

DEVELOPMENT OF A MATHEMATICAL MODEL
OF THE CLASSIFICATION PERFORMANCE IN A
4-IN CYCLONE CLASSIFIER

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A Thesis respectfully submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science in Metallurgical Engineering.

Signed:



Adrian A. Vasquez

Golden, Colorado

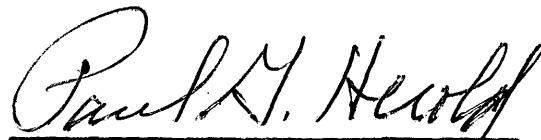
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Approved:



W. R. Bull
Thesis Advisor



P. G. Herold
Head of Department
Metallurgical Engineering

Golden, Colorado

Date: Sept. 16, 1969

ABSTRACT

A study was made of the performance in a well-controlled single cyclone classifier — Krebs type — of 4-in in diameter.

Classification tests were carried out in the single cyclone classifier using high-grade quartz as the feed material. As a result of the analysis, and by using a graphical method, a mathematical model in terms of four fundamental equations describing the performance of the classification operation in the cyclone was developed.

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INTRODUCTION

It has commonly been asserted that mineral dressing, from a chemical standpoint, consists of two steps, namely, (1) liberation of dissimilar particles from each other and (2) separation of chemically dissimilar particles. Likewise, the principal steps involved in the preparation of mineral products valued for their physical structure are (1) reduction in size and (2) separation of particles of dissimilar physical character. Thus, it will appear that in every instance mineral dressing involves a size-reducing or liberating operation or group of operations as a first step and a separating operation or group of operations as a second step. This generalization should not be emphasized too much since instances are common of operations in which liberation and separation stages are made to alternate in order to accomplish the desired ends most advantageously.

The four principal types of operations directly involved in affecting either liberation or separation are: (1) comminution, (2) sizing, (3) concentration, and (4) dewatering. A brief description of these operations are given:

Comminution means reduction to a smaller size. It is

accomplished on the dry ore or in aqueous pulp. Depending upon the size of the material being comminuted, the operation is regarded as crushing and grinding. The operation is carried out so as to liberate mineral values from the gangue.

Sizing is the separation of a material into products characterized by difference in size. This can be accomplished by screening or by classifying, the latter being a sizing method depending upon the relationship existing between the size of mineral particles and their settling velocity in a fluid medium, generally water.

Concentration depends upon the existence of an appreciable difference in some physical property between a valuable mineral and gangue, e.g., size, hardness, specific gravity, etc. If no such difference exists, flotation, which depends upon chemical rather than physical differences, must be used. If concentration is to be effected by physical means, it can, in general, be performed at any size at which the constituent minerals are sufficiently liberated to justify designation of individual pieces as concentrate and/or tailing. Flotation normally requires comminution to at least 35- or 48-mesh.

Dewatering is generally carried only to the extent of producing a damp cake, in two steps: first in thickeners to remove most of the water; then in filters, which receive the thickened pulp and yield the damp mineral cake. If further dewatering is desired, driers requiring fuel for evaporation

of moisture are essential.

In a general way, the principal steps involved in mineral dressing are: liberation and separation. The second step is impracticable if the first has not been successfully accomplished. This is partly true, since some degree of separation is possible between locked particles of various kinds, but it should be evident that a reasonable degree of liberation is a prerequisite to a fair separation.

In the flotation process of mineral concentration, particles of various sizes do not float equally well. The variation of recovery with particle size shows a similar trend regardless of mineral, collector, or flotation machine. As a rule, after flotation has been practically completed, the recovery of ore minerals at the coarser end declines rapidly to zero above about 35-mesh in conventional machines; maximum recovery being attained at about 200-mesh. With decreasing size below about 200-mesh, recovery remains sensibly constant to about 10 microns, then declines. The failure to float the extremely coarse particles arises from (i) incomplete liberation, (ii) too small a contact angle between particle and air bubble, and (iii) too violent an agitation. The failure to float extremely fine particles is frequently due to flocculation, but some other reasons may also be suggested.

In summary, successful flotation requires (i) physical liberation of the ore mineral particles, (ii) sufficient

size reduction, and (iii) classification of the selected size range of particles to permit recovery in the froth.

The hydraulic cyclone is a tool useful in many fields which require the handling and treatment of solid-liquid mixtures. It is widely used in the mineral industry and its success is primarily due to simplicity of construction and operation, and versatility in application.

Its simplicity is evident from the sketch of a cyclone in Figure 1. The cyclone consists of a cylindrical tube or shell, closed at the top by a flat plate and ending at the bottom in a cone with an opening (spigot) at its apex. Fixed in the center of the top plate is a cylindrical tube (vortex finder). The suspension to be separated is injected tangentially into the upper part of the cylindrical section, causing rotation of the fluid contained in the cyclone. In such a cyclone the vortex finder discharges the clarified liquid (overflow), while the spigot discharges the concentrated solids (underflow).

Its versatility can be demonstrated by listing the fields in which the hydraulic cyclone has found application. These are: separation according to particle size (classification), according to particle density (washing); and solid-liquid separation (thickening).

Statement of Problem

Industrial grinding circuits, which include rod mills,

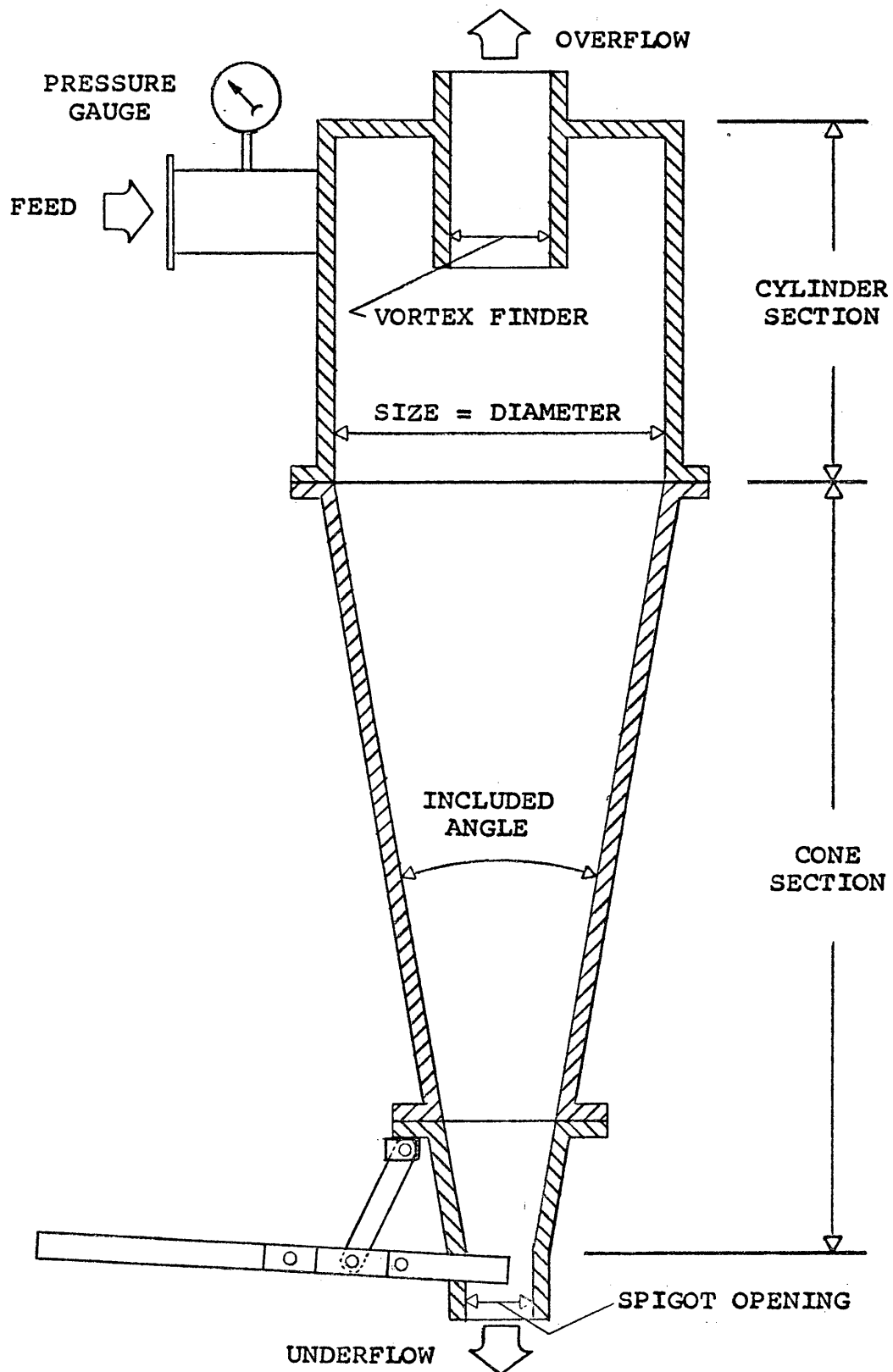


Figure 1: Schematic diagram and nomenclature of a hydrocyclone.

ball mills, and hydraulic classifiers, normally consist of an open-circuit rod-mill followed by ball-mills arranged either in series or in parallel. Each ball-mill is usually operated in closed circuit with a classifier.

In the operation of these circuits the following questions arise: (i) what is the best arrangement of the grinding-classification circuit?; (ii) for a given feed rate and feed sizing analysis, what combination of operating variables in the classification process will give the best results?; and (iii) what effects would a change in the feed conditions or solids content of the circuit product have on the sizing analysis of the circuit product and on the circulating loads, and how would these be altered by changes in the variables of classification?

In order to answer these questions experimentally would be an expensive and tedious process. They may best be obtained by defining the operating characteristics of each unit in the circuit by a series of equations, simulating the behavior of the circuit on a digital computer by use of these equations, and investigating the performance of the simulated circuit at any required conditions. This technique has been used to optimize the performance of grinding and classification circuits, and has resulted in a marked improvement in the efficiency of these circuits (14).

Classification is a unit operation for which no sound underlying theory has been developed comparable to that

which exists for some other unit operations, and the design of a classification system for a given duty is still an art based on accumulated experience. It is not for lack of either interest or investigation that a quantitative theory of classification does not exist. It is probably due to the complexity of the classification system, which involves a large number of variables, some of which are difficult to control, e.g. feed size, pulp density, and even feed rate and feed pressure. Sometimes it is assumed that the process of classification is too complex to hope for such a theory.

Since the introduction of the cyclone as a classifier in the concentration of minerals, great advances have been made in its application and in the efficiency of the separations performed. These advances have largely resulted from trial-and-error and it is only in the last half of this decade or so that attention has been directed to the development of mathematical models that describe the classification operation in terms of parameters, the magnitudes of which may be determined.

If a useful model could be established, it could be used for computer simulation of the operation. This in turn could form the basis for optimization and on-line computer control.

The purpose of this investigation is to study the development and the establishment of a useful mathematical model for a hydrocyclone of 4-in in diameter, which would

make it possible to simulate any classification system involving such a cyclone on the computer as a result of a limited number of sampling tests.

It should be noted that mathematical models have been developed ^(10,11) for larger cyclones (20-to 24-in in diameter) but it is not known if these models are valid for smaller cyclones.

Importance of the Study

Since it is nearly always a general practice to operate grinding units in closed circuit with size separation units in such a manner that the product from the closed circuit is a single product from the size separation unit, the following comments may be made:

1 - Although screens and classifiers are not comminution units, the product from a closed-circuit grinding system is one of the products from the size separation unit and these units therefore exert a marked effect on the performance of the system.

2 - These units also control the mass flow rate of mineral ore through the grinding unit and this is one of the physical limitations of the circuit which must be taken into account when the performance of the circuit is being analyzed.

3 - The cost of preparing metalliferous ores for concentration processes involving grinding and classification frequently represents a major portion of the cost of treating such ores, and it is necessary both from an economic and

a metallurgical point of view that grinding-classification circuit should be operated at their optimum efficiency.

It is, therefore, very important and necessary to develop accurate mathematical models of the various size-separation units in order that correct simulation of the behavior of close-circuit system may be obtained.

This investigation was undertaken in order to make some contribution to the problem of establishing useful mathematical models of classification operations.

Solution of the Problem

The problem was attacked experimentally by setting up a 4-in Krebs cyclone in closed-circuit with a feed preparation tank. The feed slurry to the cyclone consisted of a mixture of water and quartz. The vortex finder and spigot diameters of the cyclone could be easily varied. Classification tests were carried out over wide operating conditions of pulp density, feed flow rate, and feed pressure. The experimental observation of the performance of the cyclone was then analyzed so as to investigate and, if possible, to define mathematically the interrelationships of the various operating variables in order to determine if a mathematical model can be applied to a cyclone classifier.

SURVEY OF THE LITERATURE

Despite the publication of more than 400 papers on the subject of hydrocyclones there remained a collective inability to design cyclones for specific and detailed process requirements (1) .

Cyclones could not be genuinely designed for perfectly reasonable requirements due to two failures. One was the lack of a precise theoretical or empirical formulation of proper design factors that could be used to define variables of design and of operation for obtaining specific products from a given mixture of mineral particles. That arose from the other failure, namely, the lack of a correct analysis of the mode of action of cyclone classifiers.

Hydrocyclones

The conventional hydrocyclone, hydraulic cyclone, or cyclone as simply referred to in this thesis, is simple and inexpensive in construction, with no moving parts, as shown in Figure 1.

Description of the procedure in operating a cyclone has been discussed in detail elsewhere (2,3,4,5) and needs only brief review.

The cyclone consists of a cylindrical section mounted above a truncated cone. The feed nozzle enters the cylindrical ring tangentially with the underflow nozzle (spigot), which permits discharge of the concentrated solids, located at the apex of the cone. The overflow nozzle (vortex finder), through which the lighter particles exit, is centered in the cylindrical section at the top of the cyclone. The feed slurry enters with a tangential velocity, thus creating a spiral pattern of high centrifugal force. The solid particles of sufficient size and gravity are ejected outward to the walls and spirally discharge to the underflow. Most of the water with uneliminated fine solids move radially inward along the path of the outer spiral to a second inner spiral at the cyclone core, to pass out of the overflow. The latter spiral is the most critical fluid movement because of its small radius and higher tangential velocity. The dual spiral flow pattern in a cyclone is represented in Figure 2.

The general performance of a cyclone is influenced both by the cyclone design variables, i.e., the inlet and outlet dimensions, and by the operating variables, i.e., the feed pressure and the physical properties of the solid particles and the fluid.

The Movement of Fluid Elements and
Solid Particles within Cyclones

Fluid enters the cyclone tangentially at the circumfer-

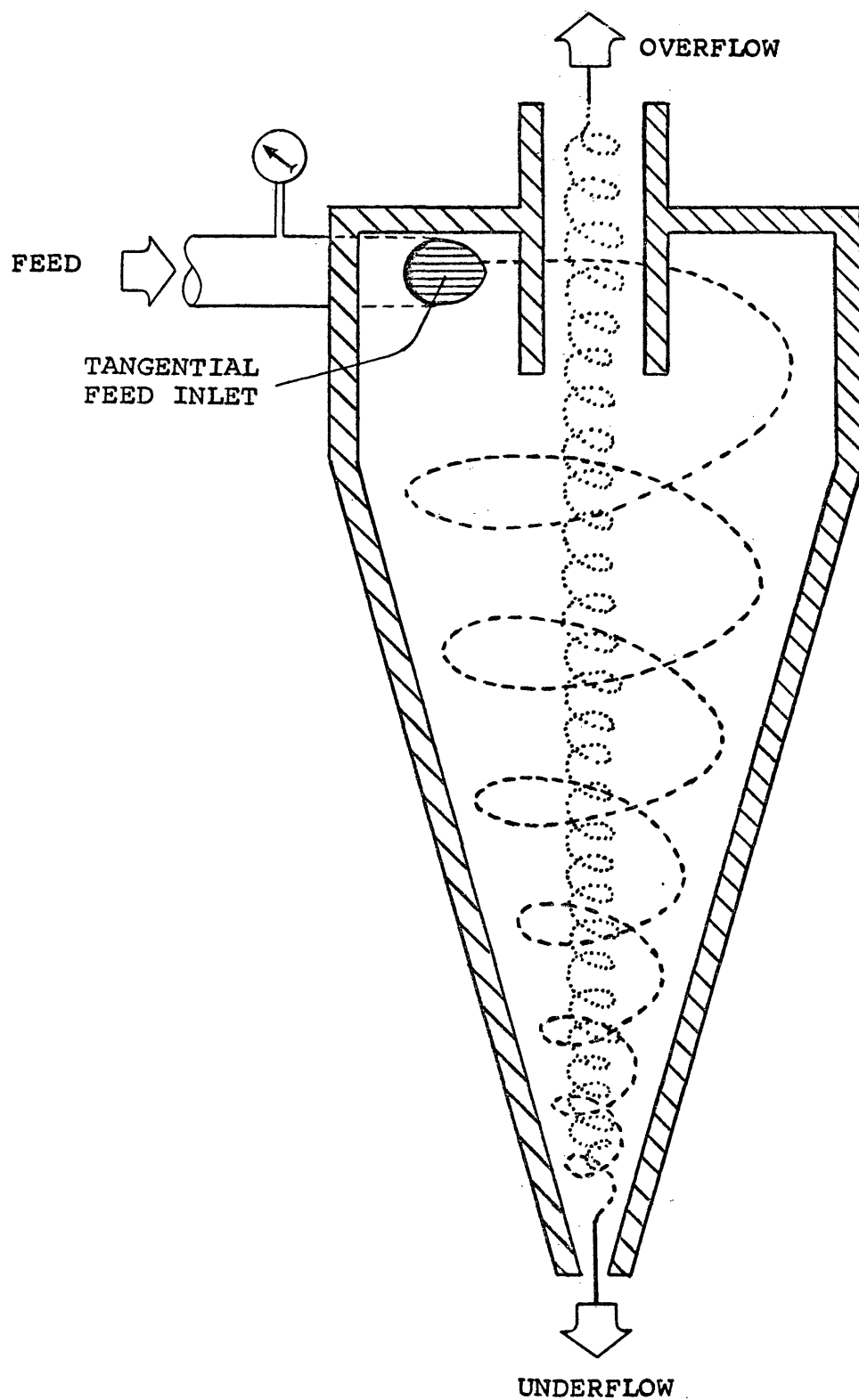


Figure 2: The spiral flow pattern in a hydrocyclone

ence and leaves the cyclone along the central axis at right angles to the direction of entry. At the points of exit the outlet streams are moving in opposite directions. Classification of solid particles of different weights contained in the inlet stream occurs as a result of the conversion of the direction and velocity of flow of the inlet stream into that of the outlet stream and is due to centrifugal, drag, and gravity forces acting on the particles.

Any velocity within the cyclone can be resolved into the following components:

- (i) Tangential velocity in a horizontal plane and at right angles to a radius from the axis of the cyclone.
- (ii) Radial velocity in a horizontal plane and along the radius.
- (iii) Vertical velocity at right angles to the other two components (i.e., parallel to the axis of the cyclone).

(2)

The general flow pattern within cyclones was studied by using an optical method of observation of the movement of fine aluminum particles as tracer particles within a transparent cyclone of 3 inches internal diameter, and a conical portion with an included angle of 20° . Some of the important facts which resulted from this work were as follows:

- (i) Below the bottom of the vortex finder fluid envelopes of constant tangential velocity,

which are coaxial with the cyclone, exist.

- (ii) The tangential velocity of these cyclinders increases as the radius decreases according to the relationship $V \cdot r^n = \text{constant}$.
- (iii) At lower levels in the conical portion the radial velocity decreases as radius decreases and becomes zero in the vicinity of the air/water interface.
- (iv) A conical envelope of zero vertical velocity separates the flow of fluid towards the spigot and the flow towards the vortex finder.

A particle suspended in the fluid rotating in the cyclone tends to move towards the wall of the cyclone if the centrifugal force acting on it is greater than the drag force, otherwise it tends to move radially inwards. Although short circuiting may occur within the cyclone causing coarse particles to appear in the discharge from the vortex finder, solid particles in general have to pass through a zone of maximum tangential velocity before emerging through the vortex finder. This ensures that all particles will be subjected to the maximum centrifugal force before they can pass from the outer to the inner spiral and it contributes to the efficiency of cyclones in rejecting coarse particles from the fine particle product.

(7)
Lilge observed that within reasonable limits changes in fluid viscosities or flow rates do not alter the flow

profiles although they cause proportionate changes in the velocity components. This type of work could only be carried out with clear fluids containing very small amounts of tracer particles and it has not been possible to work with pulps containing high mass fractions of tracer particles.

Since it has not been possible to obtain data useful in calculating the particle paths in cyclones, because no experimental technique has yet been devised to permit an investigation of the behavior of mineral pulps in cyclones, the knowledge of the performance of cyclones remains almost entirely empirical.

The Operational Characteristics of Cyclones

The development of empirical equations has been possible for large cyclones in the range 15 to 27 inches in diameter treating pulp containing 0 to 70 percent by weight of solids at pressures exceeding 4 p.s.i.g. These equations, most of which are part of mathematical models of cyclones, have been (8,9,10,11) discussed in detail elsewhere. It is noted that the limits of application of the equations include most normal operating conditions, but no claim has been made that the equations are accurate outside these limits.

The Capacity of Cyclones

For any mineral-water pulp treated in a cyclone the capacity or cyclone throughput is affected by three variables in particular. They are:

- (i) The operating feed pressure.
- (ii) The vortex finder diameter.
- (iii) The solids content of the pulp.

It may also be affected by the size and shape of the feed inlet section but this is normally not considered as an operating variable.

It has been found by several workers ^(2,4,11), and confirmed by others ^(9,10) after extensive test work on 15- and 20-inch diameter cyclones, that the following equation relates the capacity of a cyclone to the operating feed pressure:

$$\text{Capacity} = C_1 \cdot (\text{pressure})^{0.5} \quad (\text{A})$$

in which C_1 is a constant.

If the operating feed pressure is kept constant, the capacity of the cyclone is increased as the diameter of the vortex finder is increased. This relationship is expressed by the equation,

$$\text{Capacity} = C_2 \cdot (\text{Vortex finder diameter})^{1.0} \quad (\text{B})$$

in which C_2 is a constant.

⁽⁵⁾ Dahlstrom proposed a similar relationship except that the exponent quoted was 0.9.

The effect of change in solids content of the pulp on the capacity of the cyclone has been assessed on large diameter cyclones ^(10,11). The relationship is expressed by the

equation:

$$\text{Capacity} = C_3 \cdot (\% \text{ water by wt. in the feed pulp})^{0.12} \quad (c)$$

in which C_3 is a constant.

In order to use these equations in the design or optimisation of a system, it is necessary to identify the constants in the equations relating to a particular ore by one classification test.

Since scale-up factors in cyclone operation have not yet been precisely determined, it is necessary that the test be carried out on a cyclone in approximately the same size range as that which is to be used. Only when scale-up factors have been determined, will it be possible to find these constants for a large cyclone from small-scale testing.

The Distribution of Water in Cyclones

Part of the water entering the cyclone emerges in the spigot stream (underflow). A knowledge of cyclone operation leads to the conclusion that if $x\%$ is the fraction of the total water which is discharged through the underflow then, independent of any centrifugal forces acting on particles, $x\%$ of all particles must leave through the underflow ⁽⁶⁾ . Therefore it was necessary to know the manner in which the water entering the cyclone in the feed pulp is distributed between the vortex finder and spigot discharge outlets.

In an investigation on full-scale cyclones (24- to 30-in in diameter) working at a relatively low pressure (8 p.s.i.g.)

under operational conditions, Peachey⁽⁸⁾ showed that the tonnage of water reporting to the overflow of a cyclone is a linear function of the tonnage of water in the feed pulp. This function is independent of the tonnage of water and solids fed to the cyclone.

For all practical purposes the distribution of water into the overflow is independent of the diameter of the cyclone. It is dependent on the areas of spigot, inlet pipe, and vortex finder. The effect of the vortex finder diameter on the water distribution may be considered immaterial since the curves for the various sizes of vortex finders are really a series of closely spaced parallel lines, which appear to be a straight line.

It is relevant to note that the study made by Peachey^(10,11) was confirmed and extended on large diameter cyclones. The water distribution in these cyclones was expressed by the following mathematical relationship:

$$W_O = 1.1 \cdot W_{FR} + C_4 \quad (D)$$

where W_O represents the mass flow rate of water in the cyclone overflow; W_{FR} is the mass flow rate of water in the cyclone feed and C_4 is a constant.

The mass fraction of water in the feed which emerges through the spigot may be readily calculated by a simple mass balance of the known W_{FR} and W_O calculated from equation D. The mass and sizing distribution of the solid par-

ticles which emerge through the spigot associated with the water may be calculated from a knowledge of the mass flow rate of water in the feed and the mass and sizing distribution of solid particles in the feed.

The Solid Separation Characteristics of Cyclones

The Assessment of the Classification Operation

The development of empirical equations describing the solids separation characteristics of cyclones requires the selection of a method of defining quantitatively by a single parameter the result of each classification test. The selection of this method is discussed in the following sections.

The Actual Performance Curve. As a result of a classification test on a cyclone, the sizing distribution and mass flow rates of the feed, overflow, and underflow are determined; therefore, the mass fraction of each size range in the feed may be calculated. A graph of the percent of the individual size fraction in the feed to the unit which reported to the underflow (arithmetic scale) plotted against the aperture size in microns (log scale) is approximately the line shown in Figure 3. This typical curve is known as the actual performance curve for an operation and is of little use for design purposes because it is affected by all operating variables.

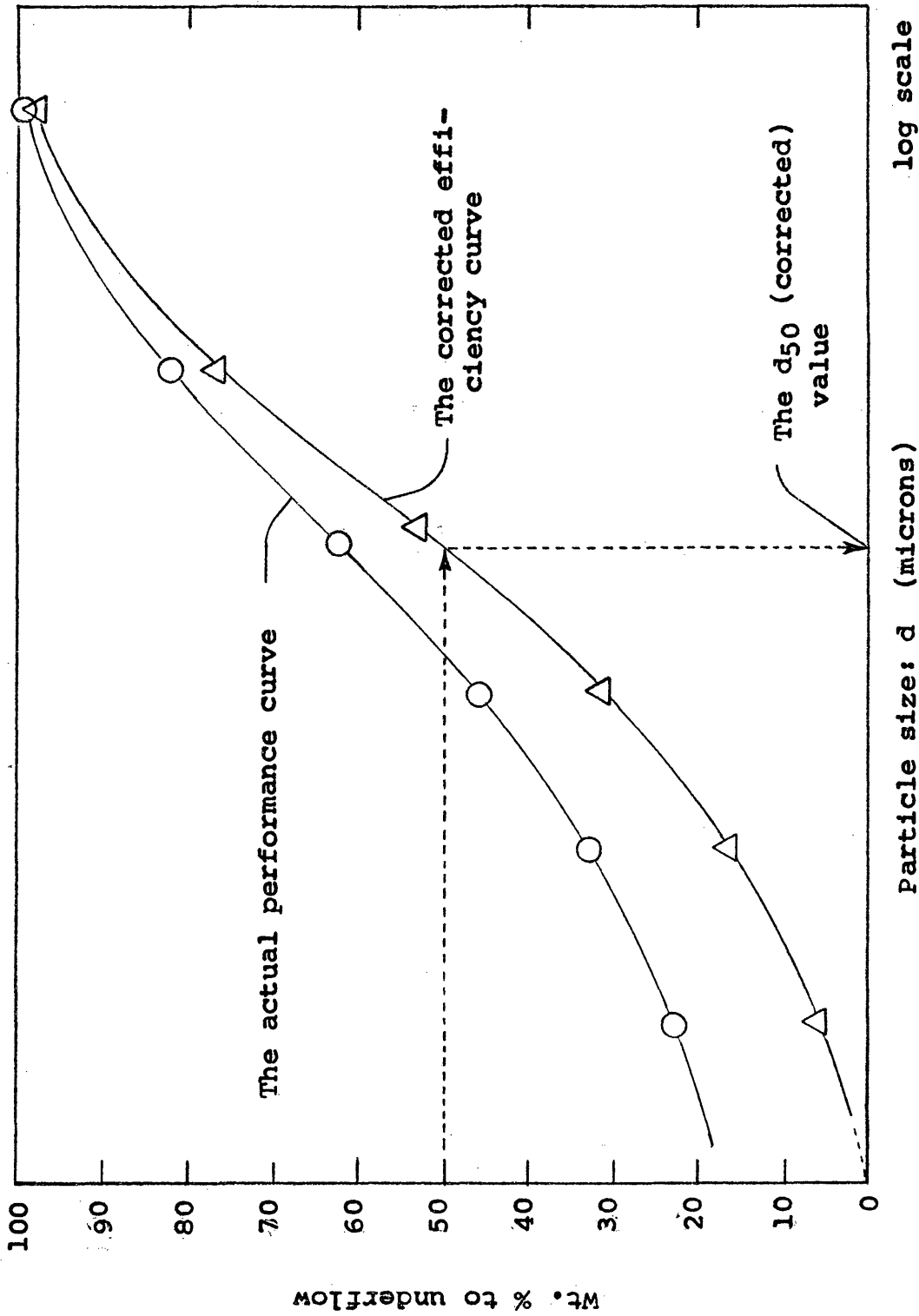


Figure 3: The performance curves of a cyclone.

