours per test.

4.2 Data Analysis

Data analysis is defined in the present context as the development of size selectivity functions for each of the test configurations and conditions that are performed during the course of the program. To develop a size selectivity function from experimental data requires fine size consist information that, in cases such as the previous DOE-KVS work and this program, cannot be obtained using conventional screening techniques. It is possible to employ subsieve size analysis techniques to obtain this information; however, these techniques are either too costly or too time consuming for routine application. For this reason (and others), researchers have turned to mathematical modelling and data reduction methods. For the most part these methods too have required fine size data when fine classification is being performed. However, a recent development in the math modelling/data reduction approach appears to have solved this problem and will thus be applied here. The new methodology and its evolution are presented in the following.

4.2.1 The Math Modelling/Data Reduction Methods

The direct, experimental approach for determining size selectivity curves is to measure the classifier feed and coarse product rates and size distributions and form the ratio

$$s(x_i) = \frac{C}{1+C}\,\frac{t(x_i)}{p(x_i)}$$

The $s(x_i)$ is the size selectivity value for material of size x_i, the quantities $t(x_i)$ and $p(x_i)$ represent the fraction of material in the classifier coarse and feed streams and the quantity C is the ratio of the classifier coarse to fine product rates and can be expressed as

$$C = 1/(P/T-1)$$

The P and T are the classifier feed and coarse stream rates.

In some cases it is possible to sample the classifier fine and coarse streams but not the classifier feed stream. For these cases the classifier feed rate and size consist are calculated from mass balance equations for the classifier. These are

$$P = T + Q$$
$$Pp(x_i) = Tt(x_i) + Qq(x_i)$$

where Q is the fine product rate and $q(x_i)$ is the fraction of material of size x_i in the classifier fine stream.

The direct approach for calculating size selectivity curves is simple and straightforward but, in general, makes subsequent data handling and interpretation cumbersome. Using math models and data reduction methods can solve this problem.

Luckie and Austin (5) have shown that the size selectivity curve can be represented by the functional form

$$s(x_i) = (1-a-b)c(D_{50},\kappa,x_i) + a$$

where the $c(D_{50},\kappa,x_i)$ represents the classification curve. The actual formulation of the $c(D_{50},\kappa,x_i)$ is a function of the classifier and is determined from the adequacy of a given formulation to model actual data. Some popular formulations that have been used are the log-normal distribution by Aso (6) and Luckie and Austin (5), the Rosin-Rammler distribution by Plitt (7) and Reid (8), and the logistic distribution by Luckie (9).

In the formulation chosen for a particular application the characteristic parameters D_{50},κ, a and b are either explicit in the formulation or contained in a size metameter. Then, since b should be zero for properly operating classifiers (5) only three parameters must be estimated to obtain the complete function. These can be estimated by fitting the experimentally determined selectivity values, $s(x_i)$, to the model by a least squares procedure, i.e.

$$\sum_{k=1}^{n} \left[\hat{s}(x_i)-s(x_i) \right]^2 = \text{minimum}$$

Ideally, the experimental data should include sufficient data so the apparent fines by-pass, a, can be easily estimated. However, for cases where subsieve size analysis is required, such data is not always available. In order to overcome this problem, Austin (10) has developed the following, new methodology which involves extrapolating the classifier feed data.

Suppose a size analysis gives size consist data for the classifier feed and coarse streams over a total of n size intervals and a size selectivity function is required for N size intervals, N n. This nomenclature assumes that the size intervals are evenly and closely spaced and that the largest size is size one with smaller sizes being denoted 2, 3, 4, ..., n, ..., N. Then, the ratio, γ_K, can be calculated as

$$\gamma_K = \frac{C}{1+C} \frac{T(x_K)}{P(x_K)}$$

where $T(x_K)$ and $P(x_K)$ are the cumulative fractions of material passing size x in the coarse and feed streams, respectively. Continuing,

$$\gamma_K P(x_K) = \frac{C}{1+C} \sum_{i=K}^{N} t(x_i)$$

where the subscript i represents the extrapolated data range. Since, by definition,

