PROCEEDINGS OF THE SYMPOSIUM

SOLIDS/LIQUIDS

SEPARATION PRACTICE

27-29 March 1979

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Institution of Chemical Engineers, Yorkshire Branch

SOLIDS/LIQUIDS SEPARATION SYMPOSIUM

March 1979

Welcome to Leeds and in particular to the Chemical Engineering Department situated in the Houldsworth School of Applied Science, the University of Leeds. The School accommodates four academic departments; Metallurgy, Fuel and Combustion Science, Ceramics, Chemical Engineering. The Chemical Engineering Department has a total of approximately 220 undergraduates studying for BSc degrees and 40 graduate students undertaking courses leading to the degrees of MSc, MPhil, and PhD. The department has seventeen full time academic staff, headed by Professor Colin McGreavy.

The presentations associated with the papers published in this proceedings will take place, according to the programme, in lecture theatre A of the Houldsworth School. It is situated on the second floor at the west end of the building. Signs will be erected at each of the three entrances to the building.

The Symposium Dinner will be held at the Parkway Hotel some five miles from the University on the A660 Leeds to Otley. Transport to and from the Hall of residence will be available on the evening and more details will be given at the Symposium. It is hoped that everyone will attend the Symposium Dinner.

Members of the Institution of Chemical Engineers will be glad to know that the President, Mr J. Solbett, will be attending on Wednesday, 28th March, and at the Conference Dinner on Tuesday evening.

For Wednesday evening a number of theatre tickets have been reserved and details of availability will be given at the Symposium.

As the Symposium is being held during the Easter vacation adequate parking will be available close to the Charles Morris Hall in Mount Preston Street.

Registration will take place from 10.30 — 11.15 on Tuesday, 27th March on the Mezzanine floor (between ground and 1st floors) at the east end of the School building. Tea and coffee will be available at this time and will also be served in the same location during the symposium. Registrants arriving on Monday evening should report directly to the Charles Morris Hall of residence, providing they have reserved accommodation. Arrangements have been made to ensure that porters will be available to distribute room keys to named individuals and to assist with baggage. Registrants, with reserved accommodation in Charles Morris, arriving on Tuesday may report to Charles Morris before registration or at the end of the first morning proceedings, during lunch.

With the exception of the Symposium Dinner, lunches and dinner will be taken in the Charles Morris Hall of residence. Lunch, coffee and tea are provided for all registrants, but only those with accommodation in the Hall will be expected for Dinner. Early morning tea is available to residents in Charles Morris.

Programme

Tuesday, 27th March

10.30 — 11.15 Registration and Coffee in the Houldsworth School

11.15 — 11.45 Welcome and Introduction.
I. Chem. E. Yorkshire Branch Chairman: M. G. D. Bailey

Session 1 *Chairman:* M. D. G. Bailey

11.45 — 12.00 Large Scale Tests of Sedimenting Centrifuges and Hydrocyclones for Mathematical Modelling of Efficiency
K. R. Gibson, English China Clays

12.00 — 14.00 Lunch in Charles Morris Hall

Session 2 *Chairman:* Dr J. F. Jackson

14.00 — 4.45 Aspects of Centrifuge Operation and Installation
R. M. McCarthy, J. A. Moir, Pennwalt Ltd

14.45 — 15.30 The Geometry of Scroll Centrifuges
E. A. Jaeger, Flottweg-Werk.

15.30 — 15.45 Tea

15.45 — 16.30 Reliability Requirements in Separating Equipment
J. Wem, I.C.I. Organics Division

16.30 — 17.15 The Multistage Counter Current Washing Column
C. C. Dell, University of Leeds

Wednesday, 28th March

Session 3 *Chairman:* L. Svarovsky

9.15 — 10.00 The Effects of Velocity and Concentration on Filter Cake Resistance
A. Rushton, M. Hosseini and I. Hassan, U.M.I.S.T.