The Corrected Efficiency Curve. It has been assumed (6,9,10,11) that the solid particles which appear in the underflow consist of two components: (1) the representative proportion of the feed particles which are carried into the underflow by the water; and (2) the particles which appear in the underflow as a result of classification. If the mass of particles which appear in the underflow due to the water is deducted from the feed and the underflow, a new performance curve may be determined from the remaining masses and sizing distributions which will pass through the origin. This curve is known as the corrected efficiency curve and is shown in Figure 3.

The Corrected d_{50} Value. The d_{50} (corrected) value is the aperture size at which 50 percent of the classified particles in the feed are present in the overflow and the other 50 percent in the underflow. The corrected d_{50} value is the important single parameter in the quantitative description of cyclone performance and may be derived from the corrected efficiency curve as shown in Figure 3. This is discussed in a later section.

The Reduced Efficiency Curve. The corrected efficiency curve represents any classification operation, which has occurred due to centrifugal action within the cyclone, but it still is not useful for design purposes because it is specific to one condition of cyclone operation having no generality.

The value of d_{50} (corrected) for any given cyclone performance is primarily of academic interest ⁽⁴⁾. What the plant engineer requires is knowledge of efficiency as a function of particle size from which he can evaluate the efficiency of the cyclone when fed with his particular material. This knowledge can be obtained by calculation of the corrected d_{50} value and use of an observation of Yoshioka and Hotta ⁽¹³⁾ that all separation characteristics have the same form and can be reduced to a single curve if, from the corrected efficiency curves, the actual size scale (on the abscissa) is replaced by the ratio of actual size (microns) to the d_{50} (corrected) value (microns), and then replotting the curves. This new curve is called the reduced efficiency curve and is a characteristic of the ore classified by the cyclone at any condition of operation. This curve is illustrated in Figure 4. It should be realized that the curve is an empirical one and that it would be preferable to establish this characteristic for every cyclone before plant use.

The need to refer to the reduced efficiency curve is avoided by the choice of a suitable mathematical expression for it. Separation in a cyclone is a matter of probability. An equation of probability ⁽¹⁰⁾ that fits the reduced efficiency curve within its experimental limits of accuracy is as follows:

$$Y = \frac{e^{ax} - 1}{e^{ax} + e^a - 2} \quad (E)$$

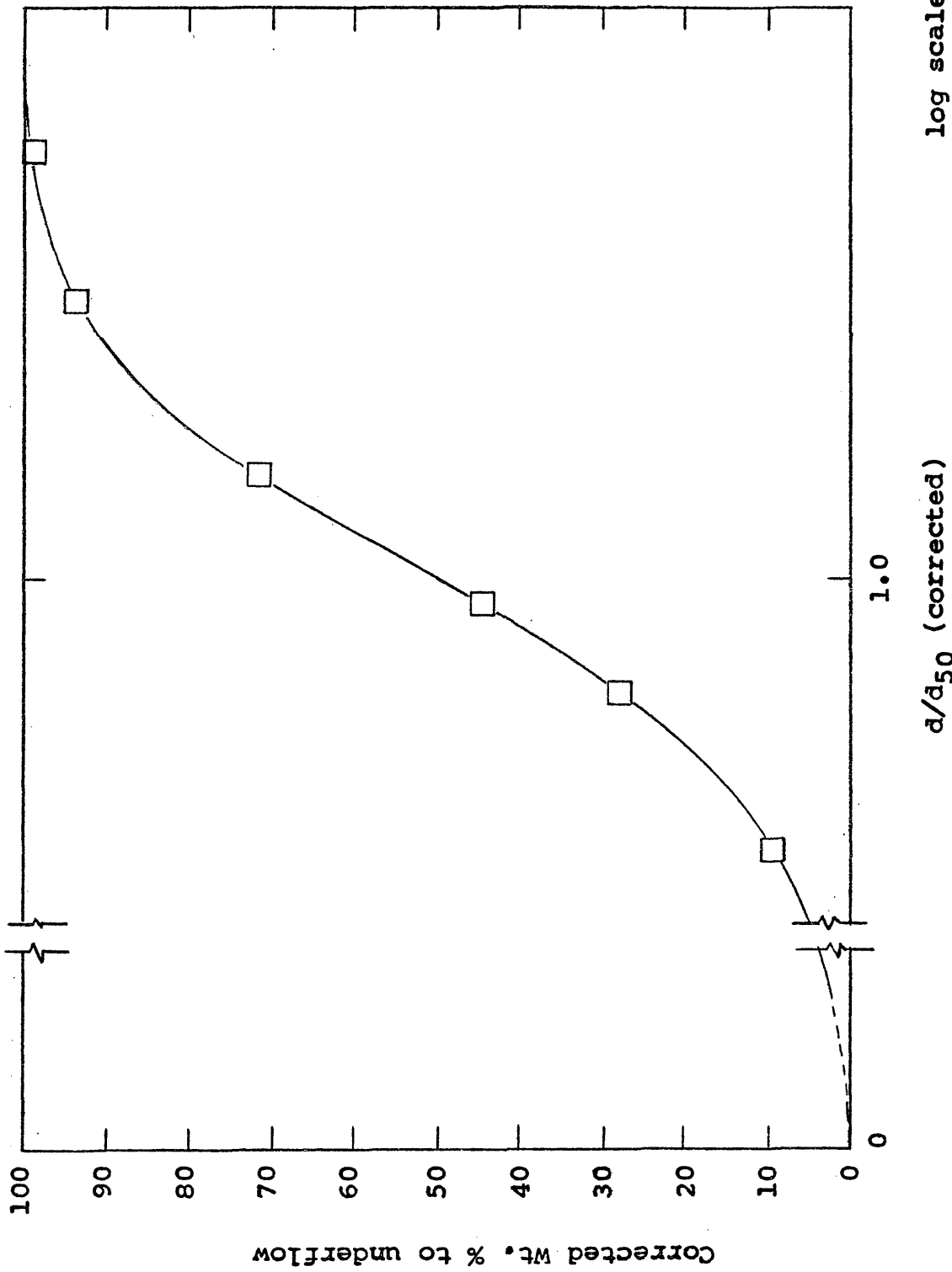


Figure 4: The reduced efficiency curve of a cyclone

in which Y = Fraction of the feed at a particular micron size which appears in the coarse product (underflow) due to classification.

X = Ratio of the mid-point of a size range (microns) to the d_{50} (corrected) point.

α = Cyclone design constant which defines the form of the reduced efficiency curve. It is a value characteristic of the mineral ore to be classified.

Provided that the corrected d_{50} value and the reduced efficiency curve of an operation are known, then the behavior of the cyclone in terms of the particles which are actually classified can be calculated directly.

Many tests were carried out at Mount Isa, Australia, over a wide range of operating conditions ⁽¹⁴⁾. As a result of this work it has been possible to confirm that the reduced efficiency curve for an ore in a cyclone is a characteristic of that system suitable for process analysis and design purposes, and it may be identified for any one system by one classification test.

Any change in the operating or design variables for any system affects the performance of the system because it alters the corrected d_{50} value and therefore it alters the abscissa of the corrected efficiency curve in its derivation from the reduced efficiency curve. For any known reduced efficiency curve, the corrected d_{50} value is the single pa-

parameter which describes the classification performances of the cyclone.

The Effect of Variables on the Corrected d_{50} Value

The corrected d_{50} value for any ore defines the mass of ore of any given feed size which appears in the underflow as a result of classification, and may be determined from the known throughput, reduced efficiency curve and the distribution of water in the cyclone.

It has been found experimentally ^(10,15) that over a wide range of feed conditions d_{50} (corrected) is a function of the mass flow rate of water in the overflow, of the diameters of the vortex finder and spigot and of the feed pressure. The form of the equation relating the d_{50} (corrected) value with the other variables is as follows:

$$\log_{10} d_{50} (\text{corr.}) = \frac{VF}{A_1} - \frac{Spig}{A_2} + \frac{P}{A_3} - \frac{WO}{A_4} + K \quad (F)$$

where A_1 , A_2 , A_3 , A_4 , and K are constants of the classification of a specific mineral ore in a particular cyclone.

The Design and Operation of Cyclones

The mathematical model which has been developed for high capacity cyclones ^(10,11), that is, cyclones with a throughput exceeding 200 gal/min, relates the composition of the underflow product, which contains predominately coarse particles, to the composition of the feed stream for different values of the operating variables. When the composi-

tions of the feed and underflow streams are known, the overflow stream can be calculated by a simple mass balance. The equations which comprise the model, include variable parameters that represent the operating variables and constants which have specific values for various ores and which can be determined by observing the performance of the cyclone under one set of operating conditions.

The equations which define the operation of large cyclones are (11) :

From equations (A), (B), and (C):

$$Q = K_1 \cdot (VF)^{1.0} \cdot (P)^{0.5} \cdot (PW)^{0.12} \quad (G)$$

From equation (D):

$$WO = 1.1 \cdot WFR - 10.0 \cdot Spig. + K_2 \quad (H)$$

From equation (F):

$$\log_{10} d_{50} (\text{corr.}) = \frac{VF}{2.6} - \frac{Spig.}{3.5} + \frac{P}{10.7} - \frac{WO}{52} + K_3 \quad (I)$$

And the reduced efficiency curve equation:

$$Y = \frac{e^{\alpha X} - 1}{e^{\alpha X} + e^{\alpha} - 2} \quad (E)$$

where: Q = Volume flow rate of feed to cyclone, Imp. gal per min.

P = Cyclone feed pressure, lb/sq in gauge.

PW = Mass fraction of water in cyclone feed.

VF = Vortex finder diameter, in.

Spig. = Spigot diameter, in.

WO = Mass flow rate of water in cyclone overflow, tons per hour.

WFR = Mass flow rate of water in cyclone feed, tons per hour.

d_{50} (corr.) = Particle size at which half of the particles in the feed to the cyclone which are classified go to the underflow and the remainder go to the overflow, microns.

K_1, K_2, K_3, Q = Cyclone constants which are representative of the classification operation.

Y = Fraction of the feed at a particular micron size which appears in the coarse product (underflow) due to classification.

X = Ratio of the mid-point of a size range (microns) to the d_{50} (corrected point).

The cyclone constants, K_1, K_2, K_3 , and Q , can be calculated as a result of determining the performance of the cyclone under one condition of operation.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

This section describes the materials, equipment, and procedure used in this investigation.

Materials Used

Ground high-grade quartz (Colorado Milky Quartz) supplied by Rocky Mountain Aggregates, Golden, Colorado, was selected for the classification tests because of its relative homogeneity in quality and ready availability. This material was previously dry-screened on a vibrating screen in order to remove the plus 48-mesh fraction; the minus 48-mesh product was used in the classification tests.

Equipment

The equipment set-up for the classification experiments is schematically illustrated in Figure 5. The sump tank of 125-liter capacity was used for the preparation of the feed slurry (water and quartz). A 2-HP centrifugal-type pump was used to pump the feed slurry into the cyclone. A pinch valve in the pipe between the sump tank and pump was used to regulate the throughput to the cyclone. The operating feed pressure was measured at the inlet to the cyclone feed nozzle by a pressure gauge. A high-speed mixer was placed

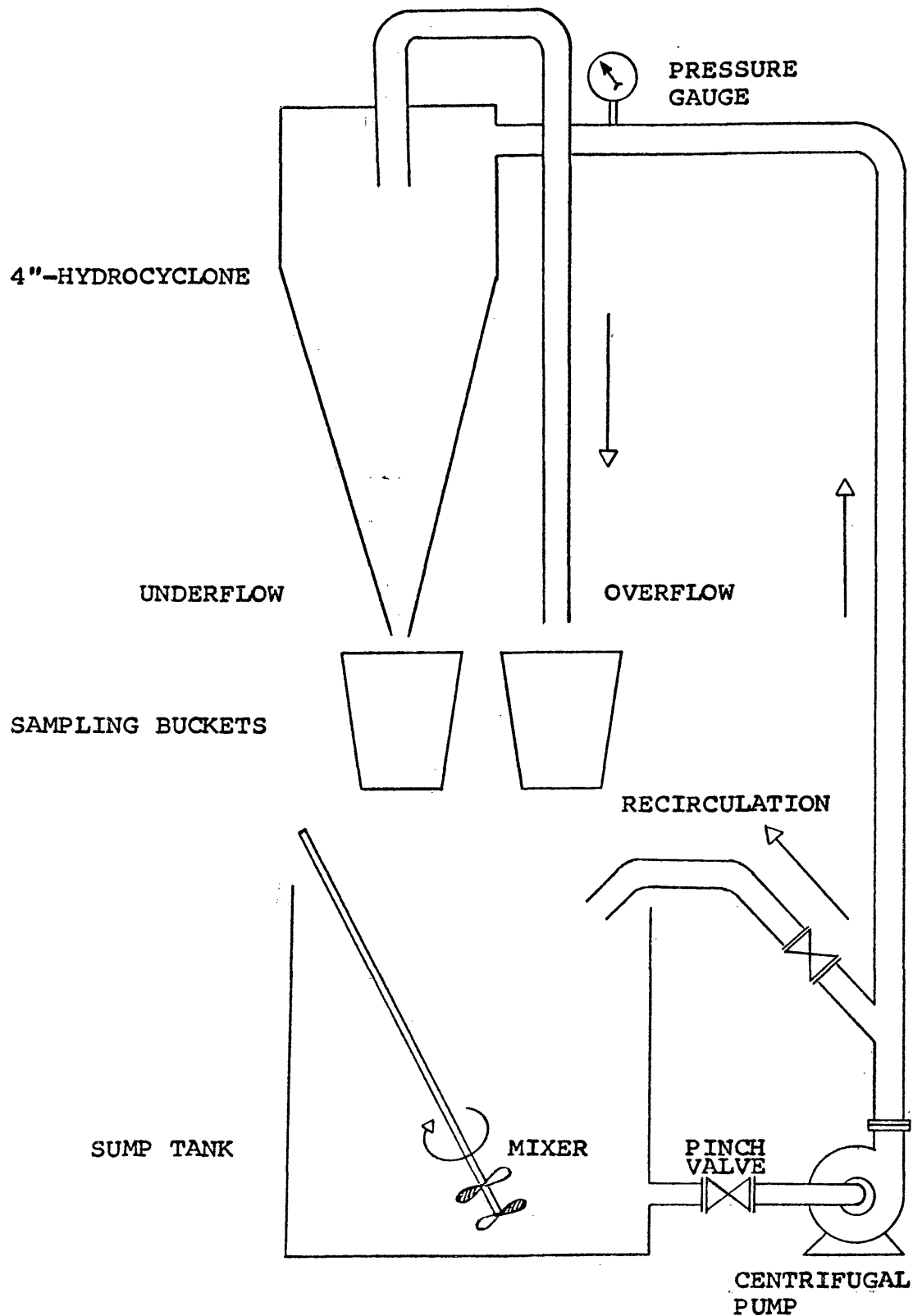


Figure 5: Schematic Diagram of the Classification Equipment.

in the sump tank in order to maintain a consistent slurry concentration. For each classification test, rate samples were taken from the overflow and underflow products in tared buckets for timed intervals. In addition, small samples of the overflow and underflow streams were taken for size analysis. The classifying unit was one D4B Krebs Cyclone manufactured by Equipment Engineers Inc., San Francisco, California, of 4 inches in diameter in the cylindrical section and 11° included angle in the conical section. The height of the cylindrical section was $8\frac{1}{4}$ inches, and the height of the conical section was 10-0 inches. The cyclone feed nozzle was a standard 2-in pipe with a reduction to a $\frac{3}{4}$ -in. square section at the entrance to the cyclone. The overflow nozzle (vortex finder) and the underflow nozzle (spigot) of the cyclone could be varied by using interchangeable vortex finders and spigots of various diameters.

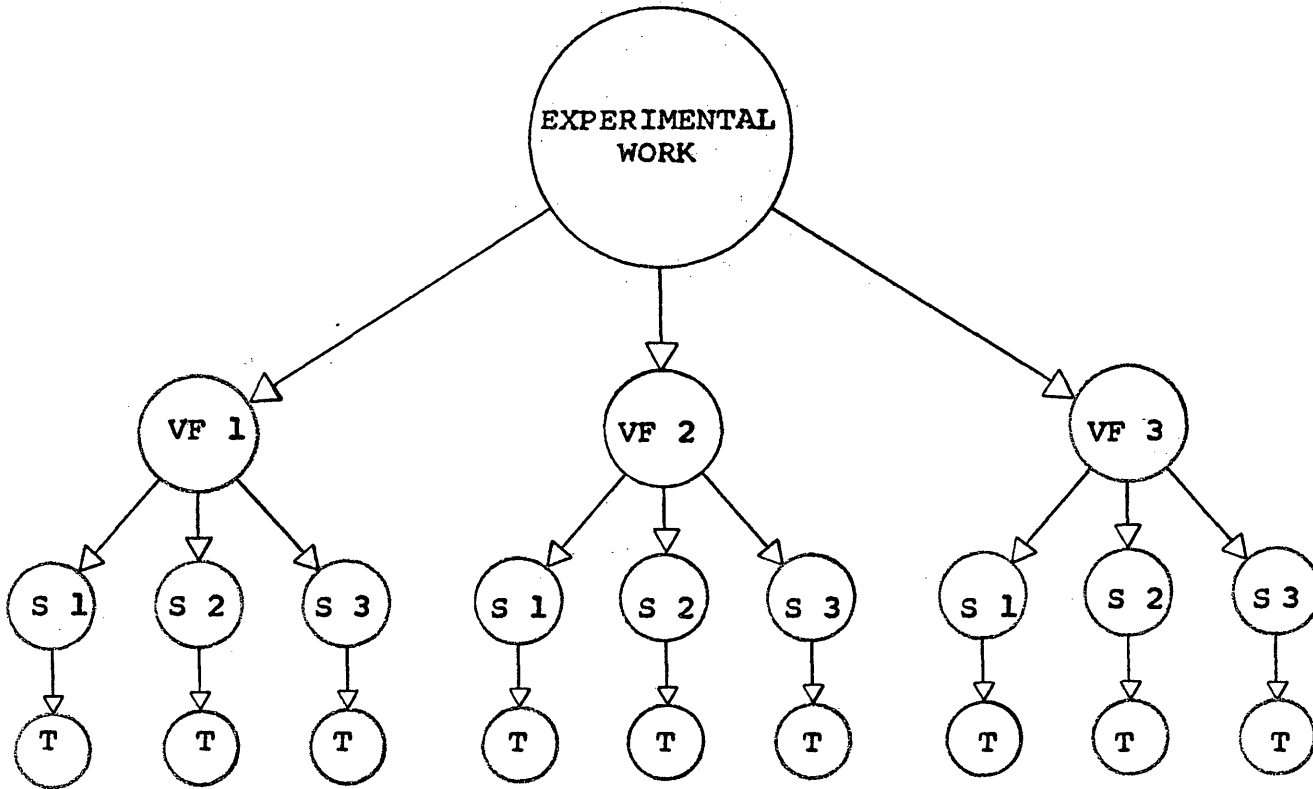
Procedure

The organization of the experimental work is schematically represented in Figure 6, which is self explanatory.

This investigation was conducted in three successive phases: 1) classification experiments, 2) analysis of samples, and 3) data acquisition.

Classification Experiments

The experimental procedure of the classification tests, conducted at room temperature, was as follows:



NOMENCLATURE

VORTEX FINDER DIAM. (in.)

VF 1	1.438
VF 2	0.970
VF 3	0.719

SPIGOT DIAM. (in.)

S 1	0.440
S 2	0.560
S 3	0.850

T Set of tests run at various operating conditions of pulp density, pressure, and feed flow rate

Figure 6: Outline of the organization of experimental work.

1. The vortex finder diameter and the spigot diameter were fixed prior to each set of experiments.
2. The feed slurry (water and quartz) was prepared in the sump tank at the desired pulp density.
3. The feed slurry was agitated and recirculated during the feed preparation.
4. After feed preparation the feed pulp was pumped into the cyclone.
5. The operating feed pressure (and therefore feed flow rate) was regulated by the pinch valve before sampling for each test.
6. Samples of the overflow and underflow streams were simultaneously taken in tared buckets for timed intervals.
7. The weight of both the overflow and underflow samples was then recorded.

Analysis of Samples

Size analyses were performed on all the classification samples. The following procedure was used for obtaining the size analysis of the solids contained on both overflow and underflow samples.

1. After recording the weights of the overflow and underflow samples, these samples were then filtered (in a Denver Pressure Filter) and dried under infra-red lamps.
2. Each dry sample was then weighed.
3. Each sample was placed in a nest of Standard Tyler Sieves (mesh 48, 65, 100, 150, 200, and 270). In most of the

cases it was necessary to split the sample by using a Denver Sample Splitter (Jones Type).

4. The sieves containing the sample were shaken for 30 minutes in a Ro-Tap sieve shaker.
5. The solids retained on each sieve were weighed and recorded.

Data Acquisition

A digital computer program was devised to calculate and tabulate all necessary results from the test. A listing of the program is shown in Appendix A.

The important input data were:

1. Weight in kilograms of the overflow and underflow samples.
2. Time of sampling in seconds.
3. Weight in kilograms of the dry solids contained in the overflow and underflow samples.
4. Size analysis by weight (grams) of the representative samples of the solids contained in each cyclone product.
5. Sieve size in mesh and in microns corresponding to the size analysis.

All data were processed by a C.D.C. 8090 digital computer. The results of computations were printed by a C.D.C. 501 printer.

The important output data from this computer program were:

1. Screen size analysis in percentage and in tons per hour

- of solids in the feed, overflow, and underflow products.
2. Total flow rate in tons per hour of solids in the feed, overflow, and underflow products.
 3. Pulp flow rate in tons per hour of feed, overflow, and underflow.
 4. Pulp flow rate in Imp. Gallons per minute of feed.
 5. Water flow rate in tons per hour in the feed, overflow, and underflow streams.
 6. Pulp density in solid percent of feed, overflow, and underflow.
 7. Distribution of water from feed in the two cyclone products, overflow and underflow, in percentage.
 8. Particle size distribution in tons per hour of feed solids, overflow solids, and underflow solids.
 9. Particle size distribution in tons per hour of solids present in the underflow due to classification and by bypassing.
 10. Particle size distribution in percent of classified solids in the feed reported in the underflow.
 11. Particle size of solids reported 50 percent to the overflow and 50 percent to the underflow by classification (referred to as the corrected d_{50} value) in microns.
 12. The mid-point (geometric mean) of a size range in microns.
 13. The ratio of the mid-point of a size range (microns) to the d_{50} (corrected) value (referred to X).

EXPERIMENTAL RESULTS

The sizing analyses of the solid material (high-grade quartz) in the cyclone feed, which was used in all the classification tests, was reasonably constant from test to test; in no case was the variation larger than 10 percent (absolute) by weight for any single size fraction between 65- and -270-mesh. This variation in size distribution of the feed was primarily due to the supplier and to the large quantities of quartz required for each set of tests.

The average size distribution of the feed used in the classification experiments is represented in Table 1.

Table 1: Average size distribution of the classification feed.

mesh	Aperture Size microns	Weight Percent retained
+ 48	350.0	0.5 - 3.0
48/ 65	247.7	9.3
65/100	174.9	23.1
100/150	123.6	16.3
150/200	87.7	14.2
200/270	62.0	12.2
-270	26.0	23.1

The conditions for all the classification tests included are summarized in Table 2. In the remainder of the text, specific classification tests are referred to by their number as given in Table 2.

The experimental results of this investigation will be presented in the following two sections: 1) the operational characteristics of the cyclone, and 2) the solids separation characteristics of the cyclone.

The Operational Characteristics of the Cyclone

The experimental results of this section are classified into two categories: 1) the capacity of the cyclone, and 2) the distribution of water in the cyclone.

The Capacity of the Cyclone

The experimental results of capacity of the cyclone, which is referred to as gal/min of cyclone feed pulp, are summarized in Appendix B (Table 1-B). The classification test conditions at which the capacity of the cyclone was determined, are summarized in Table 2.

In order to investigate the capacity of the cyclone, the cyclone feed flow rates were plotted against their respective feed pressures on a log-log scale. The experimentally observed cyclone capacity curves are represented in Figures 7, 8, and 9, for vortex finder diameters of 1.438 in, 0.970 in, and 0.719 in respectively.

As shown in Figures 7, 8, and 9, an increase in the

Table 2: Summary of classification test conditions.