$$s(x_i) = \frac{C}{1+C} \frac{t(x_i)}{p(x_i)}$$

it follows that

$$\gamma_K P(x_K) = \sum_{i=K}^{N} s(x_i)p(x_i)$$

Substituting the functional form for $s(x_i)$ gives

$$\gamma_K = a + \frac{(1-a)}{P(x_K)} \sum_{i=N}^{K} c(d_{50}, K, x_i)p(x_i)$$

Now, as before, the three parameters can be estimated from experimental data, $\hat{\gamma}_K$, by performing at least squares fitting procedure, i.e.,

$$\sum_{K=1}^{n} (\hat{\gamma}_K - \gamma_K)^2 = \text{minimum}$$

Each set of test data obtained during the program will be analyzed according to the method presented here. As a spot check of this method, selected samples will be size analyzed according to specialized procedures that have been developed during the course of the program. These procedures have been described in the November Monthly Progress Report but are also included here.

4.2.2 Fine Size Analysis Procedure

The procedure that has been derived for determining the subsieve size consist of test samples is as follows.

(1) Wet sieve down to 400 mesh.

(2) Take some of the minus 400 mesh material and put into the Coulter Counter and determine its size distribution.

(3) Using the same minus 400 mesh material, determine the size distribution by the Andreasen Pipette method.

(4) Then determine a factor such that the Coulter Counter data can be adjusted to fit the Andreasen Pipette data.

(5) Use this factor to adjust the Coulter Counter data on all tests. (Note: Check the factor by running an Andreasen Pipette test after every 10 Coulter Counter runs).

(6) Then normalize the minus 400 mesh size distribution and extend the plus 400 mesh size distribution.

It is noted that the use of this procedure will result in size distributions that are based on size as defined by sieving, i.e., the inability of a particle to pass through a square opening, even though the Andreasen technique, for instance, defines size according to the rates at which particles fall through a static fluid.

4. Test Reporting

A two page report will be developed for each test that is performed. It is intended that as these test reports become available, copies of the reports will be inserted by the reader to APPENDIX B - TEST REPORTS. (It is for this reason that the Program Plan Manual is in loose-leaf rather than bound form.) The following describes the numbering system that has been developed for easy identification and referencing of tests as well as the basic format for each test report. APPENDIX C is reserved for ASTM sulfur and ash analysis reports for classifier fine and coarse product streams. As with APPENDIX B, it is intended that the reader should insert these reports as they become available.

4.3.1 Test Report Identification

Each test will be identified using a series of five letters or numbers which indicate the classifier tested, the circuit configuration the feed size consist, the air flow rate and the classifier setting. These test numbers will have the form given by

XY-U-V-W

through a square opening, even though the Andreasen technique, for instance, defines size according to the rates at which particles fall through a static fluid.

4.3 Test Reporting

A two page report will be developed for each test that is performed. It is intended that as these test reports become available, copies of the reports will be inserted by the reader into APPENDIX B - TEST REPORTS. (It is for this reason that the Program Plan Manual is in loose-leaf rather than bound form.) The following describes the numbering system that has been developed for easy identification and referencing of tests as well as the basic format for each test report.

4.3.1 Test Report Identification

Each test will be identified using a series of five letters or numbers which indicate the classifier tested, the circuit configuration the feed size consist, the air flow rate and the classifier setting. These test numbers will have the form given by

XY-U-V-W

Classifier types are designated as H, T and V for the Hukki, twin-cone and vari-mesh classifiers, respectively. The H, T or V will fill position X. Circuit modes are given as O and C for open and closed circuit, respectively. These designations will fill position Y.

Feed sizes are designated as 1 and 2 for 3/4" x 0 and 1-1/2" x 0 coal, respectively and will be placed in position U.

Target air flow rates will be designated as the actual target values to be tested. The plan is to test all classifiers at target air flow rates of 800, 1200, 1600 and 2000 ACFM. One of these numbers will fill position V. Classifier settings will be designated as follows.

For the Hukki classifier, flow guides A and B will be adjusted in the positions as shown in Figure 4.6 with settings as defined in the following table.