10.00 — 10.45 The Plate Pressure Filter
B. H. Richter, Krauss-Maffei

10.45 — 11.00 Coffee

11.00 — 11.45 Drum Filters can still be improved — The latest developments in Design and Process
W. Stahl, Krauss — Maffei

11.45 — 12.30 The use of a Rotary Pressure Filter in Fine Chemical Manufacture
E. E. Thorpe, Beecham Pharmaceutical

12.30 — 14.00 Lunch — Charles Morris Hall

Session 4 *Chairman:* D. Anderson

14.00 — 14.45 The Rotary Drum Pressure Filter
B. H. Richter, Krauss-Maffei

14.45 — 15.30 Shear Effects in cake formation mechanisms
A. Rushton, U.M.I.S.T.

15.30 — 15.45 Tea

15.45 — 16.30 Horizontal Vacuum Belt Filters
H. G. W. Pierson, Pierson and Co.

16.30 — 17.15 Diffusion and Surface Processes during Colour Removal from Effluent by Carbon Absorption
G. McKay, A. G. Sweeny, Queen's Belfast

	Session 5 *Chairman:* W. Wilkinson
9.15 — 10.00	Developments in large Horizontal Belt Filters M. Harvey, Delfilt
10.00 — 10.45	Granular Media Filtration in Water Treatment J. G. McNaughton, R. Gregory, Water Research Centre
10.45 — 11.00	Coffee
11.00 — 11.45	Coagulation Clarification and Sludge Blanket Clarifiers D. G. Stevenson, Paterson Candy International Ltd
11.45 — 12.30	Dissolved Air Flotation for Solid/Liquid Separation A. J. Rees, D. J. Rodman and T. F. Zabel, Water Research Centre
12.30 — 14.00	Lunch — Charles Morris Hall
	Session 6 *Chairman:* C. McGreavy
14.00 — 14.45	Why do my polypropylene filter plates bend? D. Jones, I.C.I. Organics Division
14.45 — 15.30	Plenary Discussion
15.30 — 16.00	Tea Symposium closes

Contents

LARGE SCALE TESTS OF SEDIMENTING CENTRIFUGES AND HYDROCYCLONES FOR MATHEMATICAL MODELLING OF EFFICIENCY

K.R. Gibson (Member)

English Clays Lovering Pochin & Co. Ltd., St. Austell, Cornwall.

Summary

A mathematical model has been developed for the operation of a production scale, nozzle discharge, conical disc centrifuge by monitoring its operation over the range of variables normally encountered. The effective grade efficiency, expressed mathematically and stored in a computer, is the basis for the model, and the influence of discharge nozzle size, feed rate and concentration on the cut sizes obtained empirically, enables the computation of product size distributions for any feed distribution.

Model building from the results of production runs, or pilot scale runs, beyond the normal range of variables on production, via the grade efficiency, is the current approach to quantify the operation of a scroll discharge centrifuge and small diameter hydrocyclones.

A combination of the models of the classification processes used in sequence for the beneficiation of china clay, and incorporating economic data, can be used for the technical and economic optimum design of the process.

1. Introduction

The beneficiation of china clay is a sequence of progressively finer particle separations using water as the working fluid. The deposit is mobilised by high pressure water jets and coarse gangue minerals are removed by Spiral classifiers. Large hydrocyclones are used to remove other residue materials as underflow, the overflow being mainly china clay in a naturally flocculated condition, is thickened and the subsequent processing of this stream is the main subject of this paper.

To achieve efficient separation of particles according to their size, the particles must be treated as individual particles, separated from their neighbours in a 'deflocculated' condition. Deflocculation may be carried out mechanically or chemically. Mechanical deflocculation is transient and will be maintained only during conditions of high shear like inside a hydrocyclone. When the shear reduces or is eliminated, spontaneous flocculation normally takes place. In low shear separators we must use chemical deflocculation, changing the nature of the particle surface or its immediate environment to cause the particles to repel each other. Chemical deflocculation is used when operating hydroseparators and the scroll discharge centrifuges used for the production of fine clays.