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed Solids percent
1	1.438	0.440	3.5	27.47
2	1.438	0.440	3.0	28.39
3	1.438	0.440	3.0	20.77
4	1.438	0.440	6.5	11.99
5	1.438	0.440	7.0	11.22
6	1.438	0.440	4.0	8.98
7	1.438	0.440	6.0	34.22
8	1.438	0.440	5.0	34.07
9	1.438	0.440	3.5	25.52
10	1.438	0.440	4.0	27.39
11	1.438	0.440	3.5	28.06
12	1.438	0.440	3.0	25.76
13	1.438	0.440	4.0	22.10
14	1.438	0.440	3.0	5.81
15	1.438	0.440	3.5	15.43
16	1.438	0.440	7.5	34.62
17	1.438	0.440	6.0	33.64
18	1.438	0.440	5.0	33.75
19	1.438	0.440	3.5	33.47
20	1.438	0.440	3.0	29.98

Table 2 continued:

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed Solids percent
21	1.438	0.440	4.0	28.60
22	1.438	0.440	7.0	28.31
23	1.438	0.440	10.5	27.26
24	1.438	0.440	5.0	31.39
25	1.438	0.560	6.5	28.37
26	1.438	0.560	6.0	26.05
27	1.438	0.560	8.5	28.13
28	1.438	0.560	9.0	26.01
29	1.438	0.560	6.0	27.07
30	1.438	0.560	5.0	26.16
31	1.438	0.560	4.0	26.21
32	1.438	0.560	3.0	26.77
33	1.438	0.560	2.0	26.45
34	1.438	0.560	6.5	22.54
35	1.438	0.560	5.0	23.45
36	1.438	0.560	4.5	23.17
37	1.438	0.560	5.0	37.97
38	1.438	0.560	4.5	37.88
39	1.438	0.560	3.0	37.62
40	1.438	0.560	10.0	20.59
41	1.438	0.560	6.0	20.82

Table 2 continued:

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed solids percent
42	1.438	0.560	5.0	19.24
43	1.438	0.560	3.0	20.13
44	1.438	0.560	2.5	19.53
45	1.438	0.560	7.5	32.48
46	1.438	0.560	6.0	32.01
47	1.438	0.560	4.5	30.14
48	1.438	0.560	3.0	30.85
49	1.438	0.560	2.5	31.80
50	1.438	0.560	8.0	24.10
51	1.438	0.560	7.0	21.93
52	1.438	0.560	5.5	23.12
53	1.438	0.560	5.0	24.71
54	1.438	0.850	10.0	30.35
55	1.438	0.850	10.0	30.15
56	1.438	0.850	7.0	28.98
57	1.438	0.850	7.5	28.40
58	1.438	0.850	5.5	27.75
59	1.438	0.850	3.5	24.77
60	1.438	0.850	2.5	25.65
61	1.438	0.850	2.5	26.66
62	1.438	0.850	9.0	23.94

Table 2 continued:

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed solids percent
63	1.438	0.850	5.0	33.33
64	1.438	0.850	7.5	32.23
65	1.438	0.850	9.5	28.70
66	1.438	0.850	14.0	33.72
67	1.438	0.850	14.5	25.35
68	1.438	0.850	14.0	25.69
69	1.438	0.850	9.0	23.55
70	1.438	0.850	7.0	20.78
71	0.970	0.440	6.5	40.50
72	0.970	0.440	4.0	38.40
73	0.970	0.440	5.0	36.38
74	0.970	0.440	4.5	35.35
75	0.970	0.440	12.0	25.20
76	0.970	0.440	8.5	22.99
77	0.970	0.440	2.0	19.56
78	0.970	0.440	2.0	18.21
79	0.970	0.560	2.5	29.93
80	0.970	0.560	2.5	30.78
81	0.970	0.560	2.5	28.01
82	0.970	0.560	5.5	27.16
83	0.970	0.560	5.5	23.40

Table 2 continued:

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed solids percent
84	0.970	0.560	6.0	20.08
85	0.970	0.560	13.5	29.64
86	0.970	0.560	8.0	26.37
87	0.970	0.560	7.0	25.02
88	0.970	0.560	6.0	24.36
89	0.970	0.560	7.0	27.19
90	0.970	0.560	4.0	22.96
91	0.970	0.560	6.0	25.00
92	0.970	0.560	3.5	23.29
93	0.970	0.560	7.5	24.46
94	0.970	0.560	8.0	30.20
95	0.970	0.560	5.0	28.84
96	0.970	0.560	3.0	23.62
97	0.970	0.560	2.0	25.62
98	0.970	0.560	1.5	25.15
99	0.970	0.560	6.0	24.59
100	0.970	0.560	8.5	21.93
101	0.970	0.560	7.0	23.35
102	0.970	0.560	3.0	14.97
103	0.970	0.560	1.5	15.32
104	0.970	0.850	7.5	30.27

Table 2 continued:

Test no.	Vortex finder diameter in.	Spigot diameter in.	Feed pressure p.s.i.g.	Feed solids percent
105	0.970	0.850	3.0	28.27
106	0.970	0.850	2.0	26.05
107	0.970	0.850	12.5	30.70
108	0.970	0.850	4.0	26.61
109	0.970	0.850	11.0	32.61
110	0.970	0.850	5.5	33.26
111	0.970	0.850	2.5	31.56
112	0.970	0.850	2.5	31.57
113	0.970	0.850	3.0	29.96
114	0.719	0.440	12.0	30.53
115	0.719	0.440	10.0	30.99
116	0.719	0.440	8.0	29.49
117	0.719	0.440	7.5	26.85
118	0.719	0.440	6.0	26.65
119	0.719	0.440	4.5	25.43
120	0.719	0.440	2.0	22.52
121	0.719	0.440	4.0	32.93
122	0.719	0.440	10.0	30.37
123	0.719	0.440	10.5	29.24
124	0.719	0.440	10.0	27.15
125	0.719	0.440	9.5	30.35

Table 2 continued:

Test	Vortex finder	Spigot	Feed	Feed solids
	diameter	diameter	pressure	
no.	in.	in.	p.s.i.g.	percent
126	0.719	0.440	5.0	34.57
127	0.719	0.440	6.5	32.84
128	0.719	0.440	7.5	27.39
129	0.719	0.440	5.0	30.31
130	0.719	0.440	10.0	23.83
131	0.719	0.560	8.5	29.91
132	0.719	0.560	6.5	28.08
133	0.719	0.560	3.5	25.95
134	0.719	0.560	2.5	23.88
135	0.719	0.560	1.5	22.37
136	0.719	0.560	10.0	24.47
137	0.719	0.560	9.0	26.59
138	0.719	0.560	7.0	25.04
139	0.719	0.560	7.0	25.75
140	0.719	0.560	6.5	25.60
141	0.719	0.560	6.5	24.34
142	0.719	0.560	9.5	28.23
143	0.719	0.560	6.0	24.44
144	0.719	0.560	4.5	24.56
145	0.719	0.560	4.5	24.29

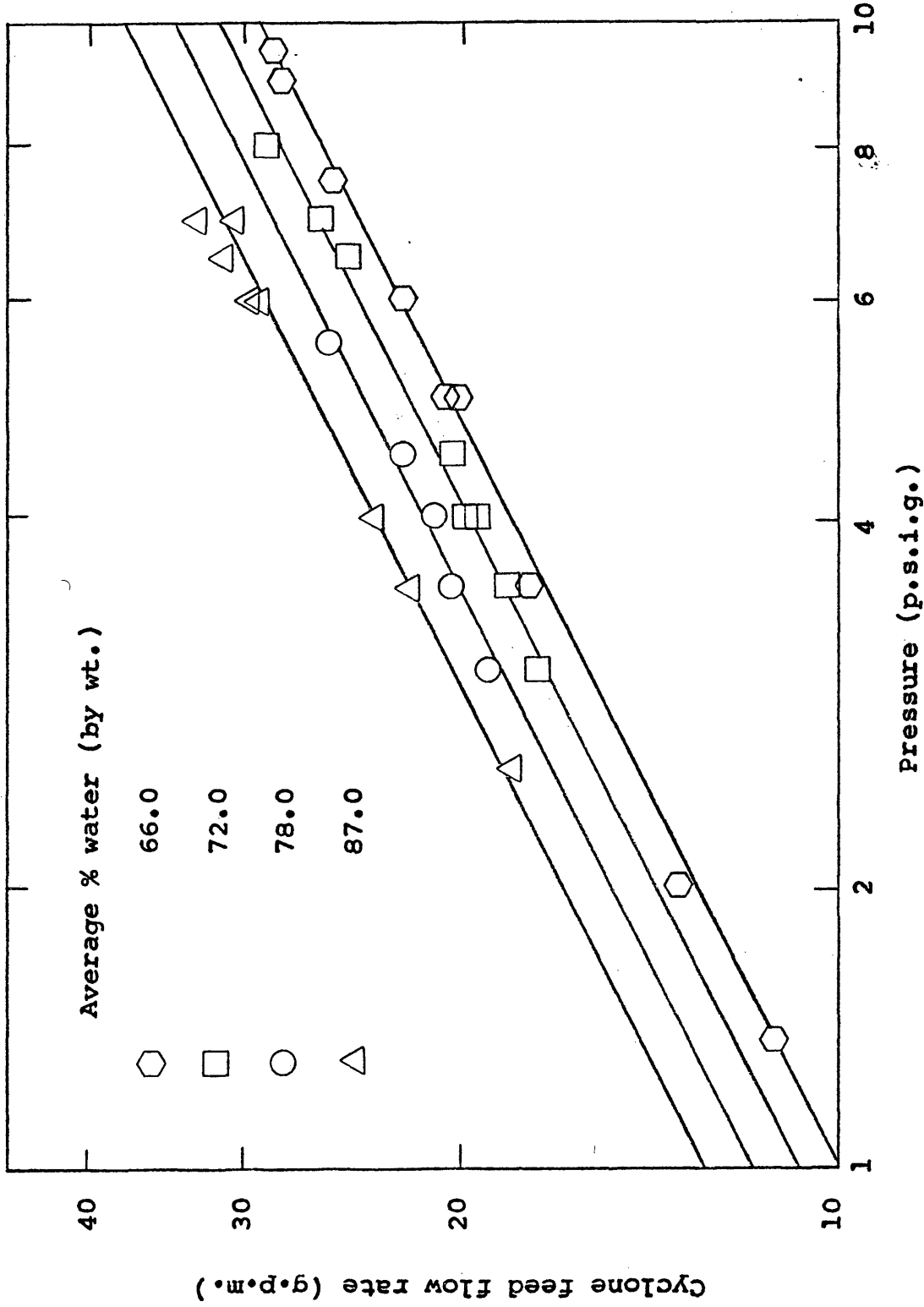


Figure 7: Cyclone feed flow rate as a function of feed pressure — the effect of change in the water content of the feed. Vortex finder diam. = 1.438 in.

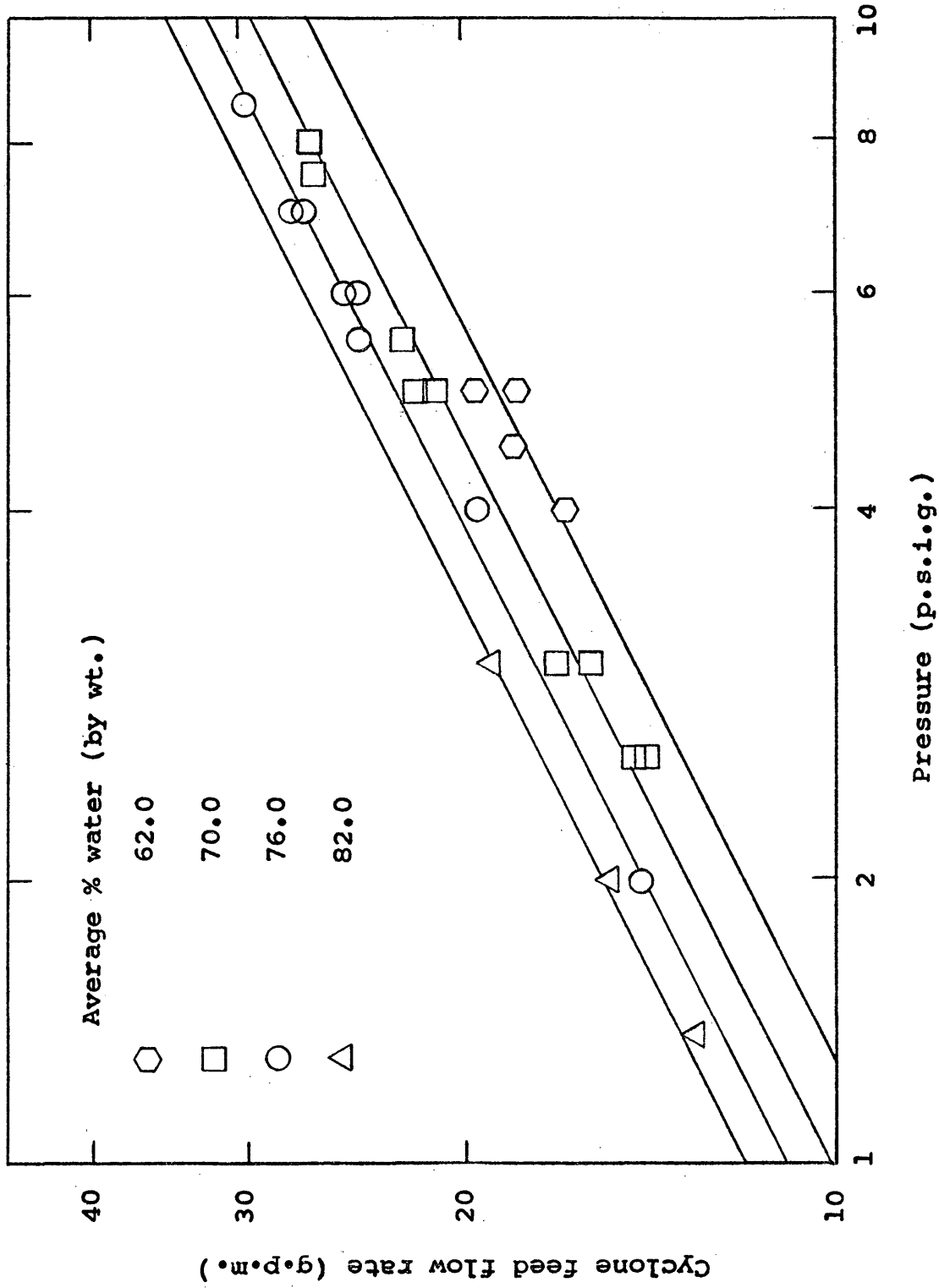


Figure 8: Cyclone feed flow rate as a function of feed pressure — the effect of change in the water content of the feed. Vortex finder diam. = 0.970 in.

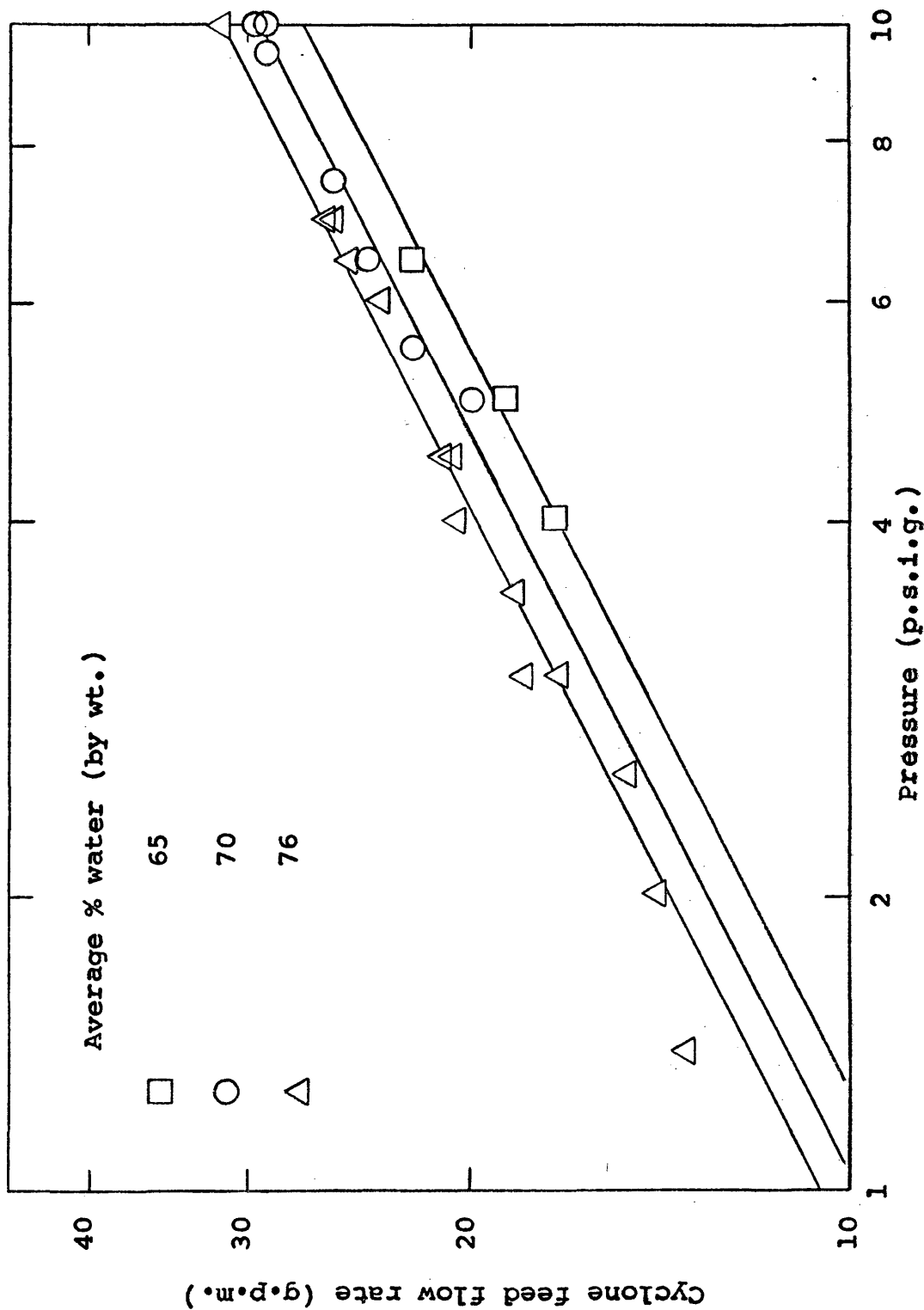


Figure 9: Cyclone feed flow rate as a function of feed pressure -- the effect of change in the water content of the feed. Vortex finder diam. = 0.719 in.

operating feed pressure and the water content in the feed resulted in an increase of the capacity of the cyclone. Also, it is clear that for a given feed pressure and water content in the feed, a decrease in the diameter of the vortex finder resulted in a decrease of the capacity of the cyclone.

The Distribution of Water in the Cyclone

The water entering the cyclone in the feed pulp is distributed between the vortex finder and spigot discharge outlets. The observations on the nature of the water distribution in cyclones made by Peachey⁽⁸⁾ were confirmed in this work. The mass flow rates of water in the feed and overflow streams for each classification test are reported in Appendix B (Table 1-B).

In order to illustrate the water distribution in the cyclone, the water flow rate in the feed is plotted against the water flow rate in the overflow stream, which is shown in Figure 10 for any condition of cyclone operation. The mass fraction of water in the feed which emerges through the spigot may readily be calculated from this figure.

From Figure 10 the tonnage of water reporting to the overflow is a linear function of the tonnage of water in the feed. Also, it is clear that the distribution of water into the overflow is dependent on the diameter of the spigot. For a given water flow rate in the feed, a decrease in the

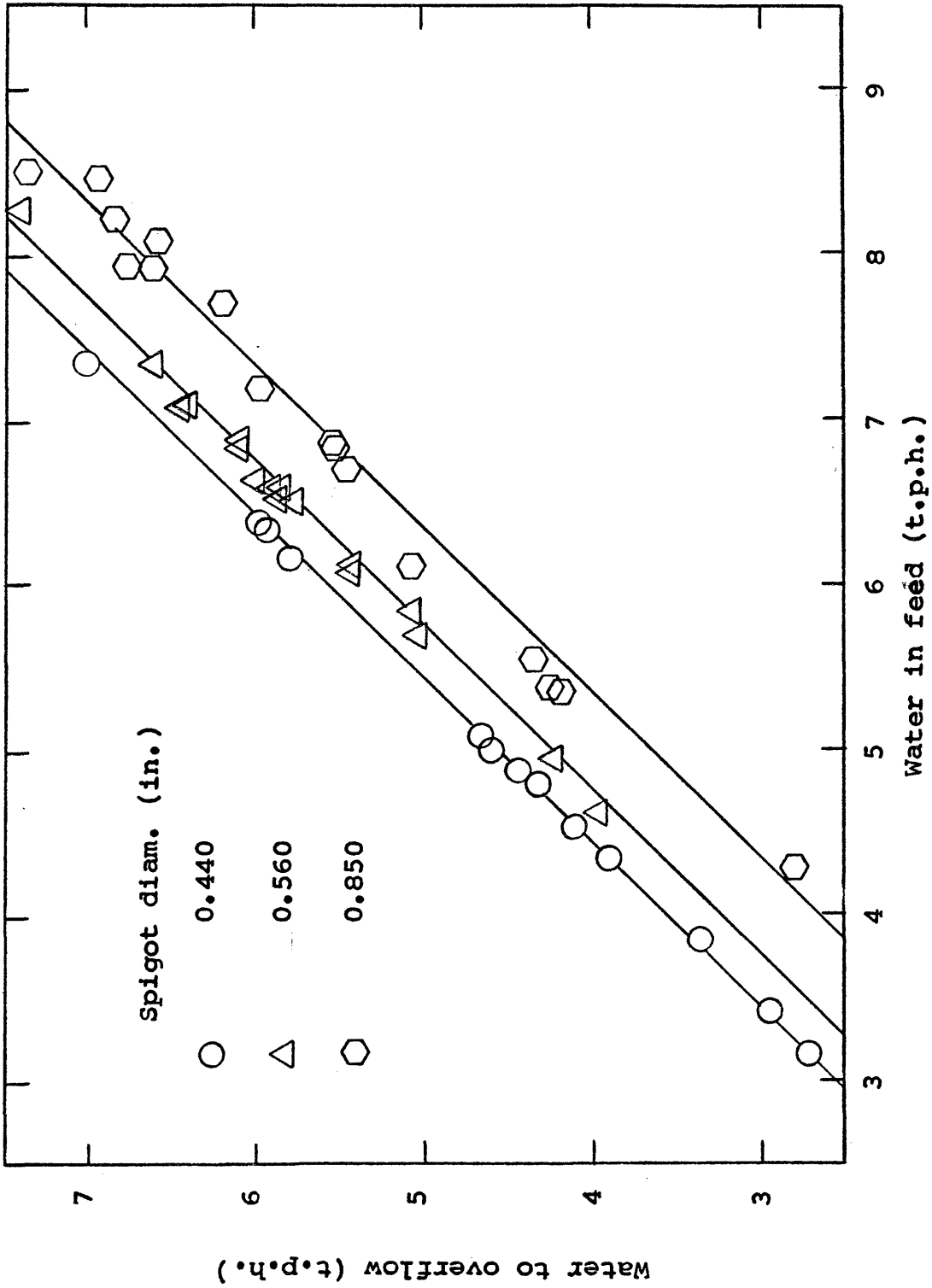


Figure 10: The distribution of water in the cyclone. The effect of spigot diameter.

spigot diameter resulted in an increase in the water flow rate in the overflow.

The Solids Separations Characteristics of the Cyclone

The experimental results of this section are classified into two categories: 1) the assessment of the classification operation, and 2) the effect of variables on the corrected d_{50} value.

The Assessment of the Classification Operation

As a result of a classification test on the cyclone the sizing distribution and mass flow rates of overflow and underflow were known. The size particle distribution of solids in both the overflow and underflow are represented in Appendix B (Table 2-B). The cyclone feed and overflow mass flow rates are shown in Appendix B (Table 1-B). From these data, the sizing distribution and mass flow rate of each size fraction in the feed may readily be reconstructed.

In Appendix B (Table 1-B) the mass fraction of water in the feed which reported to the underflow stream is given for each classification test.

From the above statements the representative proportion of the feed particles which are carried into the underflow by the water is calculated. If this mass of particles is subtracted from the feed and the underflow, the corrected efficiency curve is calculated from the remaining masses and size distribution for each classification test. The cor-

rected efficiency curve represents the classification which has occurred due to centrifugal action during the cyclone operation.

The aperture size in microns at which half of the particles, which are actually classified, appear in the overflow is referred to as the corrected d_{50} value and is derived from the corrected efficiency curve. The corrected d_{50} value is the important single parameter in the quantitative description of cyclone performance.

The corrected efficiency curve is not useful for design purposes because it is specific to one condition of cyclone operation. The corrected efficiency curves, which result from plotting the percentage of feed to the underflow due to classification (arithmetic scale) against the actual size of particles (logarithmic scale), can be transformed into one general curve by replacing the actual size scale (on the abscissa) by the value:

$$\frac{\text{actual size}}{\text{corrected } d_{50} \text{ value}}$$

and then replotting the curve. This curve is known as the reduced efficiency curve and it is a characteristic of the ore in the cyclone for any condition of operation.

To include in this thesis all the graphs representing the actual performance curve and the corrected efficiency curve for all classification tests would make the text unnecessarily long, and to include all the corrected efficiency

curves in one graph would make it incomprehensible. For the benefit of the reader, however, five actual tests: no. 17, 20, 29, 78, and 143, have been chosen and their results are fully represented in Tables 3 through 7, respectively and graphically in Figures 11 and 12. The reduced efficiency curve for the five tests above is shown in Figure 13. Figures 14 through 21 show the reduced efficiency curves for most of the classification tests.

By inspection of results, graphically represented in Figures 13 through 21, the following comments may be made about classification in cyclones:

1. A cyclone does not make a sharp split at some single micron size and, therefore, to discuss the efficiency of cyclones in terms of one size only seems to be unrealistic.
2. The process taking place within a cyclone is a selection process in which a decreasing proportion of particles of decreasing size in the feed report to the underflow.
3. The corrected d_{50} value is a selection function for any ore, which defines the mass of ore of any given feed size which appears in the underflow as a result of classification, and this may be determined from the known throughput and reduced efficiency curve, and the distribution of water in the cyclone.

Table 3: Experimental classification results of actual test no. 17

Mass fraction of water to underflow = 0.1001										
Aperture size	Cyclone feed	Cyclone U/F	Cyclone feed bypassing to U/F with water	Percent of feed to U/F by classification						
mesh	microns	T.P.H. A	T.P.H. B	T.P.H. C = 0.1001	T.P.H. A	T.P.H. A - C	T.P.H. B - C	T.P.H. A	T.P.H. A - C	T.P.H. B - C
+ 48	350.0	.060	.043	.006	.054	.037				68.95
48/ 65	247.7	.275	.157	.028	.248	.129				52.20
65/100	174.9	.762	.337	.076	.686	.261				38.07
100/150	123.6	.600	.175	.060	.540	.115				21.37
150/200	87.7	.412	.118	.041	.371	.077				20.64
200/270	62.0	.238	.048	.024	.214	.024				11.10
-270	26.0	.629	.084	.063	.566	.021				3.75

d₅₀ (corrected) = 236.4 microns

Table 4: Experimental classification results of actual test no. 20

Mass fraction of water to underflow = 0.0990										
Aperture size	Cyclone feed	Cyclone U/F	Cyclone feed bypassing to U/F with water	Cyclone feed bypassing to U/F with water			Percent of feed to U/F by classification			
mesh	microns	T.P.H.	T.P.H.	T.P.H.	T.P.H.	T.P.H.	A	B	C = 0.0990 . A	
		A	B	C	A	B	A	B	C	
+ 48	350.0	.037	.035	.004	.033	.032	.033	.032	.032	95.31
48/ 65	247.7	.177	.121	.018	.159	.104	.159	.104	.104	65.02
65/100	114.9	.503	.291	.050	.453	.241	.453	.241	.241	53.29
100/150	123.6	.374	.178	.037	.337	.141	.337	.141	.141	41.87
150/200	87.7	.282	.078	.028	.254	.050	.254	.050	.050	19.85
200/270	62.0	.159	.034	.016	.143	.018	.143	.018	.018	12.56
-270	26.0	.378	.060	.037	.340	.023	.340	.023	.023	6.70

d₅₀ (corrected) = 160.1 microns

Table 5: Experimental classification results of actual test no. 29

Mass fraction of water to underflow = 0.1203									
Aperture size	Cyclone feed	Cyclone U/F	Cyclone feed bypassing to U/F with water	Cyclone feed bypassing to U/F by classification					
mesh	microns	T.P.H. A	T.P.H. B	T.P.H. C = 0.1203 . A	T.P.H. A - C	T.P.H. B - C	Percent of feed to U/F by classification		
+ 48	350.0	.016	.016	.002	.014	.014	100.00		
48/ 65	247.7	.185	.155	.022	.163	.133	81.48		
65/100	174.9	.615	.456	.074	.541	.382	70.60		
100/150	123.6	.490	.291	.059	.431	.232	53.76		
150/200	87.7	.434	.197	.052	.382	.144	37.84		
200/270	62.0	.224	.077	.027	.197	.050	25.37		
-270	26.0	.493	.103	.059	.434	.044	10.04		

d_{50} (corrected) = 115.2 microns

Table 6: Experimental classification results of actual test no. 78

Mass fraction of water to underflow = 0.0890									
Aperture size	Cyclone feed	Cyclone U/F	Cyclone feed bypassing to U/F with water	Cyclone feed bypassing to U/F with water			Percent of feed to U/F by classification		
mesh	microns	T.P.H.	T.P.H.	T.P.H.	T.P.H.	T.P.H.	A	B	C
							C = 0.0890 . A		
							A - C	B - C	
+ 48	350.0	.030	.030	.003	.027	.027	.027	.027	100.00
48/ 65	247.7	.113	.110	.010	.103	.100	.103	.100	97.66
65/100	174.9	.205	.193	.018	.186	.175	.186	.175	93.86
100/150	123.6	.164	.140	.015	.149	.126	.149	.126	84.45
150/200	87.7	.139	.090	.012	.127	.078	.127	.078	61.31
200/270	62.0	.096	.034	.009	.088	.025	.088	.025	28.86
-270	26.0	.179	.046	.016	.163	.030	.163	.030	18.17

d₅₀ (corrected) = 78.8 microns

Table 7: Experimental classification results of actual test no. 143

Mass fraction of water to underflow = 0.1427											
Aperture size	mesh	Cyclone feed		Cyclone U/F		Cyclone feed bypassing to U/F with water		T.P.H.		Percent of feed to U/F by classification	
		T.P.H.	A	T.P.H.	B	T.P.H.	C = 0.1427	A	A - C		B - C
+ 48		350.0	.000	.000	.000	.000	.000	.000	.000	.000	100.00
48/ 65		247.7	.162	.160	.160	.023	.023	.139	.137	.137	98.75
65/100		174.9	.496	.490	.490	.071	.071	.425	.420	.420	98.64
100/150		123.6	.362	.339	.339	.052	.052	.310	.287	.287	92.47
150/200		87.7	.315	.250	.250	.045	.045	.270	.205	.205	75.86
200/270		62.0	.222	.133	.133	.032	.032	.190	.102	.102	53.45
-270		26.0	.487	.171	.171	.069	.069	.417	.101	.101	24.31

d_{50} (corrected) = 57.8 microns

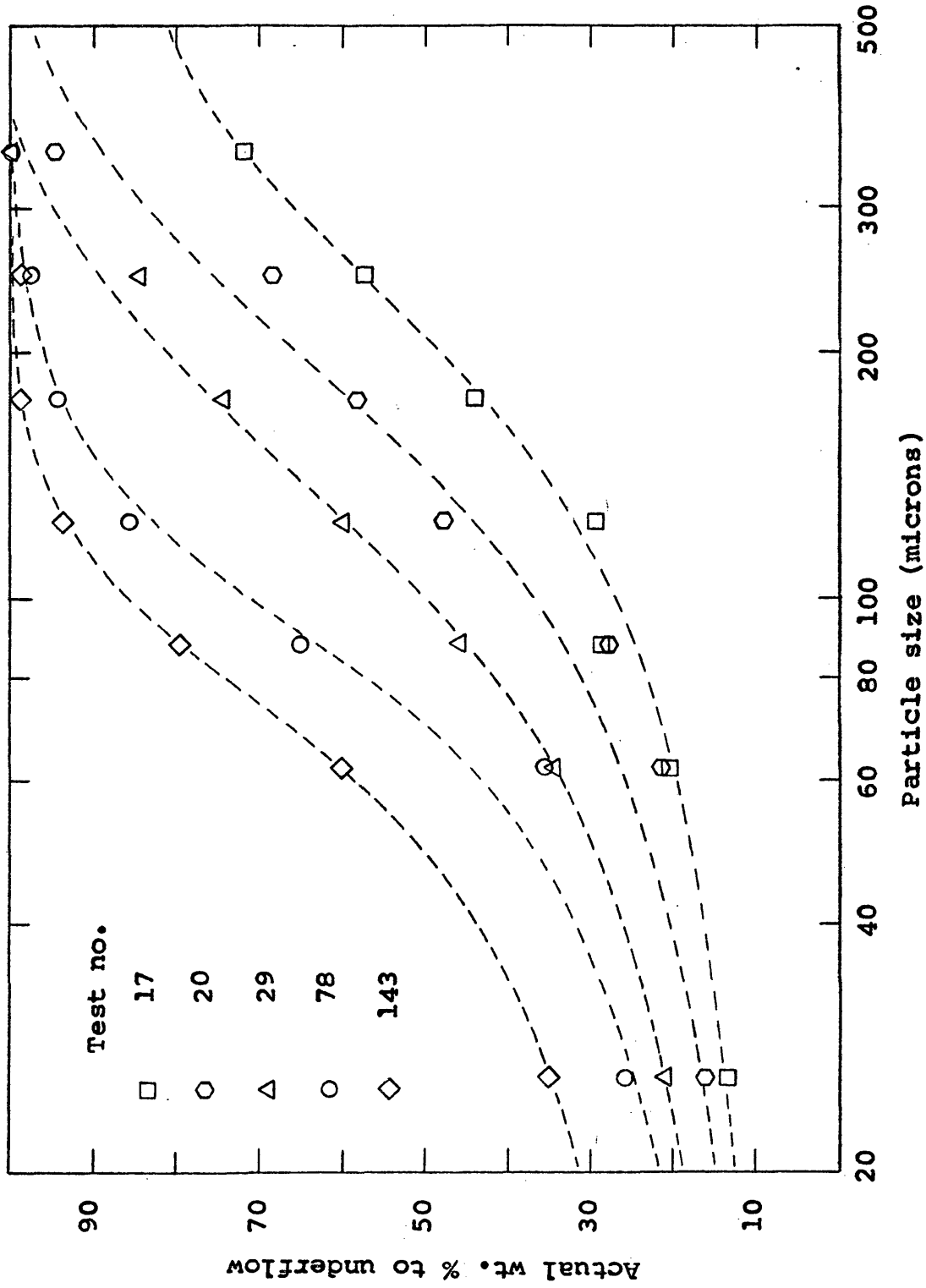


Figure 11: The actual performance curves. Tests 17, 20, 29, 78, 143.