Setting No.	Flow Guide A Position	Flow Guide B Position
1	1	1
2	2	1
3	1	2
4	2	2

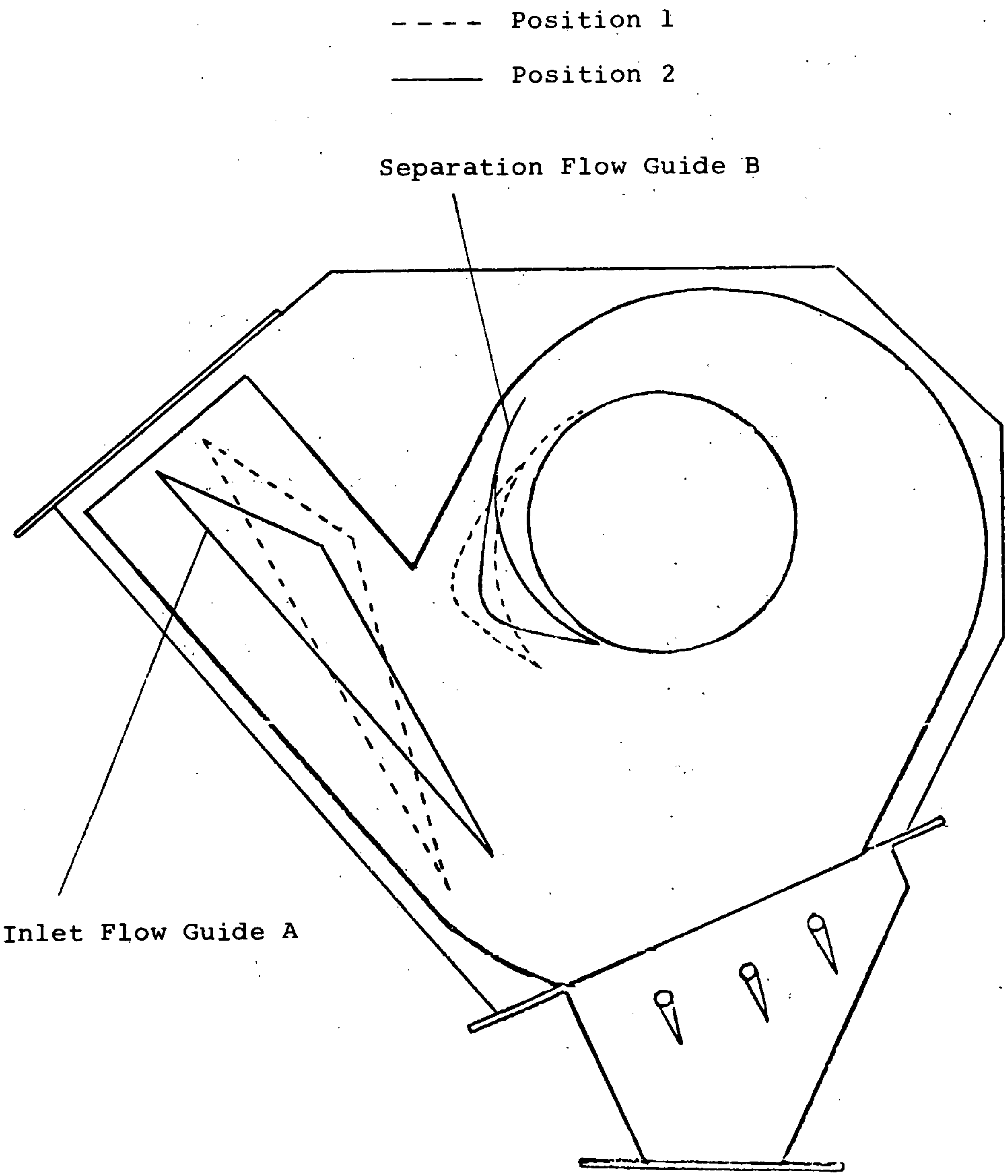


Figure 4.6 Flow Guide Settings for Tests of the Hukki Centrifugal Classifier

For the twin cone classifier, settings 1 and 2 will be 25 percent and 50 percent open vane settings, respectively.

Setting 1 for the vari-mesh classifier will indicate a 50 percent width opening; setting 2 will indicate a 100 percent width opening. The classifier setting designation will be found in position W.

With this numbering system, the reader will thus know that a test labelled as, say, Test VC-1-800-1 is a closed circuit test on the vari-mesh classifier with 50 percent width opening at a target air flow rate of 800 ACFM with 3/4" x 0 coal as the circuit feed.