2. Objectives

Wet methods of particle separation according to particle size at cut sizes from about 20μm to below 1μm are fundamental to the process and must be understood to achieve flexibility and high efficiency of operation.

To apply this understanding we must describe the operation of each type of classifier in a manner suitable for manipulation and define the influence of variables. Such a mathematical model for each process would be a part of an overall model accommodating several classifiers in series. This, combined with economic data such as power costs, would be a simulation of china clay processing which could be used to optimise classifier types, combinations and operating conditions for required tonnages at given specifications. The model, conveniently stored in a computer, could be used with chosen constraints to study the effect of feed material changes, product specification changes etc., on the optimum numbers, types and combinations of classifiers.

3. Scope

Hydroseparators cutting at 15μm, scroll discharge centrifuges with a 4μm cut size and disc centrifuges cutting around 0.5μm are current methods of separation. At an early stage it was decided to include hydrocyclones in the study. They are potentially useful for separations down to those achieved with scroll discharge centrifuges and could be a low cost alternative to hydroseparators in particular.

Many theoretical and semi-empirical relationships exist for fluid-particle systems in general and our equipment in particular, but because of the complications of raw material peculiarities such as varying aspect ratios over the particle size range, an empirical method was followed. In this way we would be modelling from actual classification results on china clay.

4. Grade efficiency

When a feed material is split into coarse and fine products, the particle size distributions of the products always overlap. There is undersized material in the coarse fraction and oversized material in the fines. The efficiency of removal of material from the feed to one of the products spans 0 to 100% in this overlap. The relationship of efficiency to particle size is the grade efficiency function for the separation, and can be used to describe the separation in graphical or mathematical terms. The size of particles having equal probability of entering the coarse or the fine fraction is defined as the cut size and corresponds to the 50% efficiency size of the grade efficiency function.

Svarovsky [1.] in his chapter 'Efficiency of Separation of Particles from Fluids' gives the basic definitions and describes a method to derive the grade efficiency directly from cumulative particle size distributions of any two of the three streams involved and the mass recovery of one of the products. This technique has been further developed [2] as a graphical method to quickly determine grade efficiency, also a computer program based on the method has been written and used to handle the large number of calculations in this study.

5. Experimental Method

The same basic method was used for the evaluation of all the equipment. The important variables, those which vary when running, and those which can be easily changed to compensate for the former, were defined and the practical limits of the variables were also defined. The equipment was then run at an arbitrarily chosen 'norm' for all but one variable and this was systematically changed within its limits, the procedure being repeated for each variable in turn. Samples of feed and both products were taken and cumulative particle size distributions were measured by a sedimentation method. Also volumetric and/or mass flow rates were measured; concentrations of the samples were normally measured by hydrometer.

The data were processed to obtain the grade efficiency function for each run. The effective cut size obtained at 50% efficiency could then be related to the other variables. Modification for underflow volume could be carried out [1,2] if appropriate to give modified efficiency and cut size.

6. Disc Centrifuge

The Alfa-Laval QX412 is a typical continuous discharge conical disc centrifuge operating with a maximum separating force of 6560 times gravity. In operation the coarse fraction leaves the bowl via a number of nozzles in the periphery. New nozzles are 1.6mm in diameter, but these wear in use, with a gradual increase in throughput accompanied by a small increase in power consumption. Nozzles are replaced when worn to about 2mm diameter. Other variables which can be changed at will are the feed concentration and feed rate.

Tests were carried out at all combinations of the following parameters:

Nozzle size	1.6mm	2.0mm		
Feed density	1,050	1,075	1,100 g/ml	
Volumetric Feed Rate	100,	150,	200,	230 gal/min

Particle size analyses of all the samples were carried out by Andreasen method at 10μm and 2μm and by Simcar centrifuge at finer sizes. The Simcar technique yields a cumulative size distribution expressed as cumulative % finer than 0.1, 0.14, 0.2, 0.28, 0.4, 0.56, 0.8, 1.12, 1.6 μm etc.