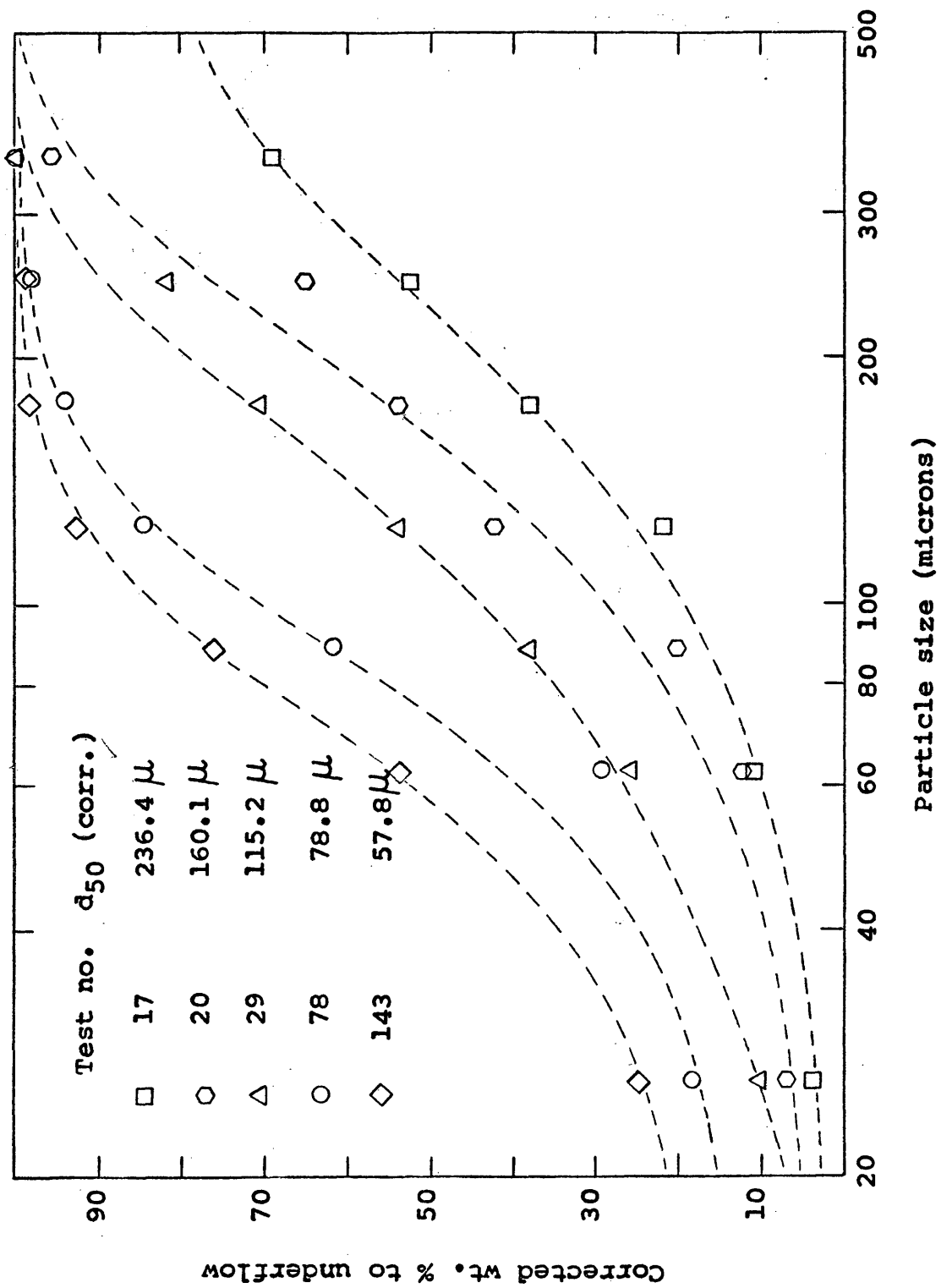


Figure 12: The corrected efficiency curves. Tests 17, 20, 29, 78, 143.

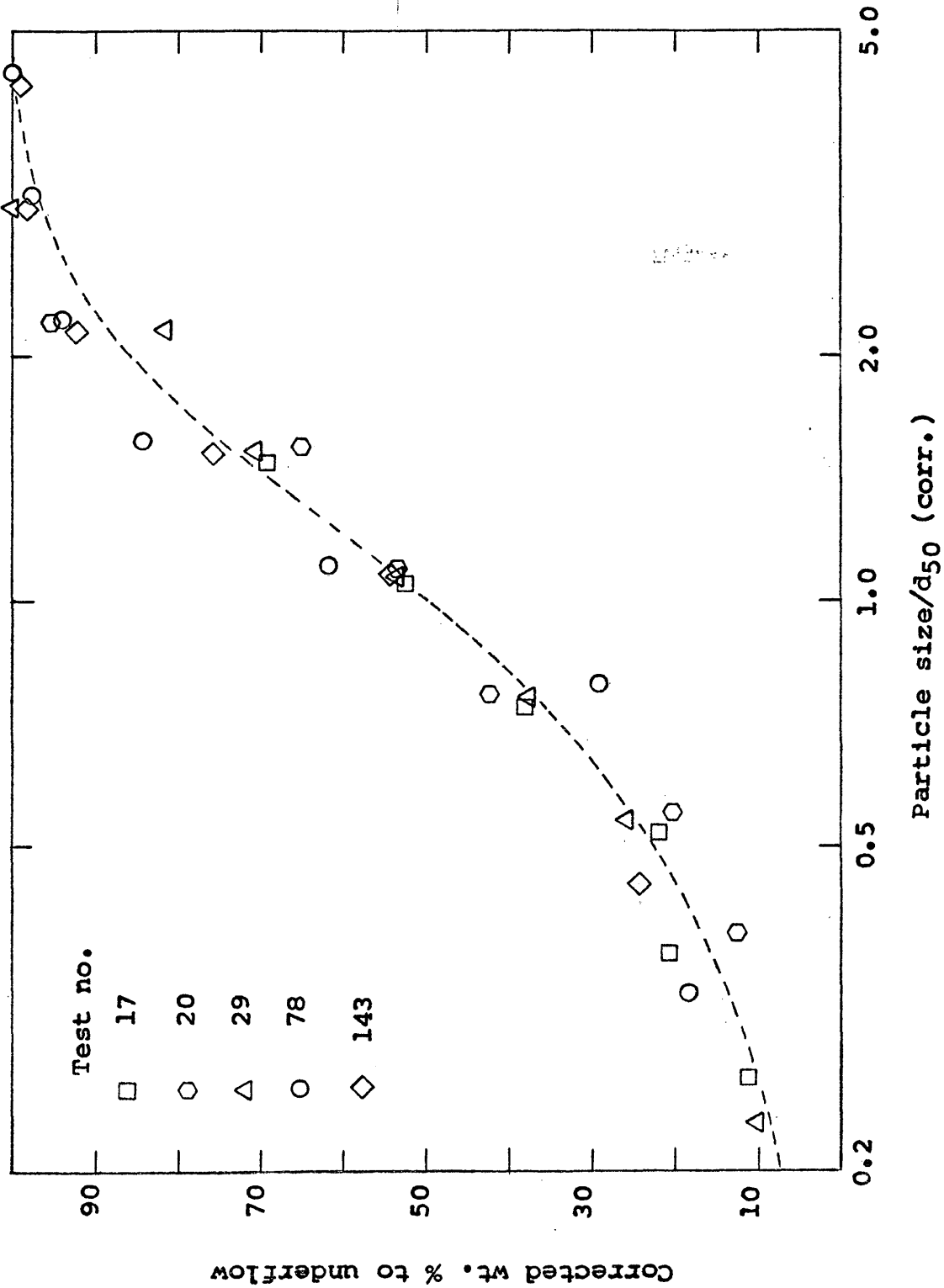


Figure 13: The reduced efficiency curve. Tests 17, 20, 29, 78, 143.

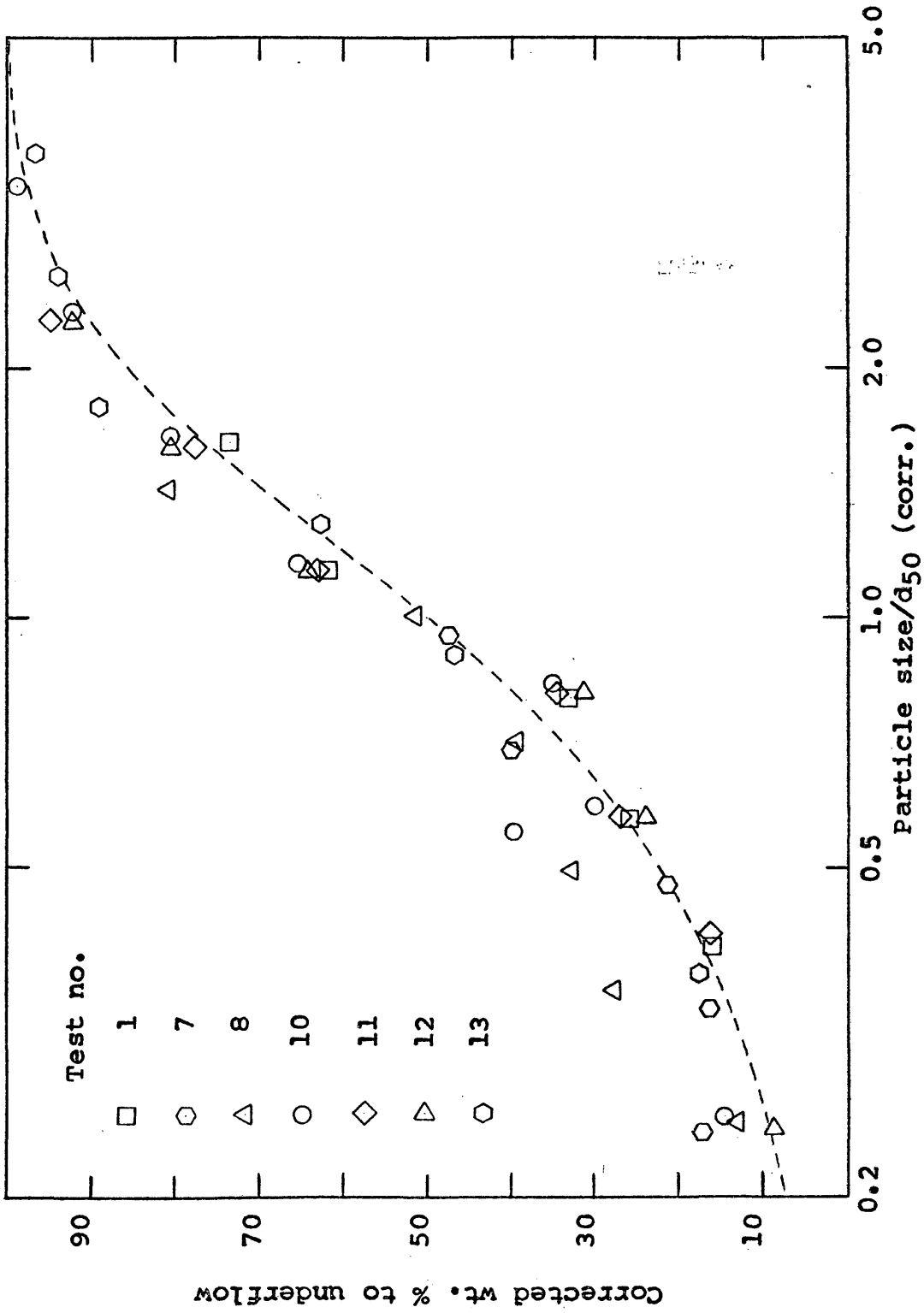


Figure 14: The reduced efficiency curve. Tests 1, 7, 8, 10, 11, 12, 13. Vortex finder diameter = 1.438 in. Spigot diameter = 0.440 in.

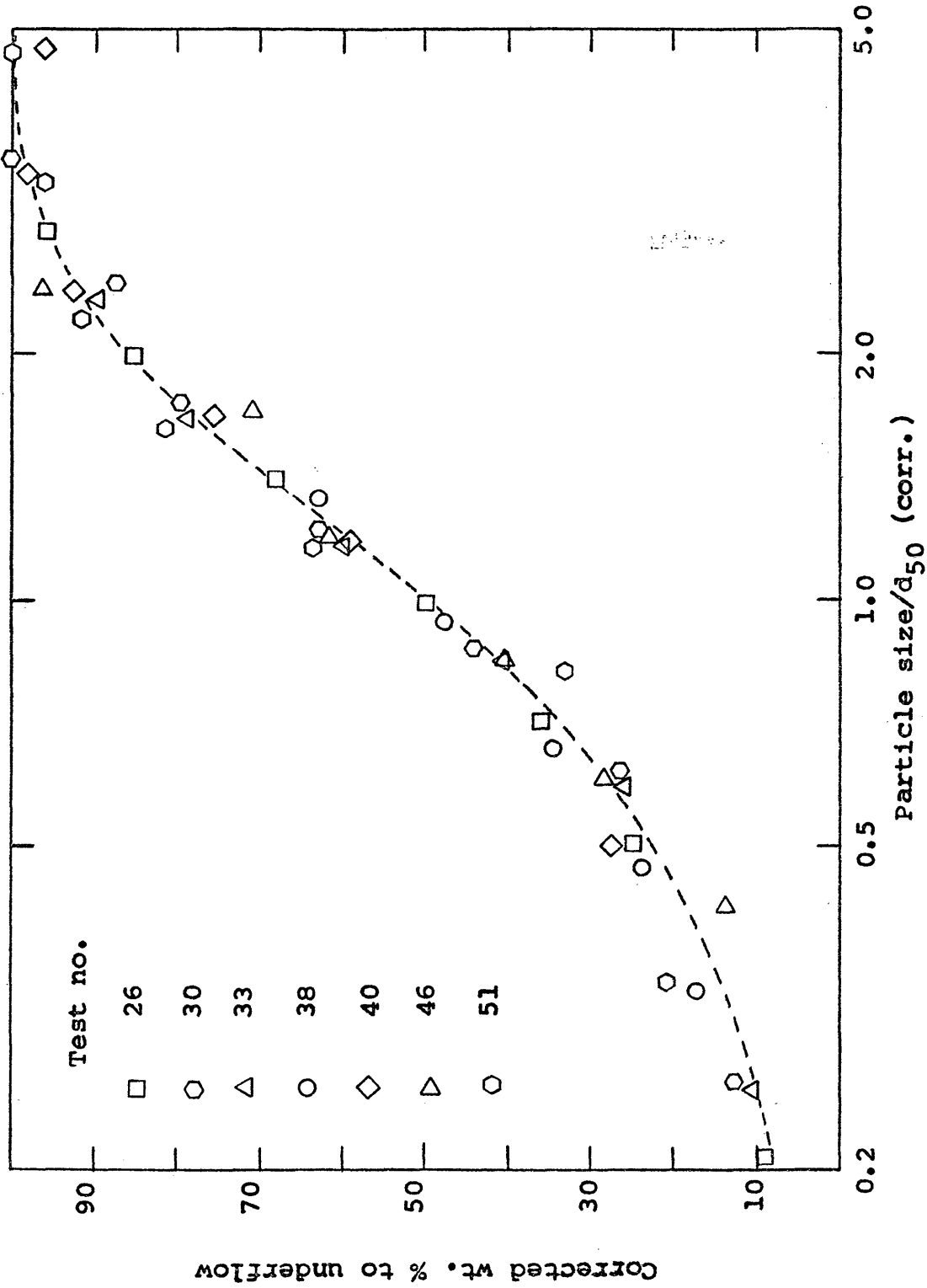


Figure 15: The reduced efficiency curve. Tests 26, 30, 33, 38, 40, 46, 51. Vortex finder diameter = 1.438 in. Spigot diameter = 0.560 in.

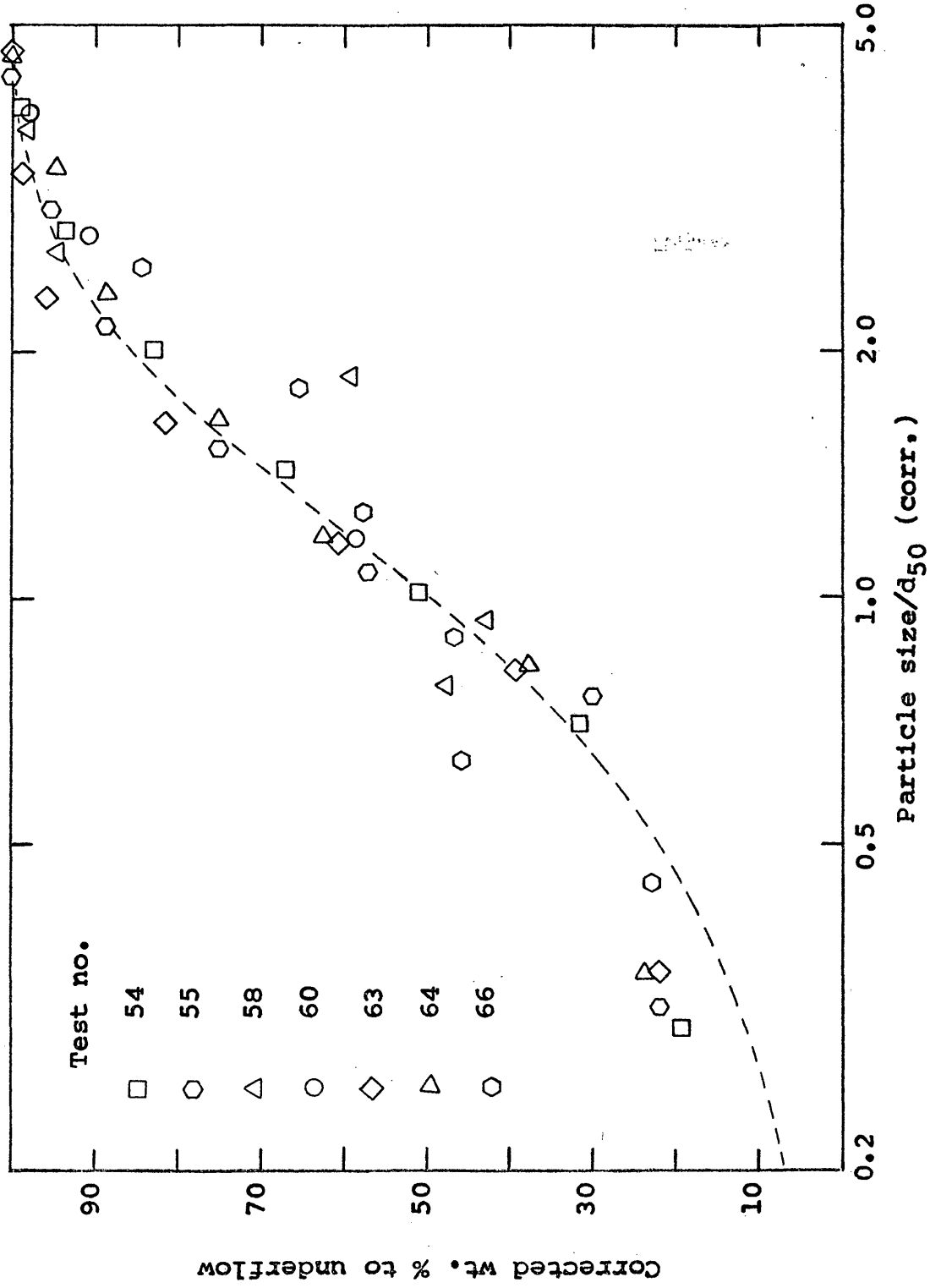


Figure 16: The reduced efficiency curve. Tests 54, 55, 58, 60, 63, 64, 66. Vortex finder diameter = 1.438 in. Spigot diameter = 0.850 in.

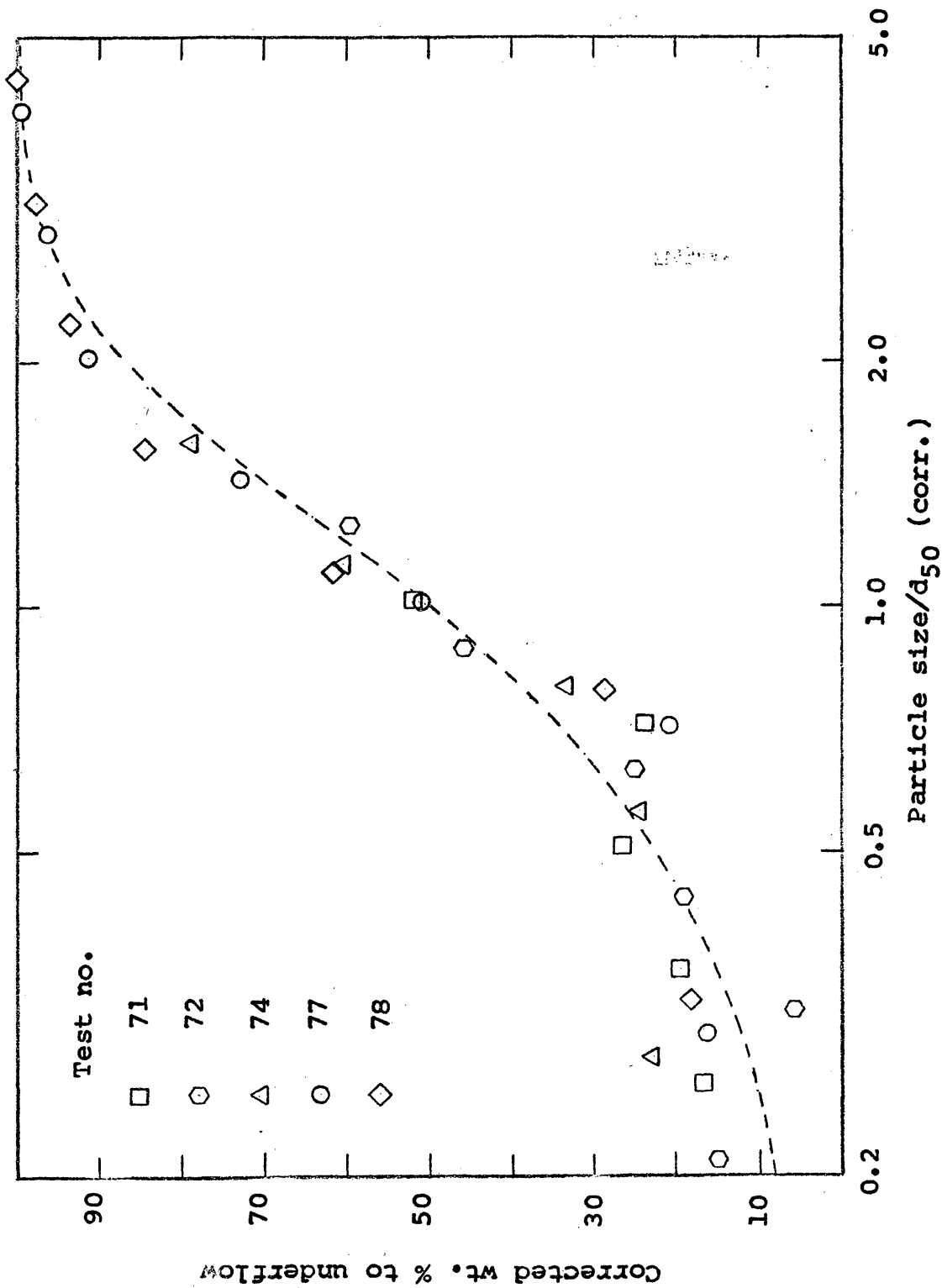


Figure 17: The reduced efficiency curve. Tests 71, 72, 74, 77, 78. Vortex finder diameter = 0.970 in. Spigot diameter = 0.440 in.