4.3.2 Test Report Format

In lieu of a written description of the test report format, a sample test report is included in the pages following the present discussion. As seen, the first page of the report is general information and physical data pertinent to the test in question. The second page gives size analyses, experimental selectivity values and a plot of experimental (given by o) and model (given by —) selectivity values. Also given are values for the D_{50}, by-pass fractions and sharpness index for the test in question. As noted earlier, the test reports are intended to be filed in the Program Plan Manual in APPENDIX B - TEST REPORTS.

TEST TC-1-1400-2

CLOSED CIRCUIT TESTING OF THE TWIN - CONE CLASSIFIER AT SETTING 2 USING 3/4" X 0" FEED AT TARGET AIR FLOW RATE OF 1400. ACFM

TEST DATE : 08-31-80

MASS FLOW RATE	LB/HR
CIRCUIT FEED	1465.0
CIRCUIT PRODUCT	1438.1
CLASSIFIER REJECTS	3240.0
DUST COLLECTOR	41.1

AIR FLOW RATE	ACFM
MILL INLET	1449.5
MILL OUTLET	1333.0
ID FAN INLET	1471.0

STATIC PRESSURE	IN.H2O
MILL INLET	0.8
MILL OUTLET	4.0
CLASSIFIER INLET	4.0
CLASSIFIER OUTLET	9.0

TEMPERATURE	DEG. F
MILL INLET	365.0
MILL OUTLET	180.0
ID FAN INLET	175.0

REJECT SAMPLES

SAMPLE NO.	SAMPLE WT(LB)	SAMPLING TIME (SEC)	SAMPLE TAKEN AT	CALC. SOLIDS RATE LB/HR
1.	13.50	15.	8:00	3240.0
2. *	13.30	15.	8:30	3192.0
3.	13.80	15.	9:00	3312.0
4. *	13.40	15.	9:30	3216.0

AVERAGE (STANDARD DEVIATION) OF SOLIDS FLOW RATE : 3240.0 (45.)

FINES SAMPLES

SAMPLE NO.	SAMPLE WT(LB)	SAMPLING TIME (SEC)	SAMPLE TAKEN AT	CALC. SOLIDS RATE LB/HR
1.	69.80	180.	8:05	1396.0
2. *	71.20	180.	8:35	1424.0
3.	68.40	180.	9:05	1368.0
4. *	70.00	180.	9:35	1400.0

AVERAGE (STANDARD DEVIATION) OF SOLIDS FLOW RATE : 1397.0 (20.)

DUST COLLECTOR SAMPLES

SAMPLE NO.	SAMPLE WT(LB)	SAMPLING TIME (SEC)	SAMPLE TAKEN AT	CALC. SOLIDS RATE LB/HR
1.	1.37	120.	8:10	41.1
2.	1.31	120.	8:40	39.3
3. *	1.44	120.	9:10	43.2
4. *	1.36	120.	9:40	40.8

AVERAGE (STANDARD DEVIATION) OF SOLIDS FLOW RATE : 41.1 (1.)