The 'old' technique for calculating the grade efficiency was to express the size distributions as frequency distributions with these Simcar points as the class limits. The grade efficiency is then the ratio of the amount in each size range in the product to the amount originally in the same size range in the feed, calculated for each size range in turn. The efficiency value for each size range plotted against a mean of each size range is the continuous grade efficiency function for the separation. The cut size is the size where 50% efficiency is obtained.

These cut sizes plotted against the other parameters are shown in Figure 1. To maintain a constant cut size, the feed rate should be decreased if the feed concentration increases. Also in the longer term as the nozzles wear from 1.6mm to 2.0mm, the feed rate should be increased to maintain the cut size constant.

To obtain the cut size from the grade efficiency data it is necessary to interpolate to 50% efficiency. Plotting efficiency against average size for the intervals on log-probability paper, straight lines are a good fit to the data. Use of the normal distribution function was therefore tried as a model for the grade efficiencies.

The function may be characterised by its mid-point position (the cut size) and its slope or standard deviation. It was found that the standard deviation was constant for each nozzle size, being 2.75 for 1.6mm nozzles and 3.4 for 2.0mm nozzles.

To check the model, assume that for any set of operating conditions, the grade efficiency levels can be represented by the cumulative probabilities from a particular normal distribution whose variate is the logarithm of the particle size. The mean of this normal distribution is given by the logarithm of the cut size.

A computer can be used to generate the grade efficiency values at the required sizes from the normal distribution function at the correct mean (cut size) and standard deviation. These efficiencies are then applied to the feed distribution and the particle size distribution of the products can be calculated and compared with those actually obtained by experiment.

A multiple linear regression analysis was performed on the data shown in Fig.1 and a polynomial expression derived of the form:

$$\text{Cut size} = k_o + k_1x_1 + k_2x_2 + k_3x_3 + k_4x_1x_3 + k_5x_2x_3 + k_6x_3^2 + k_7x_3^3$$

where x_1 = nozzle size

x_2 = feed density

x_3 = flow rate

k_i = constants

For the mathematically minded, the Multiple Correlation Coefficient = 0.998 and Residual Error = 0.01. All other cross products were eliminated.

Using the polynomial expression for generating cut sizes and the normal distribution function for the grade efficiencies, a computer was used to calculate product particle size distributions for 24 sets of operating conditions. These agreed within ± 2% with the particle size distributions obtained in practice, an accuracy similar to that of the particle size analysis methods used to obtain the experimental data.

Power consumption was recorded for each set of operating conditions, so that a production cost per tonne of product could be obtained. Along with fixed costs for maintenance, depreciation, etc., an economic and technical model of the process can be set up.

7. Scroll Discharge Centrifuge

Scroll discharge centrifuges are used for the production of our large tonnage paper coating quality clays. The influence of process variables over much wider ranges than those encountered on production was investigated using a laboratory scale centrifuge.

In this and subsequent studies of classifiers, the tedious grade efficiency calculation from frequency distributions was replaced by the computerized technique described in reference 2. The slope of the square diagram plot of cumulative feed distribution vs cumulative distribution of one product is determined by fitting a parabola to three consecutive data points, and differentiating at the mid point. This slope, multiplied by a recovery factor is the grade efficiency value for that size.

Figure 2 shows the way that cut size is influenced by changes in feed rate and feed concentration. These cut sizes are calculated from particle size analyses at 1μm, 2μm, 5μm, and 10μm, percentage undersize at these four sizes being adequate for the computer calculation of the grade efficiencies. A linear relationship between 0.5 gals/min and 10 gals/min was obtained for cut size vs feed rate.

Pond depth was found to have no influence on cut size. The increase in residence time obtained by increasing pond depth is compensated by the increase in settling distance. Limits on feed rate were obtained at the deeper ponds, due to liquid spilling over the coarse product discharge end of the bowl.