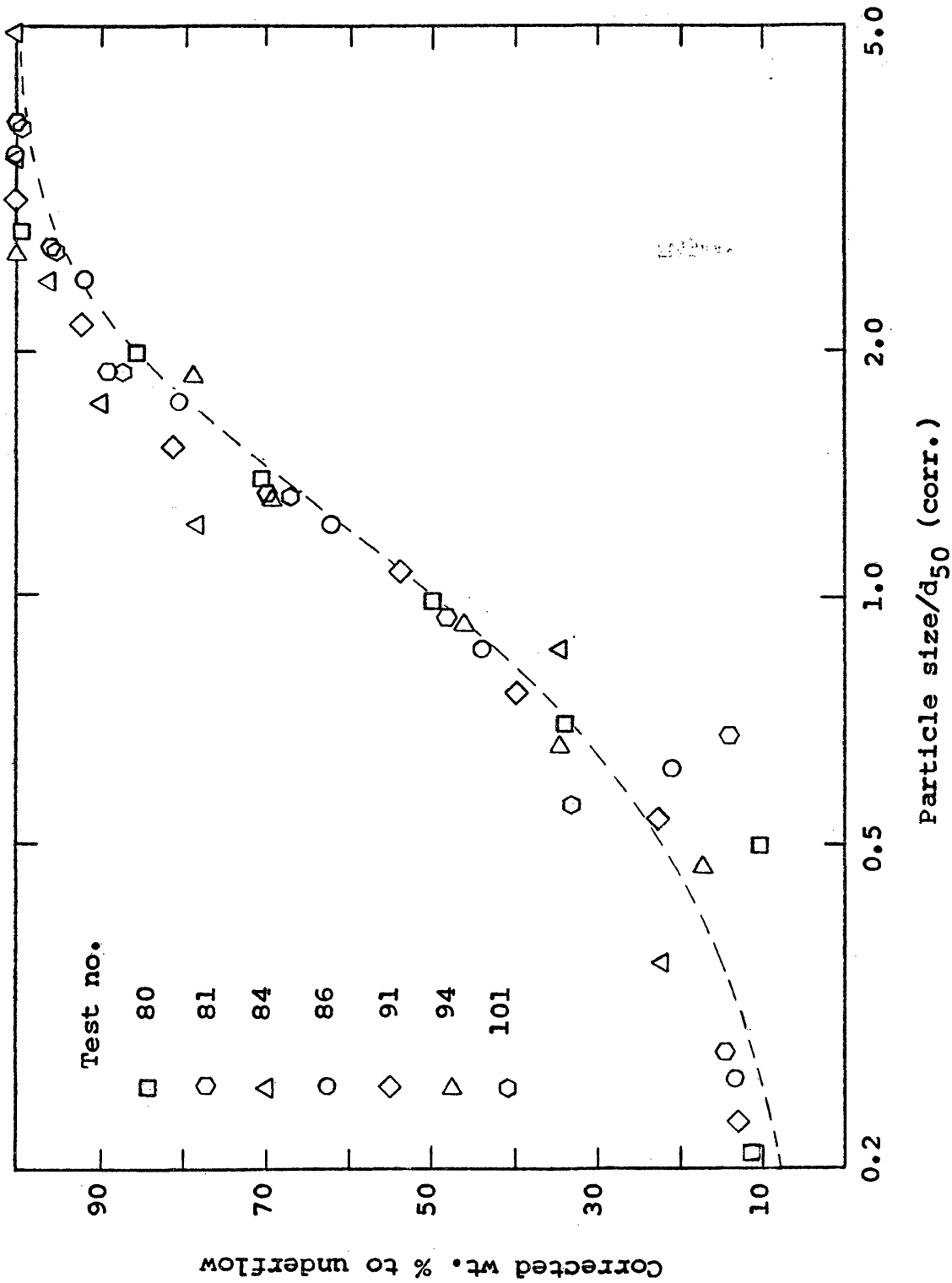


Figure 18: The reduced efficiency curve. Tests 80, 81, 84, 86, 91, 94, 101. Vortex finder diameter = 0.970 in. Spigot diameter = 0.560 in.

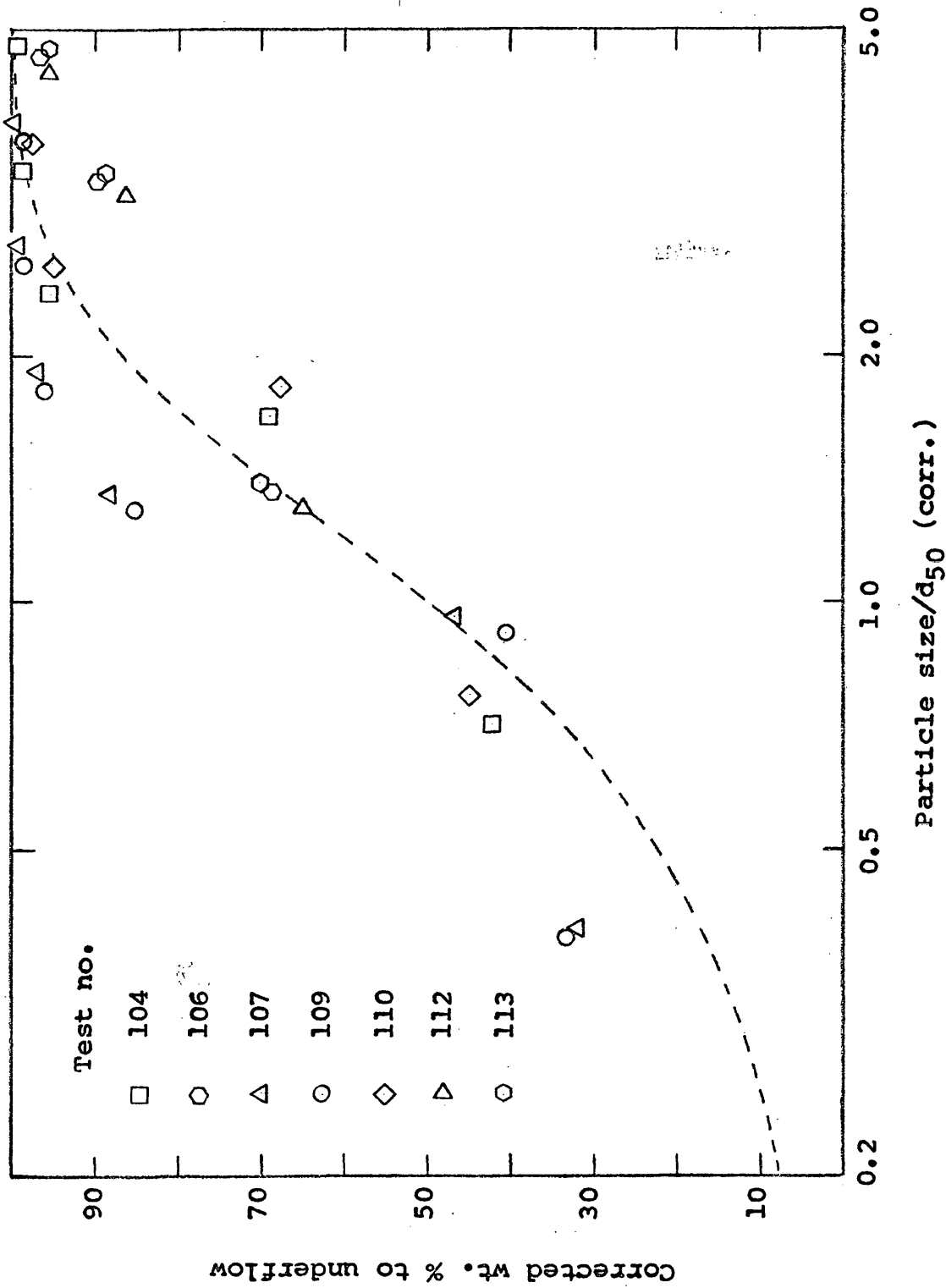


Figure 19: The reduced efficiency curve. Tests 104, 106, 107, 109, 110, 112, 113. Vortex finder diameter = 0.970 in. Spigot diameter = 0.850 in.

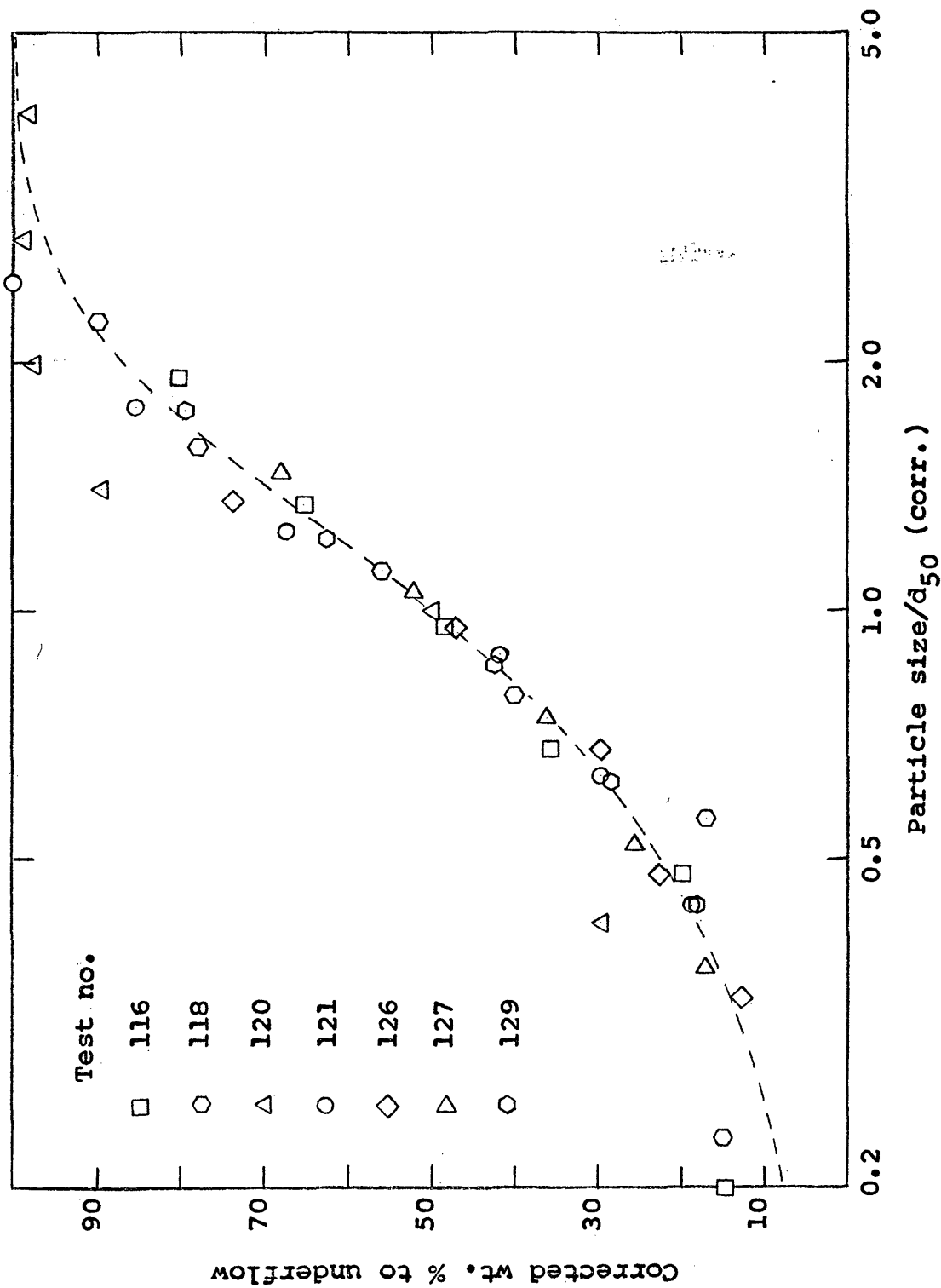


Figure 20: The reduced efficiency curve. Tests 116, 118, 120, 121, 126, 127, 129. Vortex finder diameter = 0.719 in. Spigot diameter = 0.440 in.

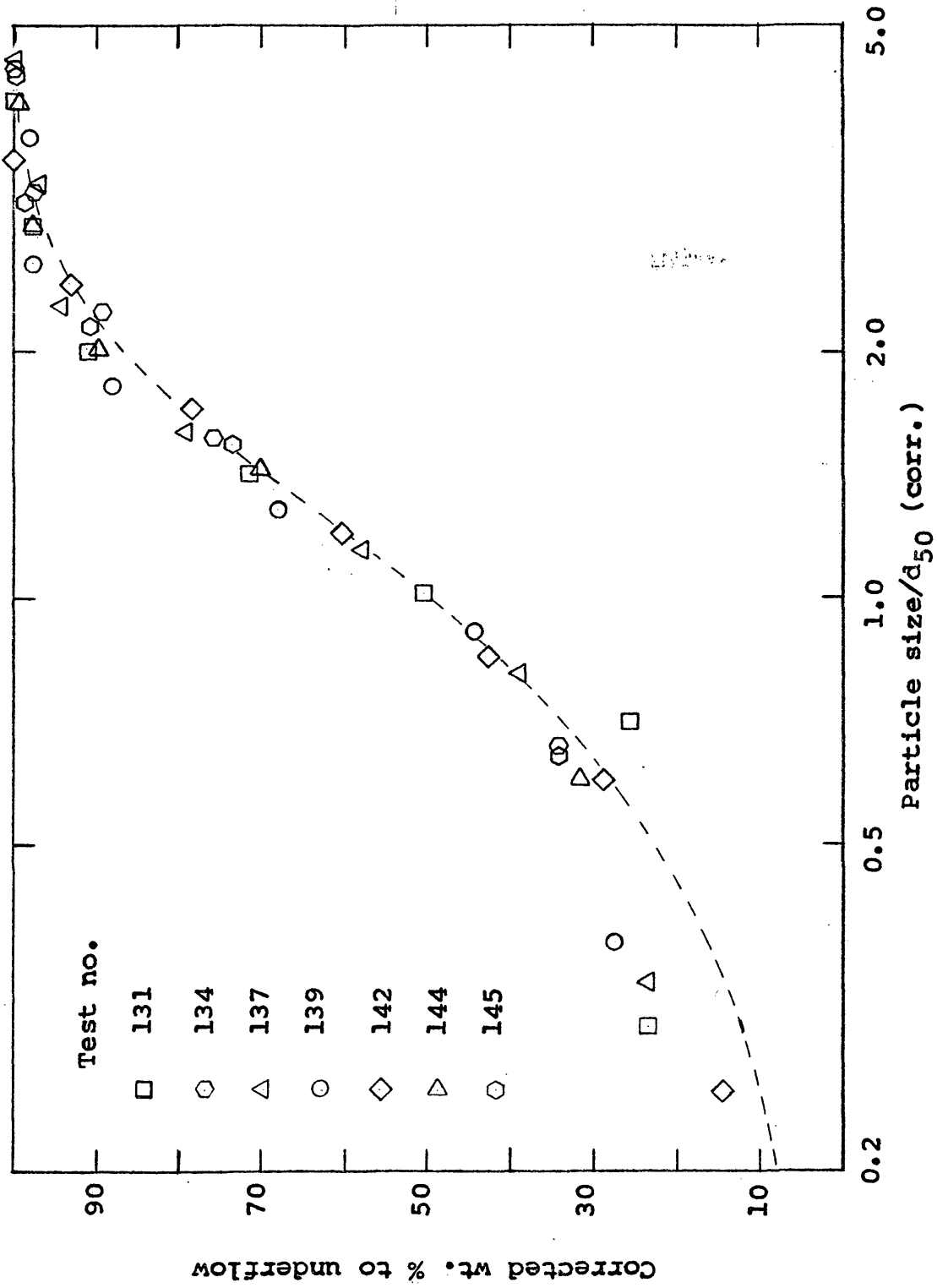


Figure 21: The reduced efficiency curve. Tests 131, 134, 137, 139, 142, 144, 145. Vortex finder diameter = 0.719 in. Spigot diameter = 0.560 in.

The Effect of Variables on the Corrected d_{50} Value.

(10)

Lynch and Rao found experimentally that over a wide range of feed conditions the corrected d_{50} value is a function of the mass flow rate of water in the overflow, the operating feed pressure, the vortex finder diameter, and the spigot diameter. The mathematical expression of the d_{50} (corrected) value is as follows:

$$\log_{10} d_{50} \text{ (corr.)} \propto \frac{VF}{K_1} - \frac{\text{Spig.}}{K_2} + \frac{P}{K_3} - \frac{WO}{K_4} \quad (J)$$

in which:

VF = Vortex finder diameter (in)

Spig. = Spigot diameter (in)

P = Feed pressure of cyclone
(lb/sq in gauge)

WO = Mass flow rate of water in the
cyclone overflow (t.p.h.)

$K_1, K_2, K_3, K_4 = \text{Constants}$

In the present investigation, it was almost impossible to correlate the corrected d_{50} value with the operating variables as stated above because of the number of variables involved in it and the limited number of tests. However, it has been found experimentally that the corrected d_{50} value is a function of the feed pulp flow rate, mass flow rate of water in the feed, and the spigot diameter, which is expressed as follows:

$$\log_{10} d_{50} \text{ (corr.)} \propto \frac{Q}{K_1} - \frac{WFR}{K_2} - \frac{\text{Spig.}}{K_3} \quad (\text{K})$$

where: Q = Feed pulp flow rate (gal/min) .
 WFR = Mass flow rate of water in the cyclone
 feed (t.p.h.)
 Spig. = Spigot diameter (in)
 K₁, K₂, K₃ = Constants

Equations J and K have certain similarities to each other since Q is a direct function of P and VF; and WFR and WO are identified by the relationship of the distribution of water in the cyclone.

The experimental results of feed pulp flow rate (gal/min) and the corrected d₅₀ value (microns) are represented in Appendix B (Tables 1-B and 2-B, respectively).

DISCUSSION OF RESULTS

In this investigation there were five variable parameters, which were considered unchangeable. Three of them belong to the cyclone and the other two to the solid material. They were:

1. The diameter of the cyclone (cyclone size): 4 in.
2. The included angle of the conical section of the cyclone: 11°
3. The area of the feed inlet to the cyclone: 0.563 sq in
4. The specific gravity of the solid material (high-grade quartz): 2.65
5. The feed size particle distribution, shown in Table 1.

The principal independent variables, which have been investigated, were:

1. The vortex finder diameter.
2. The spigot diameter.
3. The pulp density of the cyclone feed pulp.
4. The operating pressure of the feed pulp introduced into the cyclone.

The principal dependent variables, which have been investigated, were:

1. The cyclone feed pulp rate.
2. The water distribution in the cyclone.
3. The corrected d_{50} value.
4. The size particle distribution.

In the preceeding section the experimental results were graphically represented. In this section these results will be analyzed in order to define mathematically the performance of the cyclone by means of fundamental equations, which will result in the formulation of a mathematical model of the cyclone. For such a purpose this section is divided in four categories in accordance with the four fundamental equations to be developed: (1) capacity of the cyclone, (2) distribution of water in the cyclone, (3) assessment of the classification operation, and (4) the corrected d_{50} value determination.

A graphical analysis method ⁽¹⁶⁾ was used to develop each fundamental equation.

The Capacity of the Cyclone

Figures 7, 8, and 9 represent the plots of the feed pulp flow rate (Q) in gal/min against the operating feed pressure (P) in p.s.i.g., showing the effect of change of the feed water percent (PCWT) for the vortex finder diameters (VF) of 1.438 in, 0.970, and 0.719, respectively. Since these plots are on log-log scale the following general equation applies:

$$Q = P^n \cdot C \quad (1)$$

$$\text{or: } \log Q = n \cdot \log P + \log C \quad (2)$$

where n is the slope of the parallel lines drawn in each figure.

By graphical analysis of Figures 7, 8, and 9, and according to equation 2, the following expression was found:

$$\log Q = 0.503 \cdot \log P + \log C_1 \quad (3)$$

in which C_1 involves the effect of change in PCWT and VF.

For the various PCWT and VF their corresponding $\log C_1$ values are given in Table 8. They were deduced from Figures 7, 8, and 9.

For each VF the plot of $\log C_1$ against \log PCWT resulted in a linear relationship as shown in Figures 22, 23, and 24. The equation of these straight lines is as follows:

$$\log C_1 = 0.912 \cdot \log (\text{PCWT}) - \log C_2 \quad (4)$$

in which C_2 involves the effect of change in VF. On substituting Equation 4 into Equation 3:

$$\log Q = 0.503 \cdot \log P + 0.912 \cdot \log (\text{PCWT}) + \log C_2 \quad (5)$$

From Figures 22, 23, and 24, the $\log C_2$ values corresponding to the three VF are given in Table 9.

From Table 9, the $\log C_2$ values were plotted against

Table 8: Summary of the $\log C_1$ value for each PCWT and VF shown in Figures 7, 8, and 9.

Vortex finder diameter (in) VF	Water percent in Cyclone feed PCWT	Log C_1
1.438	66.0	0.9600
1.438	72.0	0.9918
1.438	78.0	1.0288
1.438	87.0	1.0713
0.970	62.0	0.9229
0.970	70.0	0.9709
0.970	76.0	1.0044
0.970	82.0	1.0336
0.719	65.0	0.9315
0.719	70.0	0.9607
0.719	76.0	0.9920

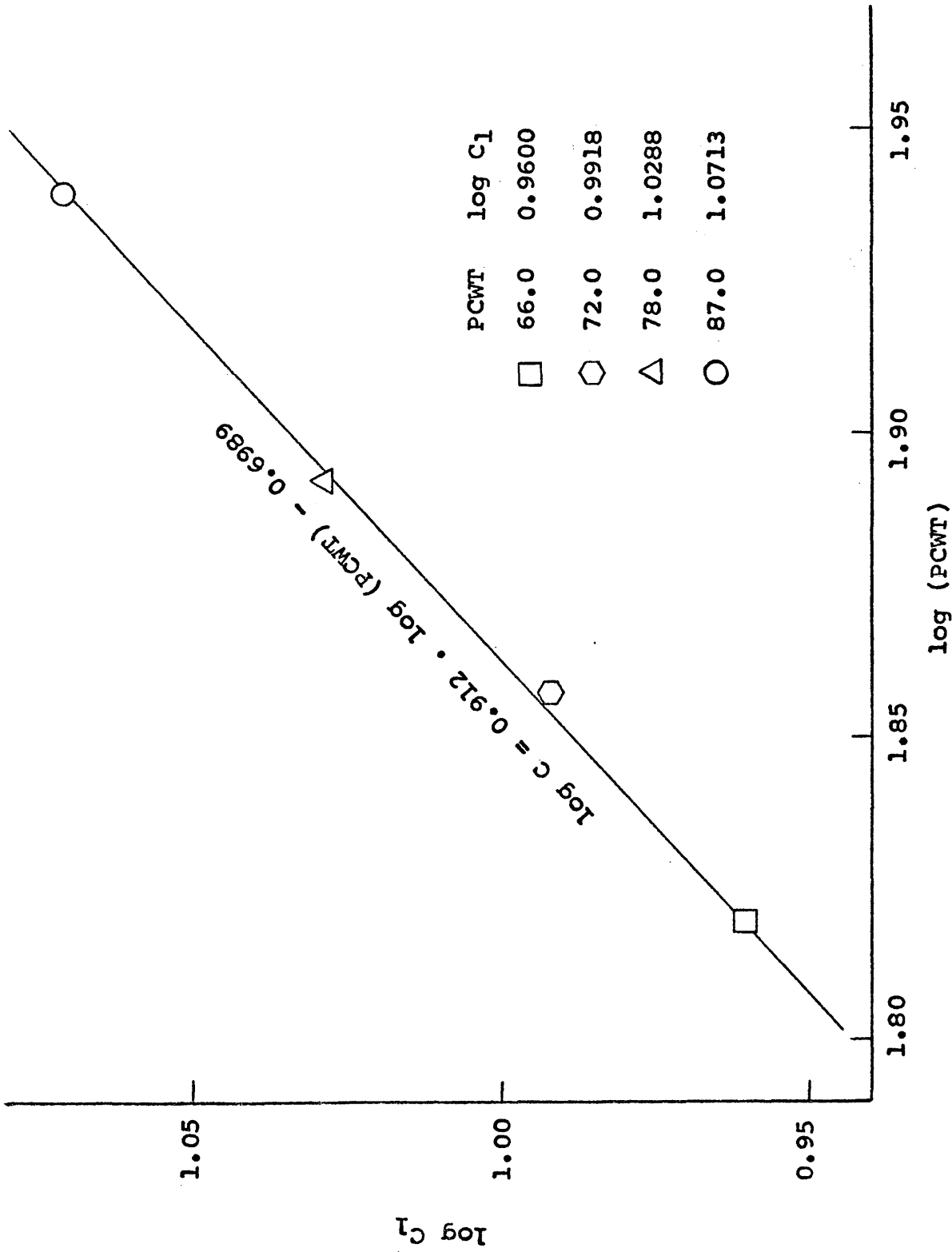


Figure 22: Plot of log C₁ versus log (PCWT) for the mathematical determination of the effect of PCWT on the capacity of the cyclone. Vortex finder diameter = 1.438 in.

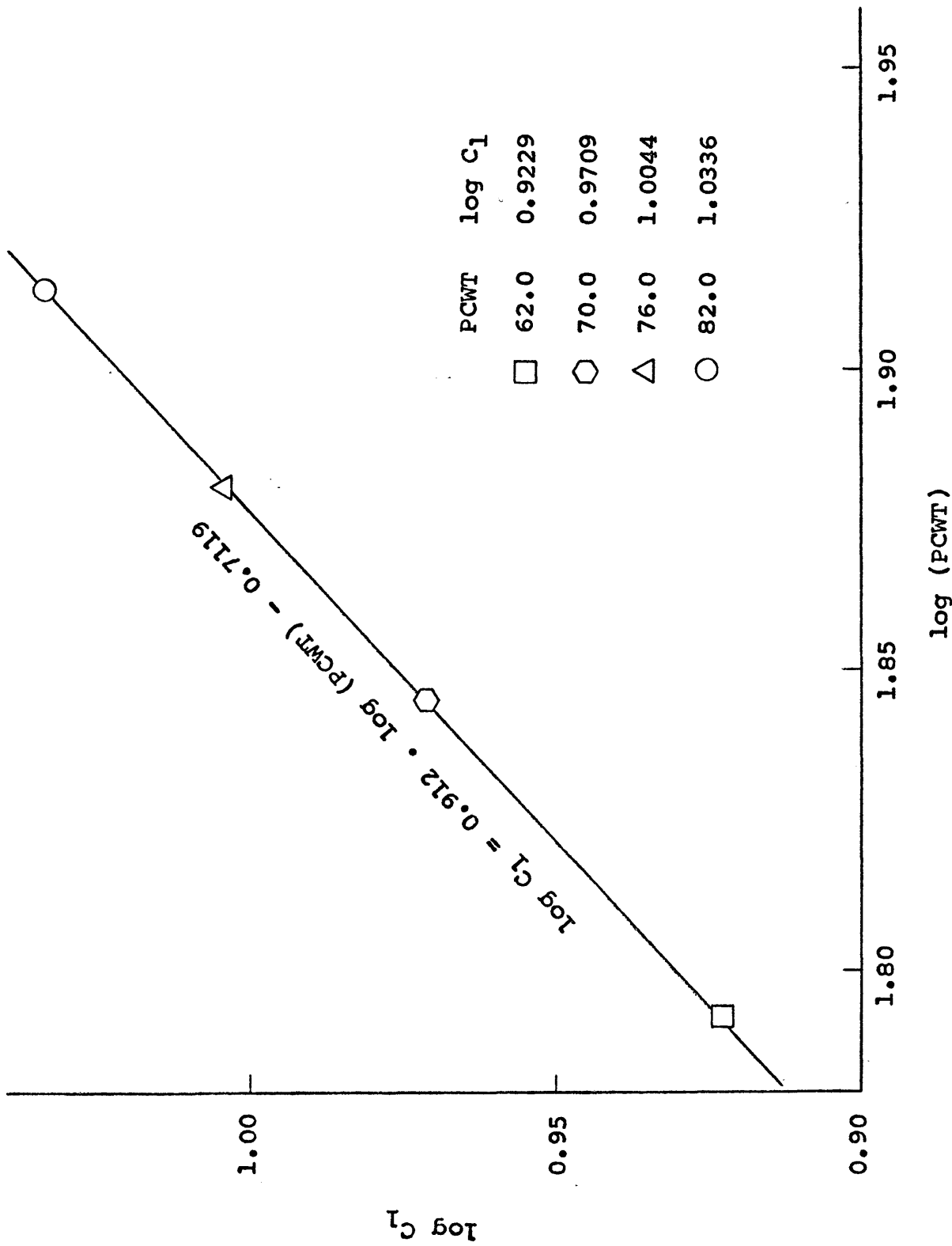


Figure 23: Plot of log C₁ versus log (PCWT) for the mathematical determination of the effect of PCWT on the capacity of the cyclone. Vortex finder diameter = 0.970 in.