(*) THESE SAMPLES SIZE ANALYZED

CLASSIFIER : TWIN - CONE

CIRCULATING RATIO : 2.25

SHARPNESS INDEX : 0.62

D50 : 67 MICRONS

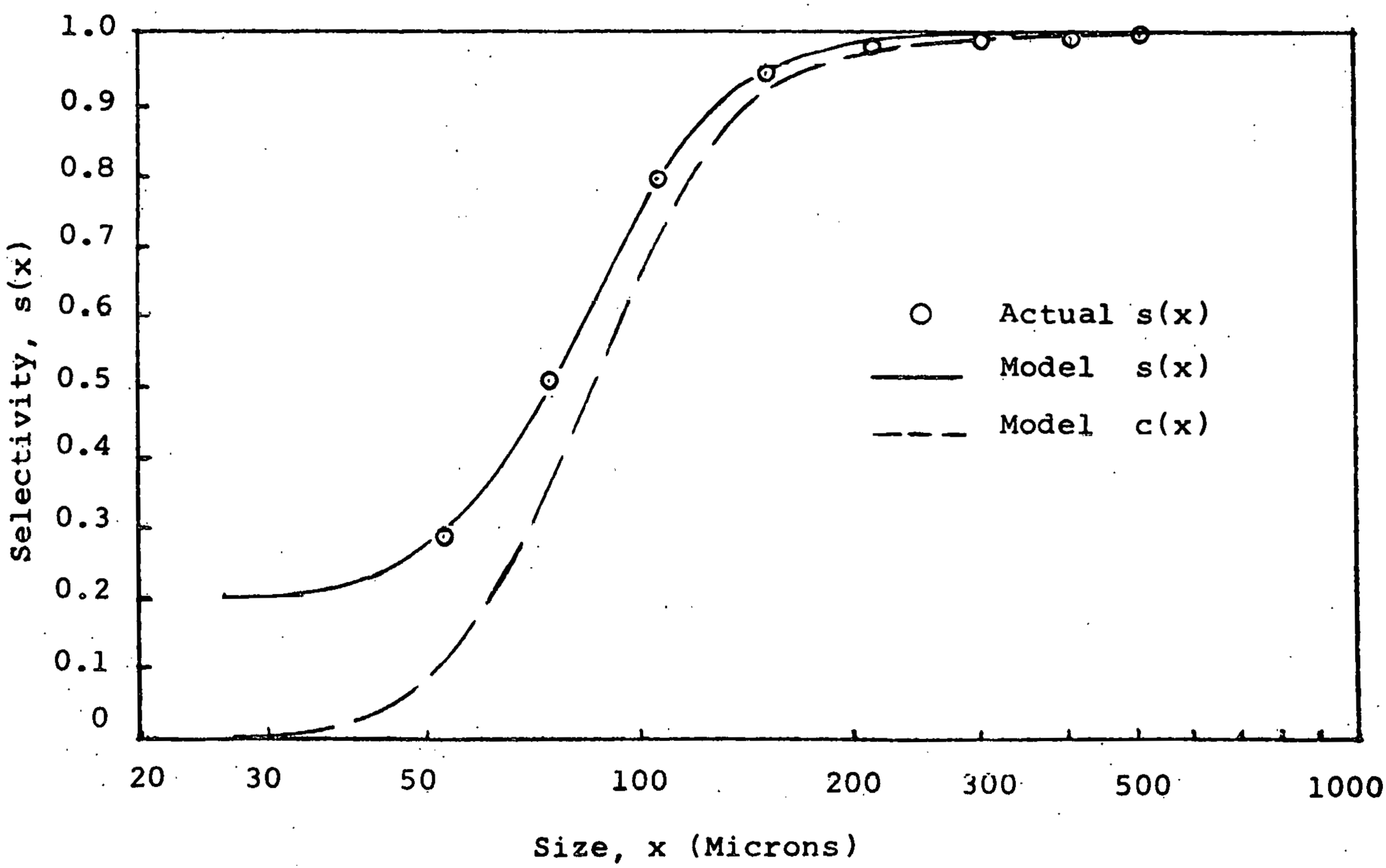
BYPASS A : 20.0 %

BYPASS B :

SIZE DISTRIBUTIONS AND SELECTIVITIES

******* PERCENT LESS THAN STATED SIZE *******

SIZE NO.	PARTICLE SIZE MICRONS	RCNSTD MILL PRODUCT	CLASSIFIER REJECTS	CIRCUIT PRODUCT	ACTUAL SELECT	CORRECTED SELECT
1	2380.	1.0000	1.0000	1.0000	1.0000	1.0000
2	1683.	0.9993	0.9990	1.0000	1.0000	1.0000
3	1190.	0.9965	0.9950	1.0000	1.0000	1.0000
4	841.	0.9896	0.9850	1.0000	1.0000	1.0000
5	595.	0.9771	0.9670	1.0000	1.0000	1.0000
6	421.	0.9501	0.9280	1.0000	0.9891	0.9863
7	298.	0.8955	0.8500	0.9981	0.9935	0.9919
8	210.	0.8035	0.7180	0.9961	0.9859	0.9824
9	149.	0.6763	0.5370	0.9903	0.9494	0.9367
10	105.	0.5348	0.3430	0.9670	0.8007	0.7509
11	74.	0.4146	0.2040	0.8890	0.5173	0.3967
12	53.	0.3182	0.1320	0.7377	0.2873	0.1091



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6. APPENDICES

APPENDIX A - TEST FACILITIES

The contents of this appendix to the Program Plan Manual includes

- A flow diagram of the KVS Air-Swept Ball Mill Test Facility (Figure A1).
- The start-up/shut-down sequence for facility operation.
- A description of each major component of the facility.

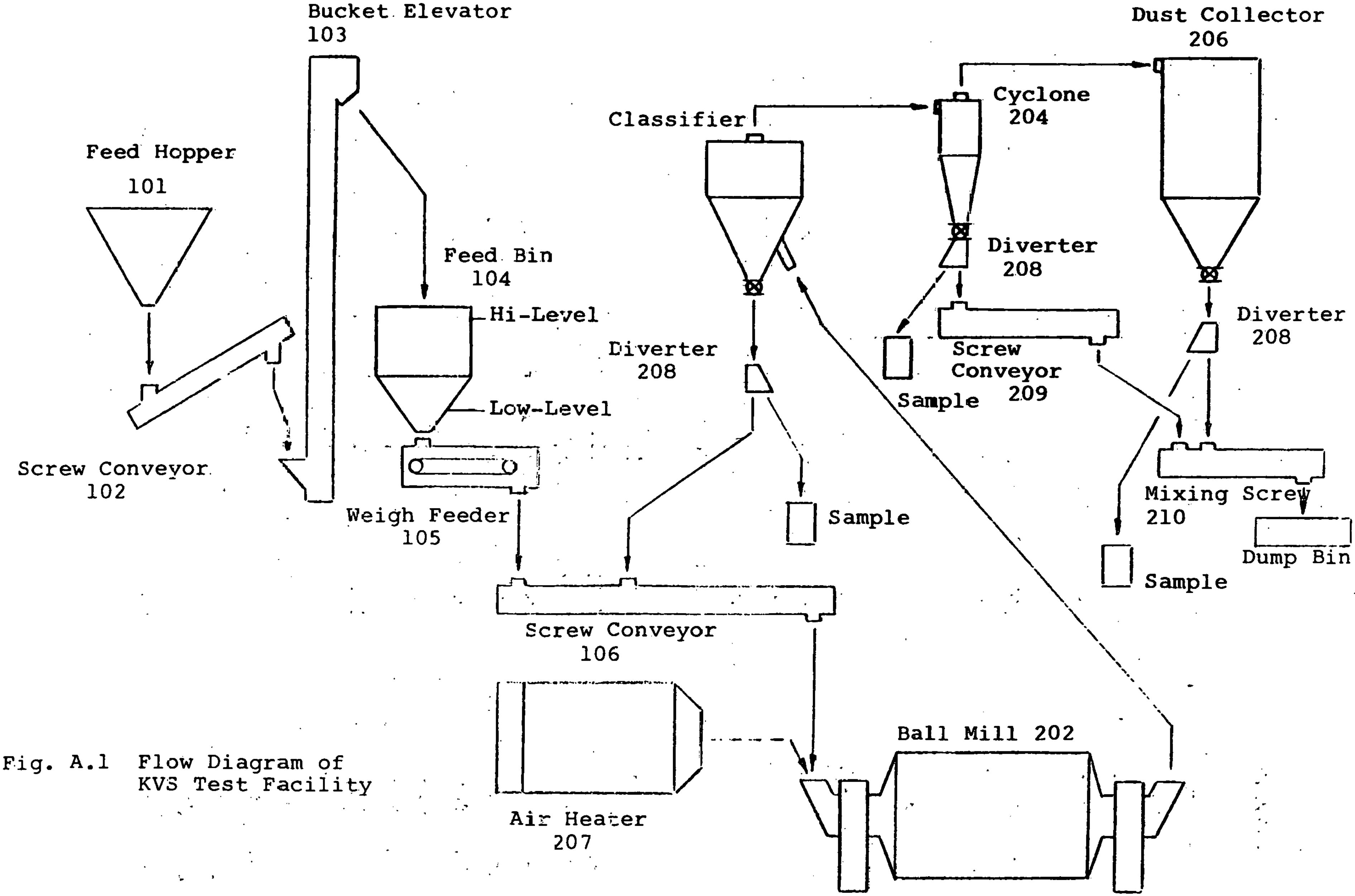

Fig. A.1 Flow Diagram of KVS Test Facility

START-UP/SHUT-DOWN SEQUENCE FOR FACILITY OPERATION

A. Raw Material Handling Sequence

1. Start bucket elevator.
2. Start screw conveyor 102.

Note: Screw conveyor 102 will automatically shut down when bin indicator (hi-level) is activated.