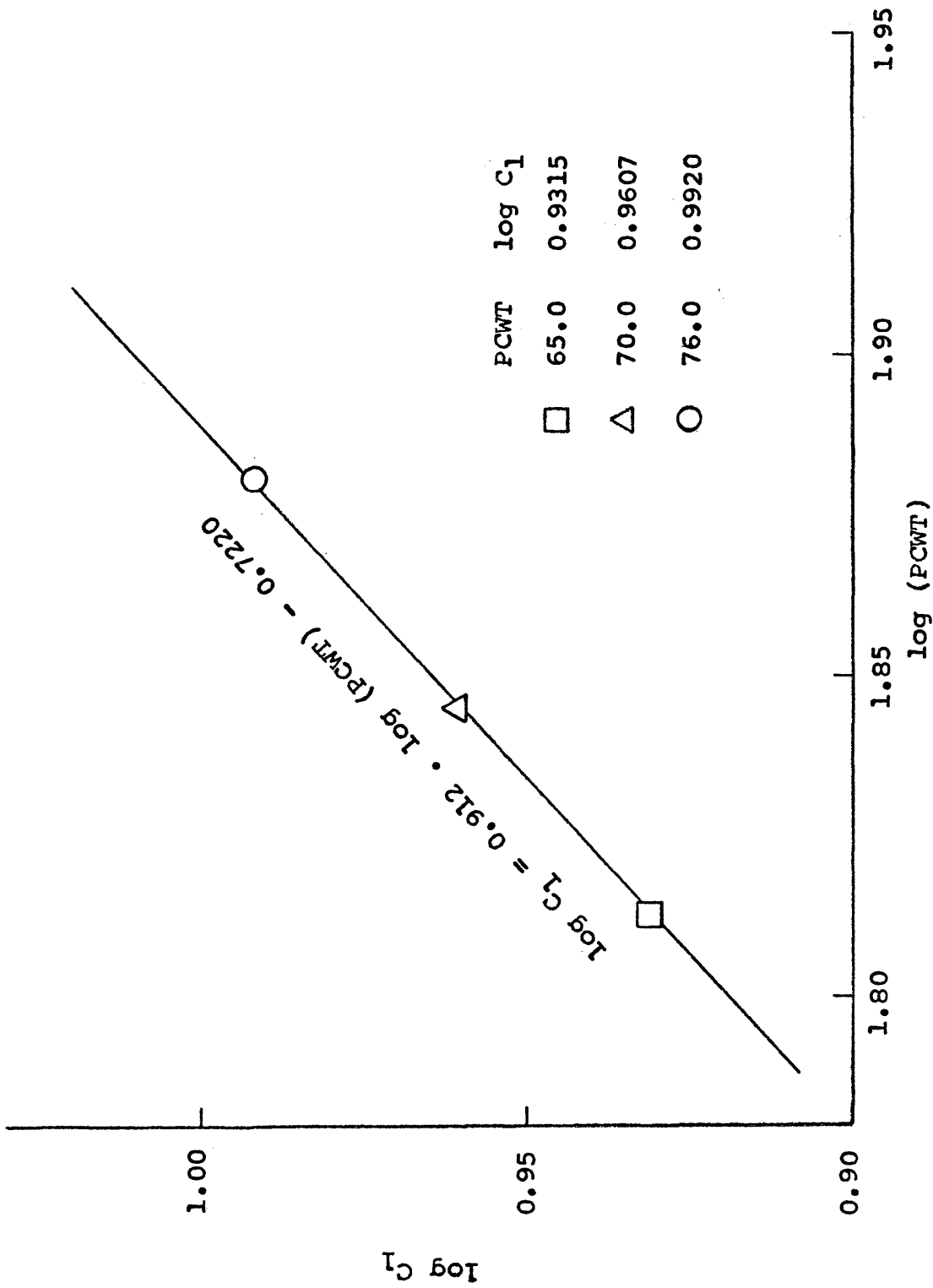


Figure 24: Plot of log C₁ versus log (PCWT) for the mathematical determination of the effect of PCWT on the capacity of the cyclone. Vortex finder diameter = 0.719 in.

their respective log VF as shown in Figure 25. A linear relationship was obtained. The equation of this straight line is:

$$\log C_2 = 0.0774 \cdot \log VF - 0.7108 \quad (6)$$

Table 9: Summary of the log C_2 value for each VF as deduced from Figures 22, 23, and 24.

Vortex finder diameter (in) VF	log C_2
1.438	- 0.6989
0.970	- 0.7119
0.719	- 0.7220

By replacing Equation 6 into Equation 5 the following equation is obtained:

$$\log Q = 0.503 \cdot \log P + 0.912 \cdot \log (\text{PCWT}) + 0.0774 \cdot \log (VF) - 0.7108 \quad (7)$$

or, Equation 7 expressed in exponential form:

$$Q = P^{0.503} \cdot (\text{PCWT})^{0.912} \cdot (VF)^{0.0774} \cdot 0.1946 \quad (8)$$

Equation 8 is a fundamental equation, which is useful to predict the capacity of the cyclone (Q) as a function of the operating feed pressure (P), the percent of water in the feed (PCWT) and the vortex finder diameter (VF).

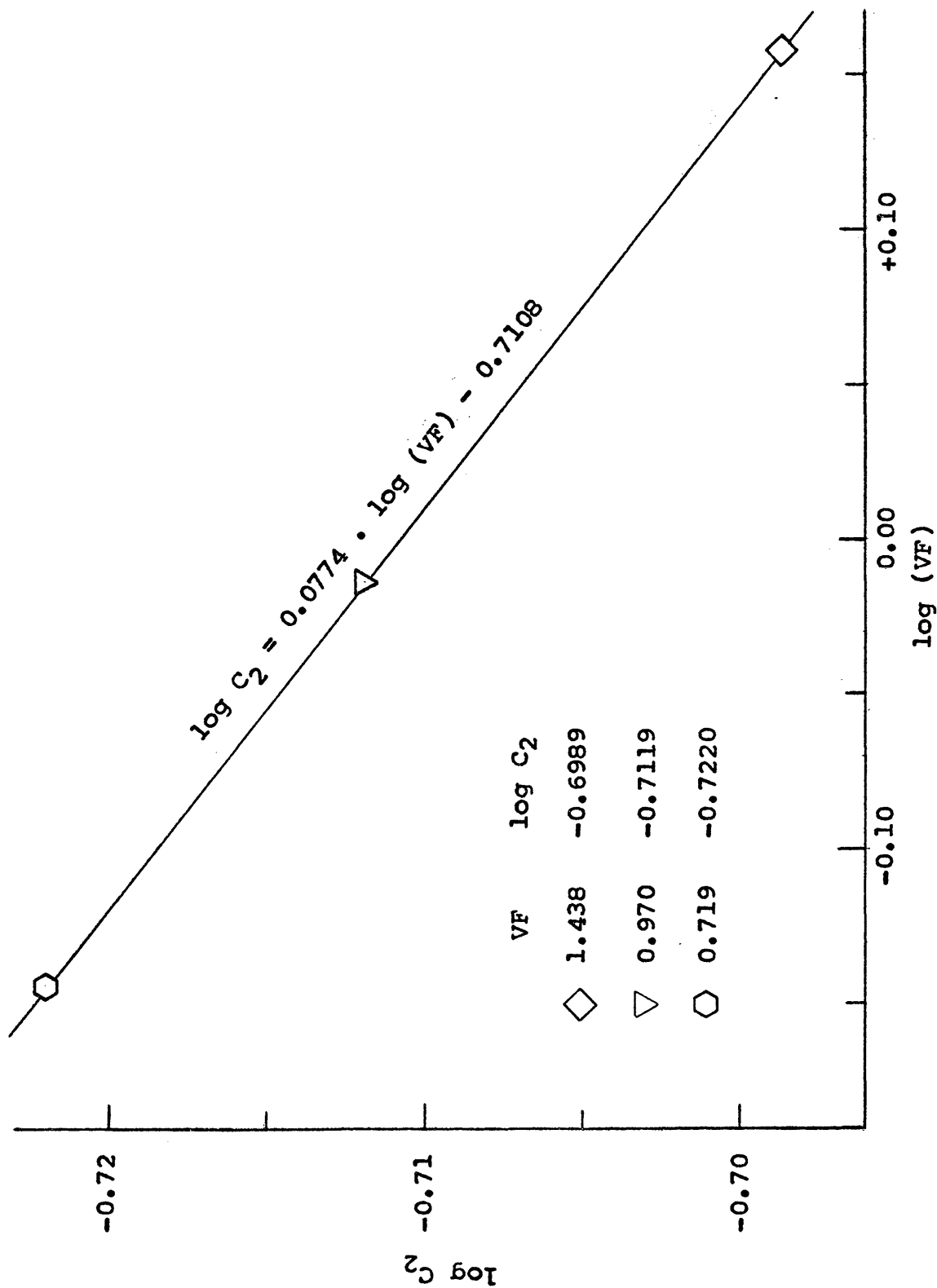


Figure 25: Plot of log C₂ versus log (VF) for the mathematical determination of the effect of VF on the capacity of the cyclone.

Experimental verification of Equation 8 is shown in Appendix C.

The Distribution of Water in the Cyclone

The experimental results of the distribution of water in the 4-in cyclone were graphically illustrated in Figure 10, in which the effect of change in the spigot diameter was shown by the three parallel straight lines.

By inspection of Figure 10, the general equation for the straight lines is:

$$WO = m \cdot WFR + C_3 \quad (9)$$

where, WO = Mass flow rate of water in the cyclone overflow
(t.p.h.)

WFR = Mass flow rate of water in the cyclone feed
(t.p.h.)

m = Slope of the parallel straight lines.

C₃ = Constant involving the effect of change in the spigot diameter.

A graphical analysis of Figure 10, according to Equation 9, resulted in the following expression:

$$WO = 1.0 \cdot WFR + C_3 \quad (10)$$

The C₃ value found for each spigot diameter is presented in tabulated form in Table 10.

Plotting the C₃ values against their respective Spig. value resulted in a linear relationship as shown in Figure

26. The equation of this straight line is:

$$C_3 = - 2.073 \cdot (\text{Spig.}) + 0.412 \quad (11)$$

On substituting Equation 11 into Equation 10:

$$W_O = 1.0 \cdot WFR - 2.073 \cdot (\text{Spig.}) + 0.412 \quad (12)$$

Table 10: Summary of the C_3 value for each spigot diameter

Spigot diam (in) (Spig.)	C_3
0.440	- 0.50
0.560	- 0.75
0.850	- 1.35

Equation 12 is the water distribution equation useful to predict the mass flow rate of water in the overflow product as a function of the known mass flow rate of water in the cyclone feed and spigot diameter.

The experimental verification of Equation 12 is shown in Appendix C.

The Assessment of the Classification Operation

The assessment of the classification operation in the cyclone was illustrated in Figures 13 through 21 in terms of the reduced efficiency curve, which present the same shape for all the classification tests carried out in the 4-in cy-

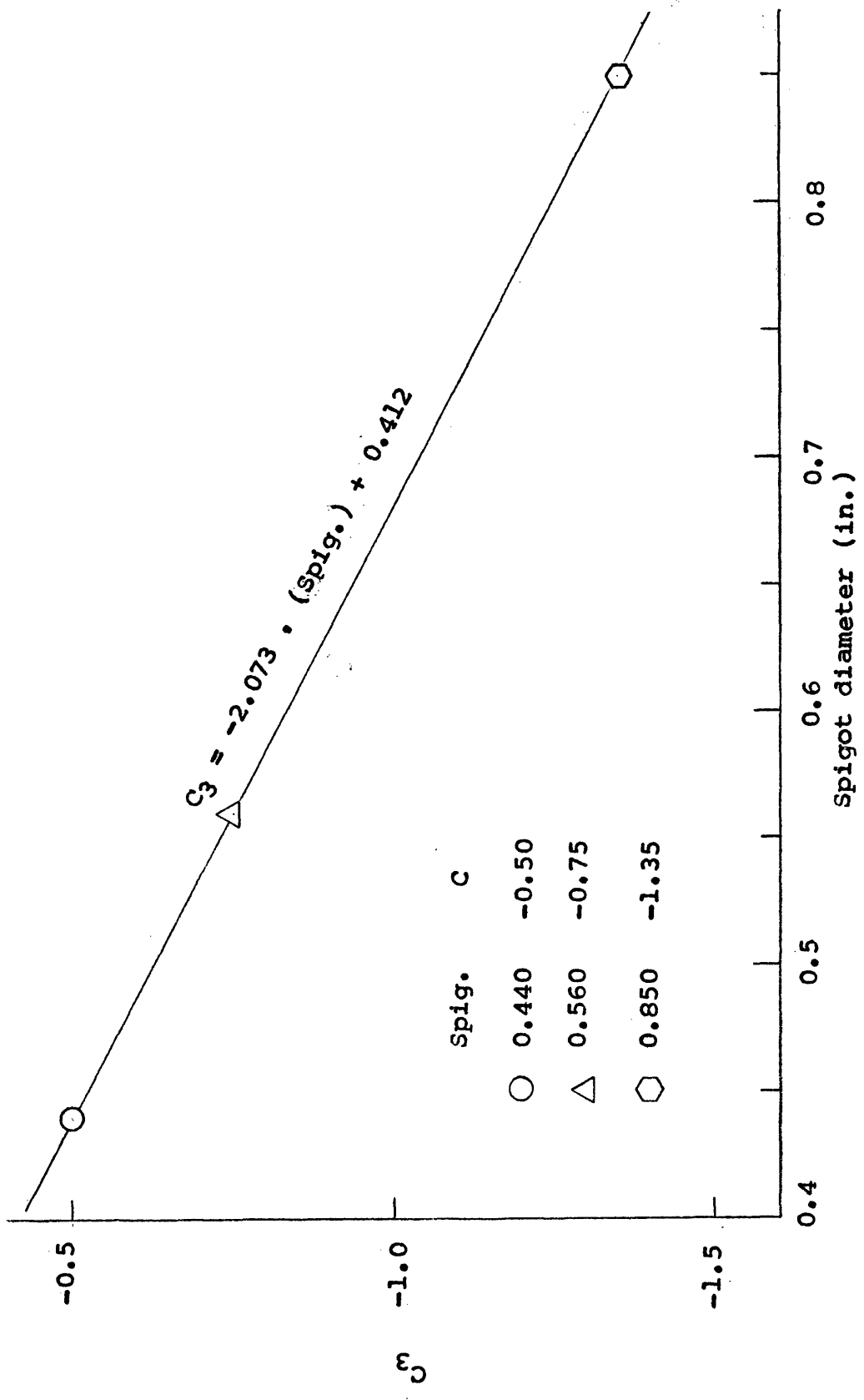


Figure 26: Plot of C3 versus Spig. for the mathematical determination of the effect of (Spig.) in the distribution of water in the cyclone.

clone.

In order to define mathematically the reduced efficiency curve the empirical equation developed by Lynch and Rao (10) was chosen. This equation is as follows:

$$Y = \frac{e^{aX} - 1}{e^{aX} + e^a - 2} \quad (13)$$

in which, Y = Fraction of the feed at a particular micron size which appears in the coarse product (underflow) due to classification.

X = Ratio of the mid-point of a size range (microns) to the d_{50} (corrected) point.

a = Constant

A value of $a = 1.75$ in Equation 13 resulted in a curve corresponding to the observed reduced efficiency curves which is shown in Figure 27.

Determination of the Corrected d_{50} Value

The correlation of d_{50} (corrected) with the operating variables of vortex finder diameter, feed pressure, spigot diameter, and mass flow rate of water in the overflow, as established in Lynch's model (10,11), was practically impossible in this investigation because of the limited number of tests.

It was found, in a second attempt, that the correlation between $\log d_{50}$ (corrected) and feed pulp flow rate resulted in a linear relationship of the form:

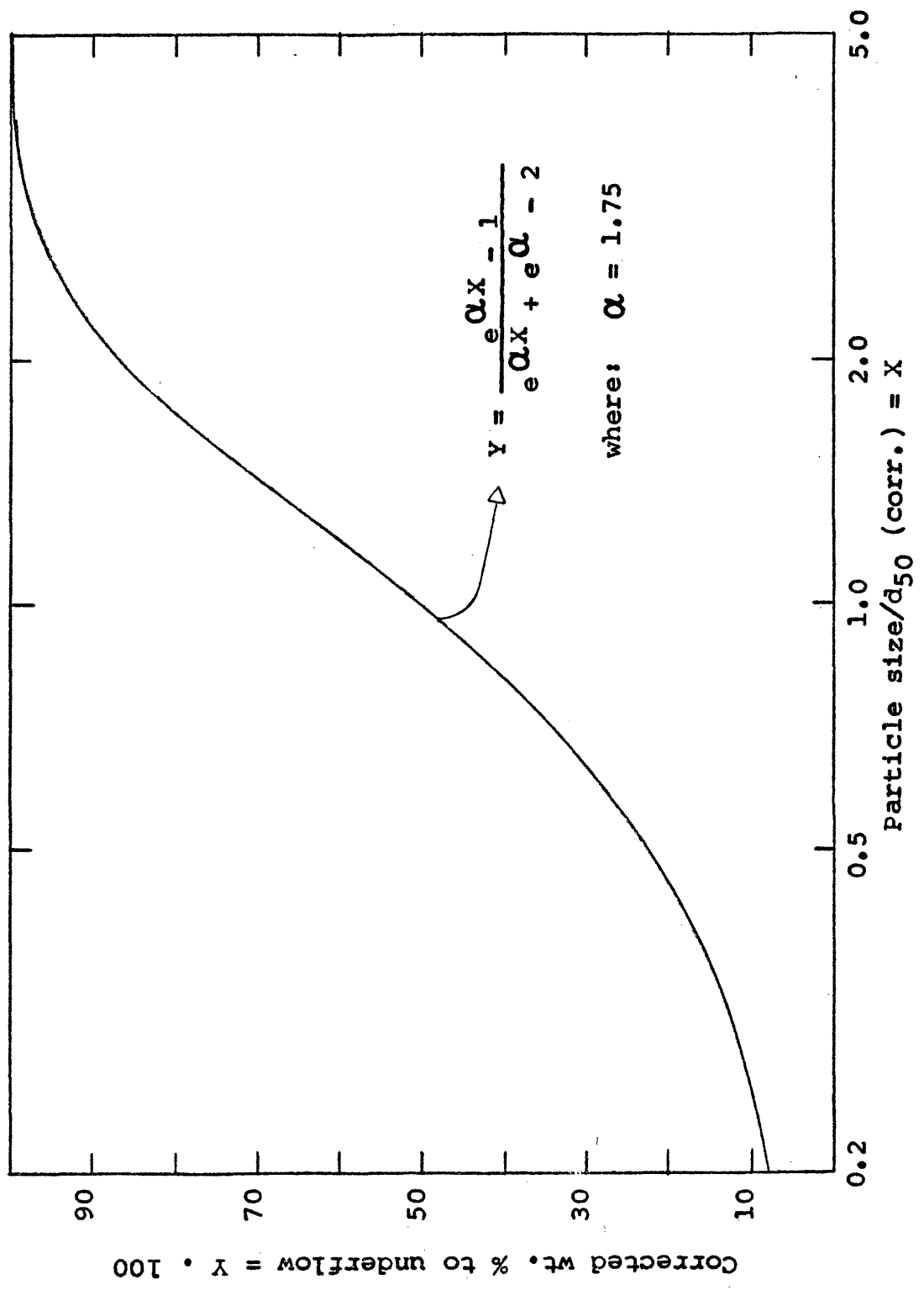


Figure 27: The general form of the observed reduced efficiency curves for all classification tests in a 4-in. cyclone.

$$\log d_{50} \text{ (corr.)} = 0.364 \cdot Q + C_4 \quad (14)$$

where, Q = Feed pulp flow rate, g.p.m.

C_4 = Constant involving the effect of the mass flow rate of water in cyclone feed and the spigot diameter.

The C_4 values for various mass flow rates of water in cyclone feed at each spigot diameter are given in Table 11.

The plots of C_4 versus water flow rate in the feed resulted in a straight line for each spigot diameter as shown in Figure 28. The equation of each straight line is as follows:

$$C_4 = - 1.291 \cdot \text{WFR} + C_5 \quad (15)$$

On substituting Equation 15 into Equation 14:

$$\log d_{50} \text{ (corr.)} = 0.364 \cdot Q - 1.291 \cdot \text{WFR} + C_5 \quad (16)$$

where, WFR = Mass flow rate of water in cyclone feed,
t.p.h.

C_5 = Constant, involving the effect of change in the spigot diameter

The C_5 value corresponding to each spigot diameter is given in Table 12.

The plot of C_5 versus spigot diameter resulted in a straight line as shown in Figure 29. The equation of this straight line is as follows:

Table 11: The C_4 values corresponding to various mass flow rates of water in cyclone feed at each spigot diameter.

Spigot diameter	Mass flow rate of	
	water in feed	
in.	T.P.H.	C_4
0.440	4.0	- 3.4909
0.440	5.0	- 4.7745
0.440	6.0	- 6.0727
0.440	7.0	- 7.3636
0.560	4.0	- 3.7090
0.560	5.0	- 4.9818
0.560	6.0	- 6.3090
0.560	7.0	- 7.5818
0.850	4.0	- 4.2000
0.850	5.0	- 5.4909
0.850	6.0	- 6.7817
0.850	7.0	- 8.0728

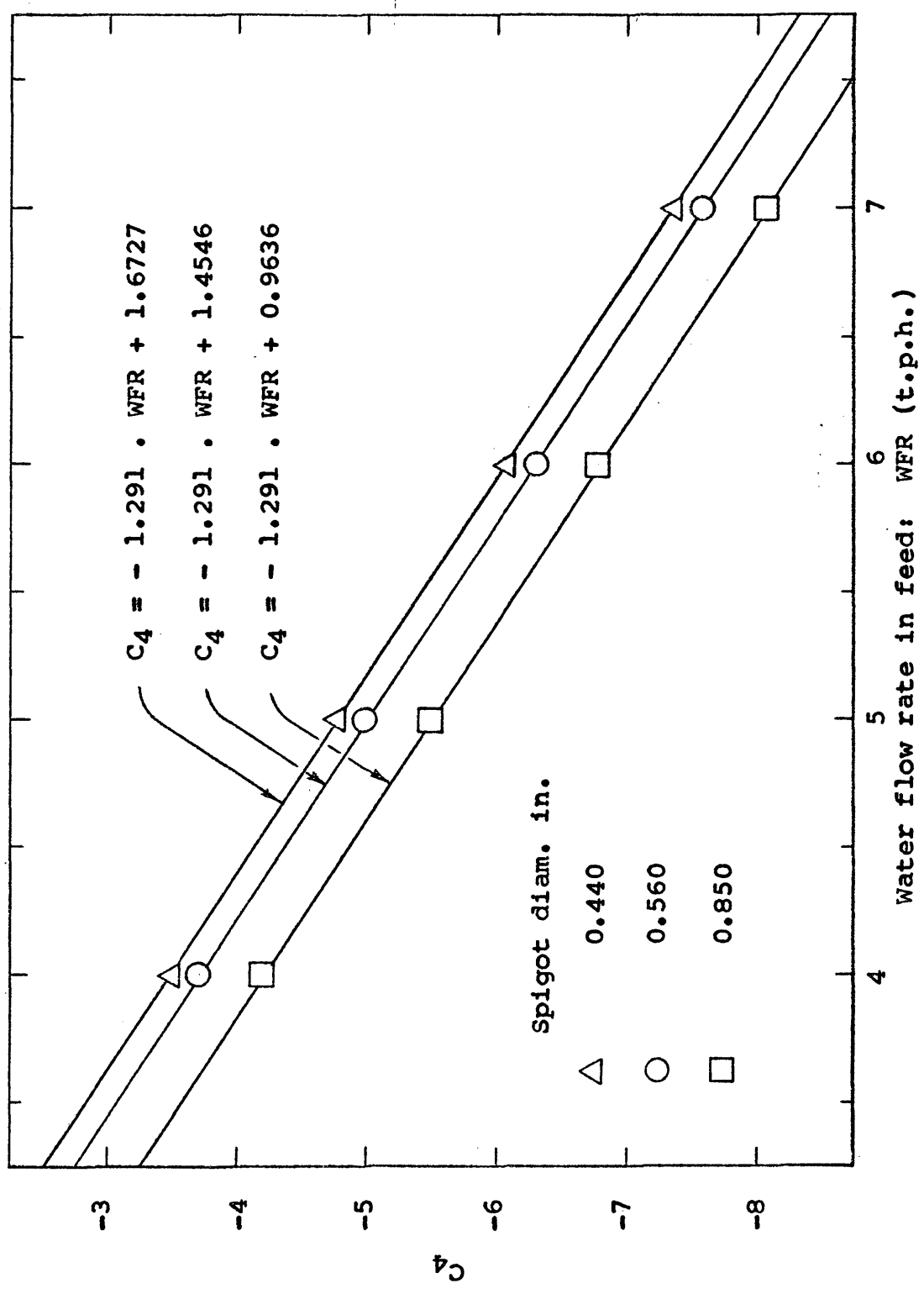


Figure 28: Plot of C₄ versus water flow rate in feed for the mathematical determination of the water flow rate in the feed in the log d₅₀ equation.

$$C_5 = 1.75 \cdot \text{Spig.} + 2.434 \quad (17)$$

On substituting Equation 17 into Equation 16:

$$\log d_{50} (\text{corr.}) = 0.364 \cdot Q - 1.291 \cdot \text{WFR} - 1.75 \cdot \text{Spig} + 2.434 \quad (18)$$

Table 12: The C_5 value corresponding to each spigot diameter.

Spigot diameter	
in.	C_5
0.440	1.6727
0.560	1.4546
0.850	0.9636

Equation 18 is the fundamental equation useful for predicting the corrected d_{50} value as a function of the feed pulp flow rate, the mass flow rate of water in the feed, and the spigot diameter.

The experimental verification of Equation 18 in terms of percent of error in the predicted $\log d_{50}$ (corrected) with respect to the experimental $\log d_{50}$ (corrected) is given in Appendix C. In summary, the mathematical model of the 4-in cyclone classifier as developed in this section is identified by the following equations:

$$Q = P^{0.503} \cdot (VF)^{0.0774} \cdot (PCWT)^{0.912} \cdot 0.1946 \quad (8)$$

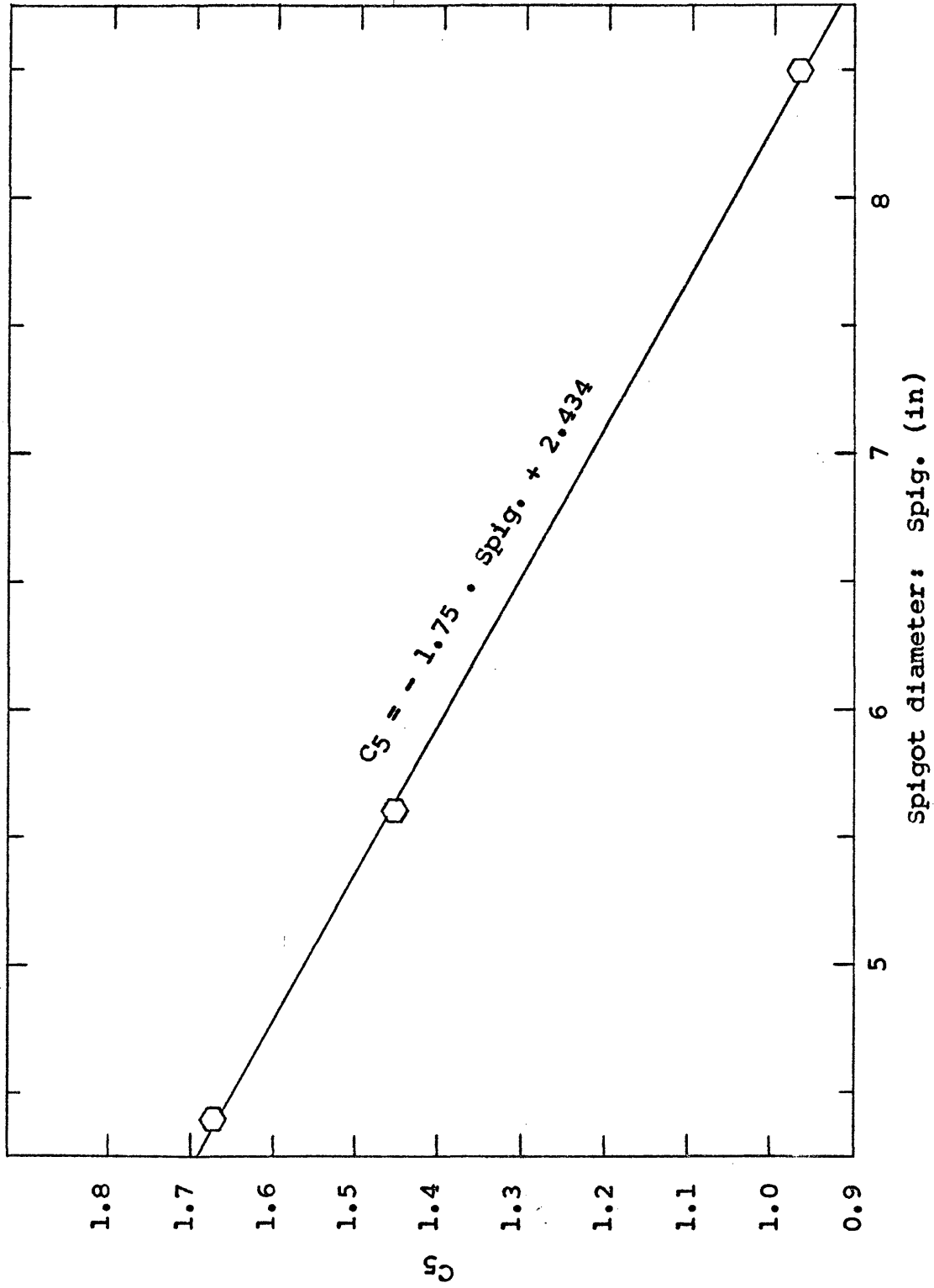


Figure 29: Plot of C_5 versus spigot diameter for the mathematical determination of the spigot diameter in the log d50 equation.

$$WO = 1.0 \cdot WFR - 2.073 \cdot Spig. + 0.412 \quad (12)$$

$$\log d_{50} = 0.364 \cdot Q - 1.291 \cdot WFR - 1.75 \cdot Spig. + 2.437 \quad (18)$$

$$Y = \frac{e^{aX} - 1}{e^{aX} + e^a - 2} \quad (13)$$

Probable Sources of Errors

It was difficult to avoid experimental error in the collection of the data used in the calculation of the parameters which are characteristic of the classification system because of the errors occurring in the sampling and sieving processes from which the data were derived. These errors could be reduced, but not eliminated, by meticulous care.