B. Grinding Sequence

Preparation: Turn on cooling water to mill.
Turn on air to baghouse and diverter gates.
Turn on propane and oil valves to combustor.
Turn power on to panel.
Check sample receivers and dumpster.

1. Start screw conveyor 210 (to dumpster).
2. Start screw conveyor 209 (from cyclone and baghouse).
3. Start rotary airlocks 211A, 211B and 206.
4. Start oil pump and primary air fan to combustor.
5. Start I.D. fan (always start with damper closed).
6. Set combustor on low fire (primary air fan at 15-20% open).
7. Start fire at combustor.
8. Increase I.D. fan to desired flow, and increase temperature by increasing primary air fan opening, or oil valve at combustor.
9. Start mill and increase temperature to desired level.
10. Start rotary airlock 201C.
11. Start screw conveyor 106 (to mill).
12. Start weigh feeder.

C. Shut-Down Sequence

1. Stop feeder.
2. Shut off oil safety valve, when pressure of oil drops then shut off panel at combustor (pilot light).
3. Stop oil pump and primary air fan.
*4. Let system empty.
5. Stop mill and I.D. fan.
6. Stop screw conveyor 106.
7. Stop all airlocks.
8. Stop screw 209.
9. Stop screw 210.

*Note: Be sure system is practically empty, (do not let hot coal remain in system).

DESCRIPTION OF MAJOR COMPONENTS OF THE FACILITY

101 - Feed Hopper

One 72 $ft.^3$ Feed Hopper fabricated by the Milton Steel Company. This Feed Hopper is fed by a front end loader. The Feed Hopper discharges into Screw Feeder 102.

102 - Screw Feeder

One 12" diameter x 20' long inclined Screw Feeder. The Screw Feeder is designed to handle 400 $ft.^3$/hr. of materials weighing as much as 100 $lb/ft.^3$ having a feed size to 1-1/2" and moisture to 10%. This screw feeder was supplied by Penn-Bangor, Inc., a 5 HP motor was supplied by KVS. The Screw Feeder discharges into Bucket Elevator 103.

103 - Bucket Elevator

One Rex Vertical Centrifugal Discharge Industrial Bucket Elevator Model #1108-1 designed to handle 10 TPH of bituminous coal weighing 50 $lb./ft.^3$ containing as much as 10% moisture with material sizes to 1-1/2". Drive is sized to handle 10 TPH of material weighing 100 lb./ft. Elevator is equipped with a service platform. The 3 HP motor was of KVS supply. Support bracing for this unit was supplied and fabricated by Milton Steel Company. The Bucket Elevator discharges into Feed Bin 104.

104 - Feed Bin

One 200 cubic feet feed bin with high and low level alarms for bin is provided by Milton Steel Company. Support steel for this item was supplied and fabricated by Milton Steel Company. The Feed Bin discharges onto Weigh Feeder 105.

105 - Weigh Feeder

One Autoweigh Model #300-18 Weigh Feeder with feed rates ranging from 0.25 to 5.0 STPH of material with a bulk density of 50 to 100 $lbs./ft.^3$ and moisture up to 10%. Materials range in size up to 1-1/2". Feeder is of dust tight construction. This Weigh Feeder was provided by Autoweigh Inc. Support steel for this unit is supplied and fabricated by Milton Steel. The Weigh Feeder discharges into Reversible Screw Conveyor 106.

106 - Reversible Screw Conveyor

One 12" diameter x 28' long Reversible Screw Conveyor. The Reversible Screw Conveyor is designed to handle 400 $ft.^3/hr.$ of materials weighing as much as 100 $lb./ft.^3$ having a feed size to 1-1/2" and moisture to 10%. This Reversible Screw Conveyor was supplied by Penn-Bangor, Inc., a 3 HP motor is supplied by KVS. The Reversible Screw Conveyor discharges through Rotary Airlocks 201 to the appropriate dry grinding mill or directly to the wet grinding mill.

107 - Chutes

One Chute - From Screw Feeder (Unit 102) to Bucket Elevator (Unit 103).

One Chute - From Bucket Elevator (Unit 103) to Feed Bin (Unit 104).

201 - (3) Rotary Airlocks

Three (3) 12 inch Newman TRV 300 Rotary Airlocks with cast housings and Type 316 Stainless Steel rotors were supplied by Newman Industries. These Airlocks are designed to handle material to 1-1/2" having a bulk density to 85 lb./ft.^{3} with moisture to 10%. Each rotary airlock is capable of handling 400 cubic feet/hour of the material. Each Rotary Airlock was supplied with a 1 HP, 3 phase, 60 hertz motor.

202 - Dry Ball Mill

One 3'-6" diameter x 5'-0" or 7'-0" long KVS Air-Swept Ball Mill. This Mill is worm gear driven and has possible mill speeds of 29.2, 31.4, 34.6, and 36.8 RPM. This unit is driven with a 25 HP motor.

204 - Cyclone

One 2'-6" diameter KVS Cyclone. This unit is designed to remove the product from the air stream. The solids discharge through Rotary Airlock 211B2 into Screw Conveyor 209.

205 - I.D. Fan

One KVS #69-5 I.D. Fan designed with a rotor to operate at either 1750 RPM or 1160 RPM. This Fan is 60" in diameter with a 5" wide rotor. This Fan was fabricated by Metalmex of Lewistown, PA. KVS supplied the 30 HP motor for this belt driven fan. The I.D. Fan receives air from Cyclone 204 and exhausts into Dust Collector 206.

206 - Dust Collector

One Mikropul 100S620 Dust Collector with 16 ounce/yd.^{2} polyester bags. One 8" Rotary Airlock with 1/2 HP TEFC with an explosion vent. Support steel for this unit was supplied and fabricated by Milton Steel. The Dust Collector exhausts to atmosphere and discharges the solids through its rotary airlock into Mixing Screw Conveyor 210.

207 - Air Heater

One (1) set of combustion equipment designed to heat 6,000 SCFM of ambient air from 80^{o}F inlet temperature to 750^{o}F outlet temperature, with a maximum gross heat release of 3.50 x 10^6 BTU/Hr. when burning No. 2 Fuel Oil. The system uses ambient air as quench air and includes: one (1) combustion chamber of a single wall design with an internal combustion chamber of 3'-3" inside diameter by 6'-0" long formed by 4-1/2" thick super-duty fireclay refractory with an outside carbon steel shell of 4'-0" diameter. The air heater has approximate overall dimensions of 4'-0 1/2" diameter by 10'-0" long (including the burner). The burner wall of the combustion chamber is lined with 6" of castable refractory. The discharge section is lined with 6" of super-duty firebrick. The chamber is fabricated with two separate inlet connections, one (1) for combustion and one (1) common outlet. The heated air is distributed to the appropriate dry grinding mill via a common manifold system which uses blank flanges to divert the air stream.

209 - Screw Conveyor

One 9" diameter x 23' long Screw Conveyor. The Conveyor is designed to handle 200 $ft.^3$/hr. of material weighing as much as 100 lb./$ft.^3$. This Screw Conveyor was supplied by Penn-Bangor, Inc. The 1-1/2 HP motor was supplied by KVS. The Screw Conveyor discharges into Mixing Screw Conveyor 210.

210 - Mixing Screw Conveyor

One 12" diameter x 30' long Mixing Screw Conveyor. The Conveyor is designed to mix water with material weighing to 100 lb./$ft.^3$ having 200 $ft.^3$/hr. of the material. This Mixing Screw Conveyor was supplied by Penn-Bangor, Inc. The 3 HP motor was supplied by KVS. The Mixing Screw Conveyor can discharge into bulk disposal containers or 55 gallon open head drums.

211 - (2) Rotary Airlocks

Two (2) Model 6022 Mikro Rotary Airlocks complete with:

1. Cast Iron Housing
2. Steel Rotor with Replaceable Blades
3. 1/2 HP TEFC Motor

These Airlocks are designed to handle 5 ton per hour 1/4" material weighing as much as 100 lb./$ft.^3$. These Airlocks are supplied by Mikropul.

APPENDIX B - TEST REPORTS /

This appendix is reserved for test reports as they become available for insertion by the reader.

APPENDIX C - ASTM SULFUR/ASH ANALYSES

This appendix is reserved for ASTM sulfur and ash analyses reports as they become available for insertion by the reader.

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