Another probable source of error in this investigation was the measurement of the operating feed pressure, which is an important variable in circuit analyses. In very few instances are accurate pressure transmitters installed on the cyclone feed pipes and the observed pressures are, in general, unreliable.

Although the experimental errors lie primarily in sampling, sieving, and pressure measurements, the mathematical model of the cyclone has not been invalidated as it has been demonstrated in terms of the percent difference between experimental value and value predicted from model in Appendix C.

CONCLUSIONS

On the basis of the experimental results obtained in this investigation for the classification operation on a 4-in cyclone, several conclusions can be reached, and several suggestions for further investigation can be proposed.

The validity of the model is supported by good agreement between the observed and predicted results. The model developed in this investigation may be refined so that better agreement between the observed and predicted results may be obtained. However, the present model required many tests for its development and it is doubtful whether the additional precision gained by further work would be commensurate with the effort involved.

Because of the limited number of vortex finder diameters and spigot diameters investigated, it is almost impossible to establish the limits of those cyclone design variables outside of which the model would fail, except in the case, found experimentally, when tests were carried out on the cyclone with a vortex finder diameter of 0.719 in. and a spigot diameter of 0.850 in. at which no classification occurred. These respective diameters, when used together,

do not represent practical conditions, however.

The sharpness of the classification operation in a cyclone is given by the value of Q in Equation 13, which fits the reduced efficiency curve. A value of 1.75 was found in this investigation. If this is compared with $Q = 2.5$ found (10,11) for larger cyclones, it indicates a lower efficiency in the classification operation in the 4-in cyclone. Since it is believed that Q is affected by the physical properties of the solid particles such as size of particles and specific gravity, it is suggested that further work be carried out on the cyclone with other feed size ranges and at various specific gravities of the feed (mixed mineral ores) to determine the effect of these variables on the Q value and then to establish the inefficiency of the cyclone.

It must also be borne in mind that the overall efficiency of a cyclone depends not only upon the efficiency with which that portion of the feed that is selected for classification is actually classified (expressed by the magnitude of Q), but that it also depends upon the proportion of the feed that bypasses directly to the coarse product. This bypassed material is responsible for a large proportion of the fine particles in the coarse product, i.e. for much of the apparent inefficiency of the process.

The main value of the model as it has been developed will be in the prediction of the classification performance of similar equipment for much smaller flow rates than could

be fed to the 20- to 24-in. cyclones, for which similar models already existed. These larger cyclones must receive a feed rate of the order of 50 tons per hour to give reasonable inlet pressures and hence classification characteristics, and are therefore used mainly in large-capacity grinding circuits. The 4-in cyclone can be used in smaller-capacity circuits with the same sort of results.

The similarity between the mathematical models derived for the 4-in cyclone on the one hand and for the larger cyclones on the other suggests that cyclones of intermediate size may be expected to behave similarly, and that scale-up factors should not be difficult to obtain.

APPENDICES

APPENDIX A

Appendix A shows a listing of the computer program used to calculate the performance of the 4-in cyclone classifier. An index is included in the listing.

C	MT	.....	CLASSIFICATION TEST NUMBER
C	OP (I)	.....	SIZE ANALYSIS OF SOLIDS IN OVERFLOW (PERCENT)
C	OS	.....	TOTAL MASS FLOW RATE OF SOLIDS IN OVERFLOW (TPH)
C	OT (I)	.....	SIZE DISTRIBUTION OF SOLIDS IN OVERFLOW (TPH)
C	OW	.....	MASS FLOW RATE OF WATER IN OVERFLOW (TPH)
C	P	.....	FEED OPERATING PRESSURE (PSIG)
C	PW	.....	PERCENT OF WATER IN FEED PULP
C	Q	.....	FEED FLOW RATE (TPH)
C	QG	.....	FEED FLOW RATE IN IMPERIAL GALLONS PER MIN.
C	Q1	.....	MASS FLOW RATE OF OVERFLOW PULP (TPH)
C	Q2	.....	MASS FLOW RATE OF UNDERFLOW PULP (TPH)
C	SG	.....	SPECIFIC GRAVITY OF QUARTZ
C	SI	.....	SPIGOT DIAMETER (INCH)
C	SO	.....	OVERFLOW PULP DENSITY
C	SU	.....	UNDERFLOW PULP DENSITY
C	SZ (I)	.....	SIZE OF PARTICLE (MICRONS)
C	T	.....	TIME OF SAMPLING (SECONDS)
C	TC	.....	TOTAL MASS FLOW RATE OF SOLIDS IN UNDERFLOW DUE TO CLASSIFICATION (TPH)
C	TS	.....	TOTAL MASS FLOW RATE OF SOLIDS IN FEED GOING TO CLASSIFICATION (TPH)
C	UP (I)	.....	SIZE ANALYSIS OF SOLIDS IN UNDERFLOW (PERCENT)
C	US	.....	TOTAL MASS FLOW RATE OF SOLIDS IN UNDERFLOW (TPH)
C	UT (I)	.....	SIZE DISTRIBUTION OF SOLIDS IN UNDERFLOW (TPH)
C	UW	.....	MASS FLOW RATE OF WATER IN UNDERFLOW (TPH)
C	VR	.....	VORTEX FINDER DIAMETER (INCH)
C	WD	.....	WATER DISTRIBUTION IN THE FEED (100.0 %)
C	WO	.....	WATER DISTRIBUTION IN THE OVERFLOW (PERCENT)
C	WU	.....	WATER DISTRIBUTION IN THE UNDERFLOW (PERCENT)
C	X (I)	.....	RATIO TO THE MID-POINT OF EACH SIZE RANGE TO THE CORRECTED D50 VALUE = GM (I)/D50

COMMON FT, FP, OT, UT, SZ, BD, GM, CS, N, VR, CL, CP, OP, UP, MS,
 1 BS, D50, FR, FS, Fw, I, L, OS, OW, P, PW, Q, QG, Q1, Q2, SI, SO,
 2 SG, SU, SS, SOP, SUP, TC, TS, US, UW, WD, WO, WU, S, T, TO, TU, X

```

C      DIMENSION FT(10), FP(10), OT(10), UT(10), SZ(10), BD(10), GM(10),
1 CS(10), MS(10), CL(10), CP(10), OP(10), UP(10), X(10)
C
20 FORMAT (8F10.4)
30 FORMAT (8I10)
15 FORMAT ( //12X15H CYCLONE SIZE =F7.2,3H IN12X,16H VORTEX FINDE
1R =F6.3,3H IN15X,9H SPIGOT =F6.3,3H IN//11X,18H INTAKE PRESSURE =
2F5.1,5H PSI645X,17H SP. GR. OF ORE =F6.2)
16 FORMAT (/54X12H TEST NO. =,I4)
17 FORMAT (1H1//31X62H ** DATA FOR THE PERFORMANCE OF A SINGLE CYCLO
1NE CLASSIFIER **)
13 FORMAT (1H1//46X29H ANALYSIS OF CYCLONE PRODUCTS/)
25 FORMAT ( //48X16H CYCLONE PRODUCTS//36X44HWEIGHT AND WEIGHT PERCE
1NT OF SOLIDS RETAINED//1X5H MESH1X5H SIZE13X5H FEED23X9H OVERFLOW,
2 19X10H UNDERFLOW//1X5HTYLER1X6HMICRONS5X8H TONS/HR3X8H PERCENT,
3 11X8H TONS/HR3X8H PERCENT 9X8H TONS/HR3X8H PERCENT/)
26 FORMAT (//44X18H FEED FLOW RATE =,F8.3,9H GAL/MIN)
35 FORMAT (//, 2X,I4,1X,F6.1,5XF7.3,4X,F7.2,2(11X,F7.3,4X,F7.2))
45 FORMAT (//7X6H TOTAL5XF7.3,4X,F7.2,2(11X,F7.3,4X,F7.2),//)
56 FORMAT (//33X,7H SOLIDS17X,7H SOLIDS17X,7H SOLIDS12X,18H PERCENT S
1OLID IN//8X,13H AVERAGE SIZE5X,21H FEED FLOW RATE (TPH)4X,18H O/F
2LOW RATE (TPH)7X,18H U/FLOW RATE (TPH)7X17H UNDERFLOW DUE TO//1X6H
3GM/D504X8H MICRONS4X27H TOTAL BYPASSED CLASSIFIED7X6H TOTAL8X,
446H TOTAL BYPASSED CLASSIFIED CLASSIFICATION//)
60 FORMAT (/F6.2,6XF6.1,4XF7.3,2XF6.3,4XF6.3,10X,F6.3,8X,F6.3,2X,
1F6.3,5X,F6.3,10X,F7.2,/)
66 FORMAT(50X5HD50 =F7.2,8H MICRONS/)
104 FORMAT (//10X,7H TOTALS5X,F7.3,2X,F6.3,4X,F6.3,10X,F6.3,8X,F6.3,
1 2X, F6.3, 5X, F6.3,//////)
115 FORMAT (/57X19HPRODUCTS OF CYCLONE //23X10HPULP (TPH)8X13H SOLI
1DS (TPH)6X,12H WATER (TPH)5X,15H SOLIDS PERCENT3X,19H WATER DISTRI
2BUTION//1X,15H FEED FLOW RATE7X,F8.3,2(11X,F8.3),2(12X,F7.2),3H %
3//1X14H OVERFLOW RATE8X,F8.3,2(11X,F8.3),2(12X,F7.2),3H %//1X15H
4UNDERFLOW RATE7X,F8.3,2(11X,F8.3),2(12X,F7.2),3H %//)
C

```

```

READ 20, SG, S, D
N = S
READ 20, (SZ (I), I = 1, N)
READ 30, (MS (I), I = 1, N)
READ 30, M
L = 1
23 READ 30, MT
READ 20, Q1, Q2, OS, US
READ 20, VR, SI, P, T
READ 20, (OP (I), I = 1, N)
READ 20, (UP (I), I = 1, N)
C
CALL CYCLON
C
PRINT 17
PRINT 16, MT
PRINT 15, O, VR, SI, P, SG
PRINT 26, OG
PRINT 25
PRINT 35, (MS (I), SZ (I), FT (I), FP (I), OT (I), OP (I), UT (I),
1 UP (I), I = 1, N)
PRINT 45, FS, SS, OS, SOP, US, SUP
PRINT 115, Q, FS, FW, FR, WD, Q1, OS, OW, SO, WO, Q2, US, UW, SU, WU
PRINT 18
PRINT 56
PRINT 60, (X(I), GM(I), FT(I), BD(I), CS (I), OT (I), UT (I), BD (I),
1 CL (I), CP (I), I = 1, N)
PRINT 104, FS, BS, TS, OS, US, BS, TC
PRINT 66, D50
IF (L - M) 21, 22, 22
21 L = L + 1
GO TO 23
22 CONTINUE
I = XEXITF (0)
END
C

```

```

C
C
SUBROUTINE CYCLON
COMMON FT, FP, OT, UT, SZ, BD, GM, CS, N, VR, CL, CP, OP, UP, MS,
1 BS, D50, FR, FS, FW, I, L, US, OW, P, PW, Q, QG, Q1, Q2, SI, SO,
2 SG, SU, SS, SOP, SUP, TC, TS, US, UW, WD, WO, WU, S, T, TO, TU, X
C
DIMENSION FT(10), FP(10), OT(10), UT(10), SZ(10), BD(10), GM(10),
1 CS(10), MS(10), CL(10), CP(10), OP(10), UP(10), X(10)
C
Q1 = Q1 / T * 3.96828
Q2 = Q2 / T * 3.96828
OS = OS / T * 3.96828
US = US / T * 3.96828
C
RECONSTRUCTION OF FEED
C
Q = Q1 + Q2
FS = OS + US
FW = Q - FS
SO = OS / Q1 * 100.
SU = US / Q2 * 100.
FR = FS / Q * 100.
PW = 100. - FR
QG = FW*2000.*(1. + FR/(SG*(100. - FR)))/(60.*0.16054*62.4)
C
THE WATER DISTRIBUTION IN THE CYCLONE
C
OW = Q1 - OS
UW = Q2 - US
WO = 100. * OW / FW
WU = 100. * UW / FW
WD = 100. * FW / FW
C
C
C

```

THE SIZE PARTICLE DISTRIBUTION IN THE CYCLONE PRODUCTS

C
C

TO = 0.0
 TU = 0.0
 DO 41 I = 1, N
 TO = TO + OP (I)
 41 TU = TU + UP (I)
 DO 42 I = 1, N
 OP (I) = OP (I) / TO * 100.
 42 UP (I) = UP (I) / TU * 100.
 DO 5 I = 1, N
 OT (I) = OP (I) * OS / 100.
 UT (I) = UP (I) * US / 100.
 FT (I) = OT (I) + UT (I)
 5 FP (I) = FT (I) * 100. / FS
 SS = 0.
 SOP = 0.
 SUP = 0.
 DO 7 I = 1, N
 SS = SS + FP (I)
 SOP = SOP + OP (I)
 7 SUP = SUP + UP (I)

C
C
C

THE ASSESSMENT OF THE CLASSIFICATION OPERATION

DO 40 I = 1, N
 RD (I) = WU * FT (I) / 100.
 CS (I) = FT (I) - BD (I)
 CL (I) = CS (I) - OT (I)
 40 CP (I) = CL (I) * 100. / CS (I)
 BS = 0.
 TS = 0.
 TC = 0.
 DO 3 I = 1, N
 BS = BS + BD (I)
 TS = TS + CS (I)

```

C      3 TC = TC + CL (I)
C      C
C      THE MID-POINT (GEOMETRIC MEAN) OF EACH SIZE RANGE
      GM (I) = 350.
      NN = N - 1
      DO 50 I = 1, NN
      J = I + 1
      50 GM (J) = SQRTF (SZ (I) * SZ (J))
C      C
C      CALCULATION OF THE D50 (CORRECTED) VALUE
      I = 0
      65 I = I + 1
      IF (CP (I) - 50.) 51, 52, 53
      53 X1 = CP (I)
      S = GM (I)
      GO TO 65
      52 D50 = GM (I)
      GO TO 80
      51 D50 = S - (X1 - 50.) * (S - GM (I)) / (X1 - CP (I))
      80 DO 24 I = 1, N
C      C
C      THE ABSCISSA FOR THE CORRECTED EFFICIENCY CURVE
      24 X (I) = GM (I) / D50
      C
      RETURN
      END

```

APPENDIX B

Appendix B shows the relevant classification data for each experimental test. Table 1-B shows the mass flow rates of pulp, solids, and water in the cyclone feed, the mass flow rates of solids and water in the cyclone overflow, and the mass fraction of water to underflow. Table 2-B shows the size analysis of the cyclone products and the corrected d_{50} value.

Table 1-B: Mass flow rates in cyclone feed and overflow. Mass fraction of water to underflow

Test no.	Cyclone feed			Cyclone overflow			Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	Water TPH	Water TPH	
1	18.286	1.821	4.808	1.076	4.323	4.323	.1009
2	17.360	1.799	4.538	1.085	4.110	4.110	.0943
3	18.138	1.300	4.960	.802	4.670	4.670	.0585
4	30.997	1.207	8.860	.226	8.281	8.281	.0654
5	32.728	1.187	9.388	.149	8.767	8.767	.0662
6	25.370	.725	7.351	.143	6.975	6.975	.0510
7	22.188	2.900	5.574	2.182	5.194	5.194	.0682
8	19.949	2.592	5.017	1.748	4.572	4.572	.0887
9	19.070	1.739	5.075	.956	4.617	4.617	.0902
10	19.804	1.965	5.210	.838	4.571	4.571	.1227
11	18.251	1.865	4.781	1.120	4.375	4.375	.0849
12	17.215	1.588	4.574	.766	4.084	4.084	.1072

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Solids TPH	Water TPH	
13	20.904	1.610	.395	4.915	.1338
14	21.583	.391	.059	5.923	.0655
15	20.947	1.074	.127	5.297	.1007
16	25.234	3.347	2.328	5.721	.0949
17	23.271	2.976	2.014	5.283	.1001
18	20.510	2.634	1.737	4.634	.1037
19	17.715	2.251	1.467	4.022	.1010
20	17.234	1.909	1.111	4.017	.0990
21	19.330	2.022	1.124	4.541	.1000
22	25.899	2.675	2.096	6.436	.0500
23	32.688	3.226	3.124	8.307	.0348
24	20.634	2.420	1.515	4.825	.0876
25	25.178	2.607	1.337	5.869	.1084
26	24.521	2.292	1.119	5.564	.1446

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Solids TPH	Water TPH	
27	29.431	3.017	1.399	6.772	.1212
28	31.192	2.909	1.384	7.383	.1079
29	25.105	2.459	1.163	5.821	.1203
30	23.129	2.173	.925	5.395	.1201
31	20.000	1.882	.856	4.676	.1177
32	18.747	1.810	.874	4.376	.1162
33	16.544	1.574	.698	3.860	.1184
34	27.558	2.172	.624	6.559	.1211
35	24.165	1.994	.686	5.735	.1191
36	22.540	1.834	.692	5.416	.1095
37	22.579	3.375	2.215	4.892	.1126
38	18.319	2.729	1.701	3.920	.1241
39	15.318	2.262	1.357	3.243	.1351
40	32.105	2.279	.630	7.856	.1061

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Solids TPH	Water TPH	
41	25.937	1.865	.652	6.389	.0990
42	23.074	1.516	.591	5.801	.0882
43	18.473	1.278	.345	4.528	.1067
44	16.532	1.105	.242	4.039	.1126
45	26.393	3.230	1.935	5.994	.1071
46	23.692	2.846	1.644	5.404	.1062
47	20.267	2.260	1.231	4.680	.1066
48	16.629	1.909	.959	3.746	.1242
49	14.984	1.786	.804	3.316	.1340
50	29.493	2.513	.928	7.064	.1076
51	28.936	2.208	.846	7.121	.0944
52	24.872	2.019	.721	6.017	.1037
53	23.608	2.072	.930	5.687	.0992
54	35.113	3.950	1.386	7.741	.1457

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Solids TPH	Water TPH	
55	30.717	3.427	1.103	6.746	.1502
56	25.877	2.750	.597	5.614	.1669
57	27.486	2.850	.547	5.962	.1702
58	23.321	2.352	.353	5.056	.1741
59	19.852	1.748	.198	4.472	.1573
60	16.481	1.512	.163	3.653	.1665
61	15.651	1.503	.169	3.402	.1775
62	32.473	2.745	.504	7.528	.1370
63	21.965	2.776	.645	4.365	.2140
64	26.242	3.180	.868	5.446	.1856
65	30.451	3.198	.786	6.659	.1618
66	35.232	4.520	2.062	7.628	.1412
67	39.757	3.597	.833	9.192	.1321
68	39.332	3.615	.671	8.899	.1489

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Solids TPH	Water TPH	
69	32.302	2.679	.428	7.529	.1343
70	29.602	2.123	.228	7.044	.1299
71	20.419	3.323	2.381	4.422	.0943
72	16.722	2.536	1.725	3.658	.1009
73	19.455	2.749	1.952	4.407	.0837
74	18.232	2.484	1.560	4.158	.0846
75	34.722	3.119	2.770	9.075	.0197
76	29.550	2.383	2.105	7.825	.0197
77	15.137	1.013	.344	3.780	.0929
78	14.988	.925	.282	3.786	.0890
79	14.529	1.606	.614	3.285	.1263
80	14.505	1.660	.652	3.253	.1286
81	14.172	1.445	.480	3.231	.1302
82	22.153	2.176	.626	5.043	.1360

Table 1-B continued:

Test no.	Cyclone feed			Cyclone overflow			Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	Water TPH		
83	24.275	1.998	6.542	.635	5.859		.1043
84	25.809	1.780	7.085	.560	6.438		.0913
85	34.867	3.810	9.041	2.319	8.243		.0882
86	27.767	2.633	7.351	1.215	6.602		.1020
87	26.744	2.382	7.138	1.025	6.401		.1032
88	24.756	2.136	6.634	.948	5.980		.0986
89	26.101	2.567	6.875	1.107	6.092		.1140
90	20.946	1.686	5.659	.492	4.981		.1198
91	24.043	2.139	6.418	.967	5.785		.0987
92	19.350	1.584	5.218	.516	4.617		.1151
93	26.501	2.298	7.097	.973	6.378		.1013
94	26.556	2.968	6.861	1.514	6.078		.1142
95	21.833	2.307	5.691	1.067	5.007		.1202
96	18.242	1.518	4.908	.459	4.297		.1247

Table 1-B continued:

Test no.	Cyclone feed			Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	Water TPH	
97	14.340	1.314	3.814	.326	3.246	.1490
98	12.463	1.117	3.324	.089	2.718	.1822
99	24.626	2.149	6.590	.737	5.837	.1143
100	29.895	2.282	8.123	.760	7.305	.1007
101	27.441	2.254	7.397	.408	6.375	.1382
102	18.976	.935	5.350	.107	4.900	.0842
103	12.849	.654	3.615	.102	3.277	.0935
104	26.432	2.963	6.825	.399	5.495	.1949
105	15.930	1.643	4.168	.089	2.434	.4159
106	14.971	1.399	3.971	.082	2.198	.4465
107	32.899	3.753	8.471	.669	6.913	.1839
108	19.573	1.876	5.174	.124	3.240	.3738
109	30.323	3.729	7.706	.731	6.182	.1977

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	
110	21.178	2.670	5.357	.357	.2265
111	14.230	1.680	3.643	.108	.4414
112	14.439	1.705	3.696	.109	.4473
113	16.844	1.864	4.359	.118	.4014
114	31.890	3.613	8.221	3.070	.0367
115	28.940	3.339	7.437	2.758	.0417
116	27.514	2.987	7.142	1.495	.0916
117	26.304	2.549	6.943	1.282	.0996
118	23.372	2.244	6.177	1.015	.1081
119	20.162	1.831	5.368	.705	.1157
120	14.217	1.119	3.850	.234	.1332
121	17.060	2.124	4.326	1.047	.1364
122	29.021	3.266	7.489	2.749	.0369

Table 1-B continued:

Test no.	Cyclone feed			Cyclone overflow			Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	Water TPH		
123	29.797	3.202	7.747	2.666	7.460		.0370
124	29.520	2.898	7.778	2.353	7.499		.0359
125	28.859	3.245	7.448	2.741	7.173		.0369
126	18.745	2.482	4.697	1.382	4.120		.1228
127	22.144	2.747	5.618	1.526	4.990		.1119
128	25.659	2.547	6.750	1.905	6.422		.0487
129	19.897	2.234	5.137	1.157	4.590		.1064
130	31.389	2.640	8.437	2.143	8.161		.0328
131	26.659	2.945	6.901	1.080	5.789		.1610
132	24.137	2.469	6.322	.771	5.293		.1628
133	18.464	1.718	4.901	.463	4.058		.1721
134	14.972	1.262	4.023	.266	3.328		.1729
135	11.158	.871	3.024	.174	2.501		.1730
136	31.088	2.697	8.325	.742	7.243		.1300

Table 1-B continued:

Test no.	Cyclone feed		Cyclone overflow		Mass fraction of water to underflow
	Pulp GPM	Solids TPH	Water TPH	Solids TPH	
137	28.211	2.702	7.459	.924	.1352
138	25.717	2.293	6.864	.592	.1441
139	26.032	2.399	6.918	.711	.1420
140	24.485	2.241	6.513	.633	.1431
141	25.068	2.161	6.718	.492	.1488
142	28.936	2.978	7.573	1.223	.1283
143	23.589	2.044	6.318	.500	.1427
144	20.308	1.770	5.435	.324	.1583
145	20.570	1.769	5.514	.303	.1583

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
6	Overflow	----	.08	2.18	3.44	24.06	24.61	45.63		25.4
	Underflow	----	2.34	15.15	28.29	22.52	12.96	18.74		
7	Overflow	1.60	5.65	18.20	22.55	16.40	10.30	25.30		365.0
	Underflow	5.15	13.35	30.95	19.90	14.60	6.65	9.40		
8	Overflow	.50	4.65	18.25	18.65	18.65	11.35	27.95		245.6
	Underflow	4.75	11.65	29.60	24.25	13.00	6.05	10.70		
9	Overflow	.05	1.20	8.40	18.50	18.15	12.95	40.75		133.5
	Underflow	3.10	13.15	34.40	21.85	14.15	5.50	7.85		
10	Overflow	.05	1.10	8.66	15.95	24.03	12.12	38.09		105.8
	Underflow	3.20	10.70	30.80	26.95	13.30	5.65	9.40		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270				
11	Overflow	.15	2.45	12.45	21.20	17.65	11.70	34.40	152.9			
	Underflow	3.95	13.80	35.15	20.90	13.05	5.25	7.90				
12	Overflow	.05	.95	7.20	14.15	22.90	13.80	40.95	109.1			
	Underflow	3.35	10.75	31.20	27.05	13.10	5.60	8.95				
13	Overflow	.19	.81	4.12	8.72	19.97	14.37	51.82	67.6			
	Underflow	2.86	10.00	32.15	29.29	13.39	5.42	6.89				
14	Overflow	1.12	4.51	4.23	3.10	3.66	3.66	79.72	21.3			
	Underflow	.50	3.88	18.33	20.32	20.62	11.70	24.65				
15	Overflow	.78	2.34	1.95	1.75	4.29	7.02	81.87	32.5			
	Underflow	2.16	9.73	30.70	22.65	16.92	7.89	9.95				

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
16	Overflow	.81	8.18	23.28	18.08	16.62	8.54	24.49	291.6	
	Underflow	4.74	13.46	33.42	22.46	11.01	5.39	9.52		
17	Overflow	.83	5.88	21.08	21.08	14.61	9.46	27.06	236.3	
	Underflow	4.48	16.30	35.05	18.23	12.24	4.95	8.75		
18	Overflow	.42	6.56	22.12	17.83	16.51	9.84	26.72	253.5	
	Underflow	5.10	14.53	34.01	22.19	10.47	4.74	8.96		
19	Overflow	.48	4.96	20.30	21.43	15.04	10.09	27.70	201.9	
	Underflow	5.10	18.04	35.92	17.27	11.10	4.41	8.16		
20	Overflow	.14	5.02	19.04	17.62	18.31	11.28	28.59	160.1	
	Underflow	4.42	15.19	36.49	22.31	9.81	4.23	7.55		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270	
21	Overflow	.36	3.18	15.13	20.00	15.95	13.17	32.21	150.9
	Underflow	3.24	17.32	36.35	18.78	11.95	4.16	7.59	
22	Overflow	.50	7.48	22.70	17.57	16.93	9.14	25.68	299.3
	Underflow	4.44	13.73	34.45	22.94	10.95	4.89	8.60	
23	Overflow	1.80	7.55	22.99	21.69	13.86	9.24	22.87	350.0
	Underflow	8.24	22.34	36.02	14.97	7.81	3.90	6.72	
24	Overflow	4.06	8.86	24.29	19.49	13.81	7.88	21.60	229.2
	Underflow	19.47	21.69	26.83	14.61	5.88	5.51	6.01	
25	Overflow	.05	3.60	15.81	17.98	19.75	11.97	30.84	133.5
	Underflow	1.60	12.78	36.39	20.72	14.56	5.78	8.17	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
26	Overflow	.04	2.34	13.85	18.73	18.57	13.61	32.87		124.3
	Underflow	1.51	9.95	36.78	23.72	13.52	5.73	8.79		
27	Overflow	.05	3.16	14.47	17.53	20.16	12.26	32.37		116.5
	Underflow	1.45	12.09	35.55	21.27	15.23	6.27	8.14		
28	Overflow	.05	2.40	13.13	18.22	18.32	13.85	34.04		113.9
	Underflow	1.52	10.13	35.65	23.91	13.83	5.96	9.00		
29	Overflow	.00	2.59	13.68	17.14	20.41	12.64	33.55		115.2
	Underflow	1.23	11.97	35.25	22.46	15.20	5.94	7.95		
30	Overflow	.00	1.78	10.83	16.61	18.26	15.13	37.39		100.5
	Underflow	1.16	9.79	35.88	24.38	13.65	5.97	9.18		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
31	Overflow	.00	1.85	11.10	16.17	21.15	13.30	36.43		
	Underflow	1.13	11.78	34.88	22.82	15.45	6.20	7.75		108.2
32	Overflow	.00	2.05	13.36	18.52	18.43	12.75	34.89		
	Underflow	1.42	10.62	36.11	24.12	13.27	5.83	8.63		117.7
33	Overflow	.00	1.46	10.82	17.12	18.22	13.33	39.04		
	Underflow	1.37	11.03	35.94	24.49	13.33	5.77	8.08		105.4
34	Overflow	.00	.89	4.18	9.58	14.84	16.85	53.66		
	Underflow	.86	8.02	32.83	25.35	16.10	7.38	9.47		67.0
35	Overflow	.00	.89	6.53	11.44	19.70	14.06	47.38		
	Underflow	.71	10.15	32.40	24.18	17.40	6.94	8.21		75.5

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
36	Overflow	.00	1.00	7.11	13.88	17.66	16.22	44.13	84.2
	Underflow	1.02	8.57	34.90	25.47	14.82	6.33	8.90	
37	Overflow	.04	3.49	17.21	18.25	16.94	11.70	32.36	230.6
	Underflow	1.00	9.10	31.39	22.49	14.43	7.36	14.23	
38	Overflow	.00	2.67	16.21	18.11	17.82	12.18	33.00	187.9
	Underflow	.89	9.29	31.11	22.18	14.67	7.60	14.27	
39	Overflow	.00	2.44	14.13	17.69	17.29	11.07	37.38	168.5
	Underflow	.63	10.66	29.91	21.10	13.19	10.21	14.28	
40	Overflow	.00	.63	1.73	4.70	13.23	14.43	65.27	52.1
	Underflow	.52	6.41	27.60	24.69	18.07	9.43	13.28	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
		Aperture size							microns
41	Overflow	.00	.80	3.07	7.27	17.35	17.82	53.70	73.9
	Underflow	.50	6.74	29.77	25.83	17.66	8.17	11.33	
42	Overflow	.00	.90	3.18	7.85	13.35	13.39	61.33	64.0
	Underflow	.25	7.03	28.60	23.77	17.75	9.79	12.80	
43	Overflow	.00	1.15	.84	2.46	7.12	10.68	77.75	43.4
	Underflow	.32	6.60	26.36	23.04	13.52	17.04	13.12	
44	Overflow	.00	1.35	.88	1.00	3.41	3.82	89.53	38.7
	Underflow	.35	5.62	24.82	24.07	19.51	11.33	14.29	
45	Overflow	.09	3.41	17.80	17.85	15.98	12.10	32.76	169.4
	Underflow	2.51	12.00	34.84	21.02	12.00	6.05	11.58	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.)	
		-48	48/65	65/100	100/150	150/200	200/270	-270	microns				
		Aperture size											
46	Overflow	.05	2.94	13.81	16.65	15.98	15.05	35.52					146.4
	Underflow	2.20	11.41	36.07	20.21	12.36	5.97	11.78					
47	Overflow	.00	1.25	11.53	15.93	17.31	12.18	41.81					129.8
	Underflow	1.21	12.88	32.65	21.72	13.21	7.12	11.21					
48	Overflow	.00	.92	8.19	15.00	17.10	15.92	42.86					117.3
	Underflow	1.49	10.30	36.38	22.00	12.64	5.87	11.32					
49	Overflow	.00	.45	6.77	15.16	18.25	17.58	41.79					107.9
	Underflow	.92	12.07	33.04	22.35	13.27	7.05	11.29					
50	Overflow	.00	1.58	5.49	10.87	13.20	16.92	51.94					73.3
	Underflow	.89	9.63	29.44	23.74	15.89	8.46	11.96					

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
51	Overflow	.00	.50	3.80	8.45	13.49	20.12	53.64	76.4	
	Underflow	.63	7.04	28.36	25.84	16.90	8.06	13.16		
52	Overflow	.00	1.13	3.62	7.87	12.76	29.10	45.52	77.15	
	Underflow	.61	9.08	28.75	24.28	16.27	8.52	12.49		
53	Overflow	.00	.79	5.67	11.09	15.14	24.65	42.65	90.0	
	Underflow	1.13	11.85	31.85	23.06	14.35	8.23	9.52		
54	Overflow	.05	1.55	10.26	16.22	17.56	16.27	38.08	86.9	
	Underflow	2.67	13.78	32.96	22.17	13.01	6.30	9.11		
55	Overflow	.00	1.12	7.69	13.90	16.66	18.39	42.23	81.5	
	Underflow	2.40	10.90	33.51	23.87	13.51	5.89	9.92		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	microns	
56	Overflow	.00	.60	3.06	6.97	13.33	21.74	54.29	62.4	
	Underflow	1.68	10.89	29.97	22.93	15.54	8.32	10.67		
57	Overflow	.00	1.11	1.28	3.44	8.57	32.54	53.06	66.27	
	Underflow	1.19	7.64	28.16	24.57	17.04	8.52	12.88		
58	Overflow	.00	1.83	1.51	2.26	5.16	31.94	57.31	33.2	
	Underflow	.79	8.54	26.48	22.79	17.12	10.94	13.34		
59	Overflow	.00	2.10	3.06	1.94	2.74	7.90	82.26	22.3	
	Underflow	.68	5.54	23.53	22.29	17.67	10.76	19.52		
60	Overflow	.00	2.36	1.79	1.98	2.08	7.64	84.15	22.4	
	Underflow	.55	7.37	24.20	21.29	16.74	11.01	18.84		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
61	Overflow	.00	1.89	2.61	1.98	2.88	9.64	80.99	23.0
	Underflow	.92	6.33	24.90	22.28	17.06	10.00	18.52	
62	Overflow	.00	1.87	1.68	2.71	5.48	16.45	71.81	35.8
	Underflow	.64	7.79	25.12	22.26	16.77	11.28	16.13	
63	Overflow	.00	.32	3.72	12.30	19.68	17.73	46.25	75.2
	Underflow	7.12	11.22	31.41	22.44	13.15	5.84	8.82	
64	Overflow	.00	1.76	8.54	14.37	13.49	22.85	38.99	75.1
	Underflow	5.68	14.08	30.76	20.94	11.41	8.23	8.90	
65	Overflow	.00	.93	5.32	11.51	16.55	17.53	48.16	66.3
	Underflow	5.40	10.04	29.97	22.58	14.57	7.02	10.41	

Table 2-B continued

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270	
66	Overflow	1.65	8.08	20.80	19.10	10.47	16.46	23.44	137.3
	Underflow	8.93	16.02	30.79	19.27	10.35	7.01	7.63	
67	Overflow	.05	.98	5.60	11.05	15.06	14.39	52.88	56.9
	Underflow	8.46	16.70	31.61	19.58	9.65	6.72	7.27	
68	Overflow	.00	.98	4.00	7.94	9.48	20.37	57.23	66.0
	Underflow	8.14	12.90	33.35	20.87	11.79	5.14	7.80	
69	Overflow	.00	.38	1.63	4.51	8.64	11.71	73.14	39.7
	Underflow	7.24	14.78	29.52	19.82	8.03	11.21	9.40	
70	Overflow	.00	.61	1.65	1.83	2.87	9.13	83.91	25.2
	Underflow	3.58	12.35	27.61	20.04	9.67	12.84	13.91	

Table 2-B continued:

Test no.	Cylone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
		Aperture size							microns
71	Overflow	5.37	13.19	23.74	17.73	4.01	16.61	19.35	343.0
	Underflow	17.61	14.91	29.90	16.92	9.19	2.42	9.07	
72	Overflow	4.73	9.75	25.23	19.09	13.14	7.36	20.70	278.2
	Underflow	17.62	21.93	25.91	15.16	5.01	7.51	6.87	
73	Overflow	3.66	11.40	22.29	18.32	6.35	15.63	22.34	315.4
	Underflow	15.99	14.94	30.44	17.43	9.53	4.07	7.61	
74	Overflow	2.42	8.10	24.35	20.16	14.25	7.96	22.27	220.0
	Underflow	17.25	23.95	26.25	15.11	3.45	8.33	5.67	
75	Overflow	8.85	14.68	23.31	17.14	12.32	6.50	17.20	212.7
	Underflow	18.30	20.01	27.82	15.68	8.72	3.19	6.27	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
76	Overflow	6.68	13.47	23.16	17.76	13.42	7.41	18.10	218.0	
	Underflow	15.13	19.81	27.99	16.69	10.00	3.70	6.69		
77	Overflow	.05	1.26	5.60	11.30	17.61	27.04	37.14	86.3	
	Underflow	6.29	18.06	34.66	17.89	11.64	5.35	6.12		
78	Overflow	.00	.85	4.06	8.22	17.43	22.09	47.34	78.8	
	Underflow	4.65	17.12	30.03	21.82	14.04	5.26	7.08		
79	Overflow	.00	4.66	9.62	12.73	15.39	17.69	39.91	110.7	
	Underflow	19.55	19.55	28.75	12.81	8.25	4.35	6.74		
80	Overflow	.33	4.87	14.46	16.10	14.84	14.79	34.61	124.7	
	Underflow	21.74	21.95	27.00	13.29	6.96	2.63	6.44		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
81	Overflow	.00	1.66	6.26	11.34	15.22	21.33	44.20	91.9
	Underflow	14.98	20.57	28.85	15.78	8.98	3.43	7.41	
82	Overflow	.00	2.17	5.32	9.20	12.75	18.27	52.30	77.9
	Underflow	14.57	20.35	30.48	11.42	9.92	5.37	7.90	
83	Overflow	.00	1.06	2.79	5.85	10.78	23.55	55.95	77.2
	Underflow	11.04	16.72	26.50	17.62	12.03	5.45	10.64	
84	Overflow	.00	.17	2.17	3.60	7.31	27.00	59.76	71.3
	Underflow	7.38	17.46	25.99	16.11	13.55	8.28	11.24	
85	Overflow	.06	7.36	20.06	17.63	15.96	11.10	27.83	192.8
	Underflow	.81	17.31	34.52	20.16	12.46	5.23	9.51	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	microns	
86	Overflow	.00	1.28	8.26	13.65	17.68	17.87	41.26		100.4
	Underflow	.26	13.59	32.82	22.44	14.70	6.16	10.01		
87	Overflow	.00	1.12	7.72	12.91	16.91	22.10	39.25		93.7
	Underflow	.58	11.79	35.86	20.75	14.16	7.44	9.41		
88	Overflow	.00	1.09	6.67	12.05	17.44	24.94	37.82		93.8
	Underflow	.30	13.41	31.91	22.36	14.99	6.35	10.67		
89	Overflow	.00	1.77	12.74	15.82	18.33	18.16	33.18		112.4
	Underflow	.59	14.82	40.56	18.01	11.95	6.33	7.73		
90	Overflow	.00	1.02	1.19	2.90	9.32	31.31	54.26		71.9
	Underflow	.19	10.76	28.11	22.77	17.63	8.49	12.02		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
		Aperture size							microns
91	Overflow	.00	1.46	9.86	15.90	17.81	18.70	36.26	114.0
	Underflow	.66	15.74	38.26	18.42	12.25	6.58	8.10	
92	Overflow	.00	.87	2.80	7.33	15.32	28.71	44.97	79.3
	Underflow	.29	13.52	32.86	22.58	15.33	6.49	8.93	
93	Overflow	.00	.89	6.82	12.53	15.97	32.22	31.56	86.8
	Underflow	.19	10.07	33.32	23.85	15.08	7.15	10.35	
94	Overflow	.00	2.87	14.29	18.05	16.03	15.02	33.75	133.4
	Underflow	.80	12.65	39.73	20.15	12.02	5.67	8.99	
95	Overflow	.00	1.33	10.88	16.56	17.52	19.76	33.96	117.6
	Underflow	.51	14.41	37.17	20.02	11.98	6.59	9.32	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270	
96	Overflow	.00	.79	1.46	3.59	4.74	29.97	59.45	71.7
	Underflow	.41	8.56	33.61	23.16	16.14	7.53	10.60	
97	Overflow	.00	.19	1.29	5.49	13.12	32.51	47.38	77.7
	Underflow	.04	17.78	36.33	19.96	12.07	5.12	8.70	
98	Overflow	.00	2.39	1.59	2.52	3.72	5.98	83.80	31.0
	Underflow	.05	19.38	36.85	17.93	11.32	6.07	8.42	
99	Overflow	.00	1.28	6.34	11.72	15.36	22.73	42.57	85.1
	Underflow	.10	19.15	36.86	18.91	11.36	5.15	8.47	
100	Overflow	.00	.80	3.26	8.00	13.67	17.55	56.72	74.1
	Underflow	.12	15.66	33.62	19.72	13.59	7.10	10.19	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d50 (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
101	Overflow	.00	.54	1.62	4.21	8.36	17.38	67.89	46.2	
	Underflow	.05	13.91	32.17	19.67	14.95	8.41	10.85		
102	Overflow	.00	3.93	3.61	2.19	2.73	8.42	79.13	18.8	
	Underflow	.01	7.61	21.19	17.33	15.80	11.99	26.07		
103	Overflow	.00	1.66	1.07	1.30	2.25	3.68	90.04	24.1	
	Underflow	.01	11.62	20.52	19.55	14.80	10.30	23.20		
104	Overflow	.00	.68	.87	1.80	3.60	18.09	74.95	36.7	
	Underflow	.04	16.63	26.78	20.42	14.39	8.39	13.35		
105	Overflow	.00	3.22	3.22	3.61	5.27	8.11	76.56	18.4	
	Underflow	.04	14.51	23.65	18.41	13.97	8.24	21.18		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270				
106	Overflow	.00	4.02	2.93	3.37	5.10	8.90	75.68	19.0			
	Underflow	.05	13.30	22.84	18.56	14.34	8.65	22.26				
107	Overflow	.00	.17	.96	2.35	6.17	24.52	65.83	64.3			
	Underflow	.05	17.44	33.12	18.61	12.47	6.82	11.50				
108	Overflow	.00	4.13	4.05	3.29	3.53	8.85	76.16	18.5			
	Underflow	.04	12.34	25.82	16.22	12.43	9.73	23.42				
109	Overflow	.00	1.10	1.34	2.33	7.33	26.40	61.51	67.5			
	Underflow	.05	20.39	26.48	19.29	13.50	7.04	13.24				
110	Overflow	.00	1.27	2.22	2.28	3.49	19.20	71.55	33.9			
	Underflow	.05	14.99	30.34	17.62	13.23	8.83	14.94				

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270				
111	Overflow	.00	2.57	2.30	3.12	4.41	10.74	76.86	19.6			
	Underflow	.05	17.48	20.94	17.28	12.97	8.32	22.97				
112	Overflow	.00	2.54	3.47	3.55	4.47	12.57	73.40	20.0			
	Underflow	.08	12.97	26.19	16.73	12.81	10.28	20.93				
113	Overflow	.00	4.30	2.89	3.02	5.51	9.20	75.08	18.6			
	Underflow	.09	15.25	22.52	17.08	13.09	8.63	23.32				
114	Overflow	.00	19.25	21.51	13.02	11.53	12.36	22.34	292.0			
	Underflow	.12	19.21	36.05	18.38	10.87	5.32	10.05				
115	Overflow	.00	12.35	25.26	16.68	13.41	10.47	21.83	281.1			
	Underflow	.10	23.75	31.81	18.14	10.62	5.21	10.37				

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained								d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270		
116	Overflow	.00	5.70	13.25	16.46	15.86	15.05	33.68		129.1
	Underflow	.05	25.50	29.34	18.51	11.20	5.60	9.81		
117	Overflow	.00	2.98	12.14	15.40	16.36	16.58	36.54		122.1
	Underflow	.05	16.96	35.70	19.49	12.06	6.07	9.67		
118	Overflow	.00	2.84	9.24	14.67	16.68	19.13	37.43		110.8
	Underflow	.07	23.24	30.93	18.52	11.93	5.52	9.79		
119	Overflow	.00	.45	4.95	11.05	16.12	26.01	41.43		87.7
	Underflow	.04	16.32	34.74	20.04	12.75	6.44	9.68		
120	Overflow	.00	1.17	.96	1.54	5.58	30.27	60.49		62.1
	Underflow	.06	15.70	24.13	20.06	15.04	10.41	14.60		

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.)
		-48	48/65	65/100	100/150	150/200	200/270	-270	
		Aperture size							microns
121	Overflow	.00	3.49	14.30	17.24	15.87	12.59	36.53	140.3
	Underflow	.13	23.34	35.58	16.48	9.93	5.19	9.35	
122	Overflow	.00	17.07	24.96	18.01	13.03	7.89	19.05	287.2
	Underflow	.11	24.97	33.39	18.20	9.79	4.34	9.21	
123	Overflow	.00	15.92	24.33	16.24	12.38	10.08	21.06	286.3
	Underflow	.11	23.30	35.46	17.57	9.91	4.77	8.89	
124	Overflow	.00	13.19	21.66	17.32	13.39	8.58	25.85	279.9
	Underflow	.06	24.01	32.60	18.70	10.45	4.75	9.44	
125	Overflow	.00	14.23	24.67	17.34	12.44	9.17	22.14	284.6
	Underflow	.05	25.30	33.51	17.14	10.45	4.90	8.65	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained							d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270	
126	Overflow	.00	8.01	22.04	18.13	13.83	10.66	27.33	182.4
	Underflow	.10	33.59	32.15	13.99	8.26	4.13	7.77	
127	Overflow	.00	9.71	19.23	16.92	13.72	8.90	31.52	168.2
	Underflow	.13	30.51	32.40	16.20	8.71	3.98	8.08	
128	Overflow	.00	8.60	21.50	16.91	13.42	11.04	28.53	241.3
	Underflow	.09	30.24	32.44	14.65	9.36	4.75	8.47	
129	Overflow	.00	5.87	15.45	16.67	15.18	10.12	36.71	142.3
	Underflow	.11	27.80	32.93	17.15	9.23	4.10	8.68	
130	Overflow	.00	9.31	20.69	15.64	12.18	11.91	30.27	264.8
	Underflow	.11	29.07	31.53	15.99	9.39	4.86	9.06	

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns
		-48	48/65	65/100	100/150	150/200	200/270	-270				
131	Overflow	.00	.42	4.50	11.20	17.17	24.45	42.25	86.9			
	Underflow	.05	11.78	31.51	20.33	14.17	8.51	13.66				
132	Overflow	.00	.25	1.70	6.55	14.62	17.77	59.11	70.2			
	Underflow	.09	10.59	26.49	21.95	15.99	8.86	16.03				
133	Overflow	.00	.18	.61	3.30	9.41	20.05	66.44	62.3			
	Underflow	.04	8.67	24.03	21.74	17.57	10.38	17.57				
134	Overflow	.00	.28	.61	1.72	6.67	12.68	78.03	39.4			
	Underflow	.02	6.86	23.10	20.31	18.46	13.54	17.70				
135	Overflow	.00	.20	.59	2.17	5.72	15.26	76.05	31.1			
	Underflow	.02	5.66	18.98	20.12	18.63	12.77	23.80				

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns	
		-48	48/65	65/100	100/150	150/200	200/270	-270					
136	Overflow	.00	.30	2.48	6.84	12.25	19.68	58.45					
	Underflow	.11	13.03	28.82	21.37	14.63	8.34	13.69					66.2
137	Overflow	.00	.58	3.40	9.35	16.91	18.70	51.07					
	Underflow	.05	9.48	30.97	21.87	15.29	8.72	13.63					77.1
138	Overflow	.00	.14	.75	4.01	11.22	19.59	64.29					
	Underflow	.05	10.07	25.59	22.70	17.20	9.31	15.08					61.0
139	Overflow	.00	.37	1.42	6.10	14.86	19.79	57.46					
	Underflow	.03	8.58	28.34	22.75	16.48	9.09	14.74					68.3
140	Overflow	.00	.13	1.25	6.12	13.03	19.95	59.51					
	Underflow	.05	12.70	26.73	22.14	15.87	8.86	13.65					66.8

Table 2-B continued:

Test no.	Cyclone product	Weight percent retained										d ₅₀ (corr.) microns	
		-48	48/65	65/100	100/150	150/200	200/270	-270					
141	Overflow	.00	.26	.52	2.34	10.29	19.47	67.12					48.8
	Underflow	.05	8.04	26.32	21.53	17.46	10.57	16.03					
142	Overflow	.00	1.84	10.56	15.59	17.32	14.69	40.00					102.7
	Underflow	.08	19.93	31.67	20.56	12.05	6.26	9.44					
143	Overflow	.00	.35	1.15	4.67	13.03	17.69	63.11					57.8
	Underflow	.02	10.37	31.77	21.94	16.18	8.64	11.07					
144	Overflow	.00	.31	.57	2.27	7.12	13.79	75.94					43.41
	Underflow	.05	15.40	25.93	21.05	16.03	9.06	12.48					
145	Overflow	.00	.33	.38	1.54	6.91	13.82	77.02					40.6
	Underflow	.00	9.92	29.31	21.48	16.58	9.97	12.73					

APPENDIX C

Appendix C shows the percent difference between experimental value and value predicted from the mathematical model. QC represents the predicted feed pulp flow rate (g.p.m.). WOC represents the predicted mass flow rate of water to overflow, and $d_{50} C$ represents the predicted log d_{50} (corrected).

1

TEST NO.	PERCENT DIFFERENCE BETWEEN EXPERIMENTAL VALUE AND VALUE PREDICTED FROM MODEL.		
	QC	WOC	D50C
1	2.26	-.35	-3.91
2	-1.48	-1.75	-4.00
3	3.41	-4.50	10.82
4	-1.75	.95	-2.55
5	-2.64	1.38	8.10
6	-3.04	-1.78	-.92
7	1.10	-2.31	-1.23
8	2.81	-1.21	1.93
9	.45	-.91	-3.94
10	1.08	3.04	5.43
11	1.69	-2.15	-2.78
12	2.66	-.25	-1.14
13	2.10	5.29	5.66
14	1.75	-1.42	-.44
15	2.69	1.75	10.55
16	-1.10	1.75	8.47
17	-2.83	1.66	7.05
18	.44	.77	1.61
19	-2.44	-1.17	.83
20	-2.77	-1.45	-1.48
21	1.98	.11	-.22

TEST NO.	PERCENT DIFFERENCE BETWEEN EXPERIMENTAL VALUE AND VALUE PREDICTED FROM MODEL.		
	QC	WOC	D50C
22	1.24	-2.52	-5.90
23	-.33	-2.41	-4.47
24	3.07	-.77	-1.06
25	.25	-.59	-.99
26	1.79	3.45	-6.13
27	-1.55	2.75	6.40
28	-1.83	1.95	2.31
29	-1.83	.83	-1.40
30	-1.68	-.24	-2.95
31	1.57	-2.67	-7.62
32	.62	-3.97	-9.48
33	-3.35	-5.98	-10.22
34	-1.74	2.36	-.65
35	-2.75	.46	-2.53
36	-.79	-1.53	-6.91
37	1.76	-2.63	7.63
38	.56	-4.92	2.57
39	-1.55	-7.46	-2.13
40	-1.15	2.34	3.26
41	2.42	-.73	-7.73
42	1.43	-3.24	-10.06

TEST
PERCENT DIFFERENCE BETWEEN EXPERIMENTAL
VALUE AND VALUE PREDICTED FROM MODEL.

NO.	QC	WOC	D50C
43	2.28	-4.59	-.92
44	4.99	-5.86	-.13
45	-2.62	-.50	6.70
46	-2.42	-1.98	4.25
47	1.12	-4.08	-2.71
48	-.37	-5.82	-4.56
49	-.39	-7.11	-3.81
50	.15	1.45	4.67
51	-2.06	-.10	-3.52
52	-.48	-.88	-3.30
53	-1.95	-2.16	-3.69
54	-.70	-.38	3.48
55	-.26	-2.34	-2.67
56	.46	-4.01	-8.15
57	-1.35	-2.13	-8.98
58	.29	-5.64	-.19
59	-2.62	-11.52	-2.92
60	-2.02	-16.97	-5.50
61	1.90	-18.11	-4.98
62	-3.30	-2.06	-4.46
63	-5.67	-3.69	-6.90

TEST
PERCENT DIFFERENCE BETWEEN EXPERIMENTAL
VALUE AND VALUE PREDICTED FROM MODEL.

NO.	QC	WOC	D50C
64	-1.73	-2.00	-1.42
65	-.10	-.98	-3.61
66	-1.82	-1.25	6.70
67	-1.30	.53	-2.04
68	-2.39	2.33	4.39
69	-2.33	-2.42	-8.97
70	-2.98	-4.25	-10.66
71	1.24	-.91	9.72
72	-.05	-2.46	1.83
73	-1.02	-2.23	1.06
74	1.65	-2.79	3.56
75	-.15	-3.49	.05
76	1.30	-4.38	-10.33
77	-.62	-2.99	-7.82
78	1.90	-3.46	-7.93
79	2.13	-8.34	-8.07
80	1.17	-8.27	-9.09
81	-4.07	-8.23	-7.87
82	-1.66	.87	4.11
83	-1.42	-1.12	-3.10
84	.69	-1.58	-9.08

TEST NO.	PERCENT DIFFERENCE BETWEEN EXPERIMENTAL VALUE AND VALUE PREDICTED FROM MODEL.		
	QC	WOC	D50C
85	-.22	.60	7.30
86	.37	.00	2.58
87	-.93	-.19	-.77
88	-.17	-1.59	-4.43
89	-1.18	.56	.58
90	-2.15	-1.42	-5.25
91	2.00	-2.00	-7.40
92	-1.35	-3.20	-7.94
93	4.21	-.47	-.89
94	-.04	.56	5.71
95	-2.32	-1.30	-1.44
96	-3.55	-3.21	-5.89
97	-2.33	-5.57	-7.92
98	-2.20	-5.26	13.42
99	.08	.07	-1.83
100	1.38	.95	-2.15
101	-1.49	4.28	12.69
102	2.36	-6.10	13.17
103	6.16	-12.54	5.28
104	-2.87	-.36	11.18
105	-4.84	15.77	7.03

TEST
PERCENT DIFFERENCE BETWEEN EXPERIMENTAL
VALUE AND VALUE PREDICTED FROM MODEL.

NO.	QC	WOC	D50C
106	-6.94	19.24	-1.43
107	.33	3.01	8.66
108	.17	18.02	8.75
109	-.49	2.81	10.24
110	-.35	-3.31	12.74
111	2.07	12.68	9.49
112	.58	14.83	9.33
113	-3.48	15.33	13.45
114	-.70	-2.50	7.04
115	-.77	-2.67	5.32
116	-4.86	2.39	15.68
117	-.38	3.05	8.24
118	.46	3.05	6.74
119	2.30	2.55	6.04
120	-.09	.36	3.71
121	3.44	2.41	6.13
122	-.24	-3.11	3.39
123	1.05	-2.86	1.37
124	2.21	-2.95	-3.98
125	-2.21	-3.14	3.31
126	2.98	1.87	6.67

TEST NO.	PERCENT DIFFERENCE BETWEEN EXPERIMENTAL VALUE AND VALUE PREDICTED FROM MODEL.		
	QC	WOC	D50C
127	1.86	2.56	10.43
128	1.44	-2.68	-4.57
129	2.76	1.02	5.07
130	.11	-2.75	-10.12
131	.68	6.27	15.12
132	-.53	5.29	11.74
133	-2.19	2.32	2.31
134	4.44	-1.62	6.57
135	-6.13	-9.03	7.47
136	.30	4.60	9.99
137	2.14	3.41	10.00
138	.64	4.09	8.50
139	-1.44	3.93	8.06
140	1.14	3.28	6.47
141	.31	4.39	11.93
142	.24	3.38	8.96
143	2.27	2.81	6.09
144	2.64	2.43	10.93
145	1.67	2.67	12.55

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