A model is currently being developed along similar lines to those for the Alfa-Laval.

8. Small diameter hydrocyclones

Hydrocyclones are widely used in the mineral processing industry for classification duties including de-gritting, de-sliming and thickening. These duties differ only in the position of the chosen cut size with respect to the feed particle size distribution. In general the coarse product or underflow is always thickened and the overflow may be so devoid of particles for the process to be called de-watering. The high shear conditions within the hydrocyclone are normally sufficient to deflocculate the feed mechanically and therefore, hydrocyclones can effectively classify a clay feed which is naturally flocculated.

Generally, the smaller the diameter of the hydrocyclone, the finer is the cut size at which it operates. The main interest in this study is in the finer cut sizes obtainable on 2 inches and 1 inch diameter hydrocyclones. The units manufactured by Richard Mozley Ltd.[3] were chosen for this investigation.

The experimental procedure was again similar to that used for the other classifiers; the important variables are feed concentration, pressure drop across the hydrocyclone and the size of underflow and overflow orifices. The coarse product from hydrocyclones is usually more dilute and greater in volume than that from a centrifuge and allowance must be made for the effect of underflow volume on the grade efficiencies obtained.

Three configurations of hydrocyclone were tested at a range of feed concentrations, the results are shown in Figure 3. The influence of feed pressure on throughput and cut size for the 1" hydrocyclone was shown to follow the following relationships:

$$x^{1}_{50} \propto Q^{-0.6}$$

$$\Delta p \propto Q^{2.1}$$

$$\text{and } x^{1}_{50} \propto \Delta p^{-0.29}$$

where x^{1}_{50} is the cut size modified for underflow volume

Q is the volumetric feed rate

and Δp is the pressure drop

Bradley[4] summarises correlations, the exponent in $x^{1}_{50} \propto Q^{x}$ is theoretically predicted by several workers as x = -0.5, with empirical values of -0.5 (Yoshioka and Hotta), -0.53 (Dahlstrom), -0.57 (Haas) and -0.60 (Matschke and Dahlstrom). Theoretical and empirical values for exponent y in $\Delta p \propto Q^{y}$ are y = 2, except for the empirical value of 2.26 by Haas.

The underflow volume can be predicted approximately by apportioning the flow as the ratio of the underflow nozzle cross-sectional area to the total area of vortex finder plus underflow nozzle.

A form of efficiency curve attributed to Yoshioka and Hotta and described by Bradley[4] is the reduced efficiency curve. Efficiency is plotted against a 'reduced particle size' x/x^{1}_{50}. If the hydrocyclone results are plotted in this way, on log-probability paper, straight lines are a good fit to the data for 2" hydrocyclones. For each vortex finder size the slope of the line (which is related to the standard deviation of the log normal distribution) is different. The results obtained are:

for 9/16" Vortex finder, standard deviation = 1.57
" 7/16" " " " " = 1.75
and " 5/16" " " " " = 2.0

This means that the quality of the separation deteriorates slightly with smaller vortex finders.

For a given hydrocyclone and feed concentration, a modified cut size can be calculated from Figure 3 and the volume of underflow estimated as the ratio of underflow cross-sectional area to total out-flow area. The effective grade efficiency can then be calculated from the appropriate reduced efficiency function and applied to a feed particle size distribution to estimate the product distribution. Alternatively one could select a hydrocyclone to give a desired cut size. A model is currently being developed from these data.

9. Conclusions

It has been demonstrated that the normal distribution function with a logarithmic variate is an adequate model for the grade efficiency function of a range of particle classifiers. Empirical relationships have been measured for the effect of important process variables on the grade efficiency and a model has been developed to describe the operation of a disc centrifuge. Models for a scroll discharge centrifuge and small diameter hydrocyclones are currently being developed.

FIG 1 Alfa-Laval QX 412

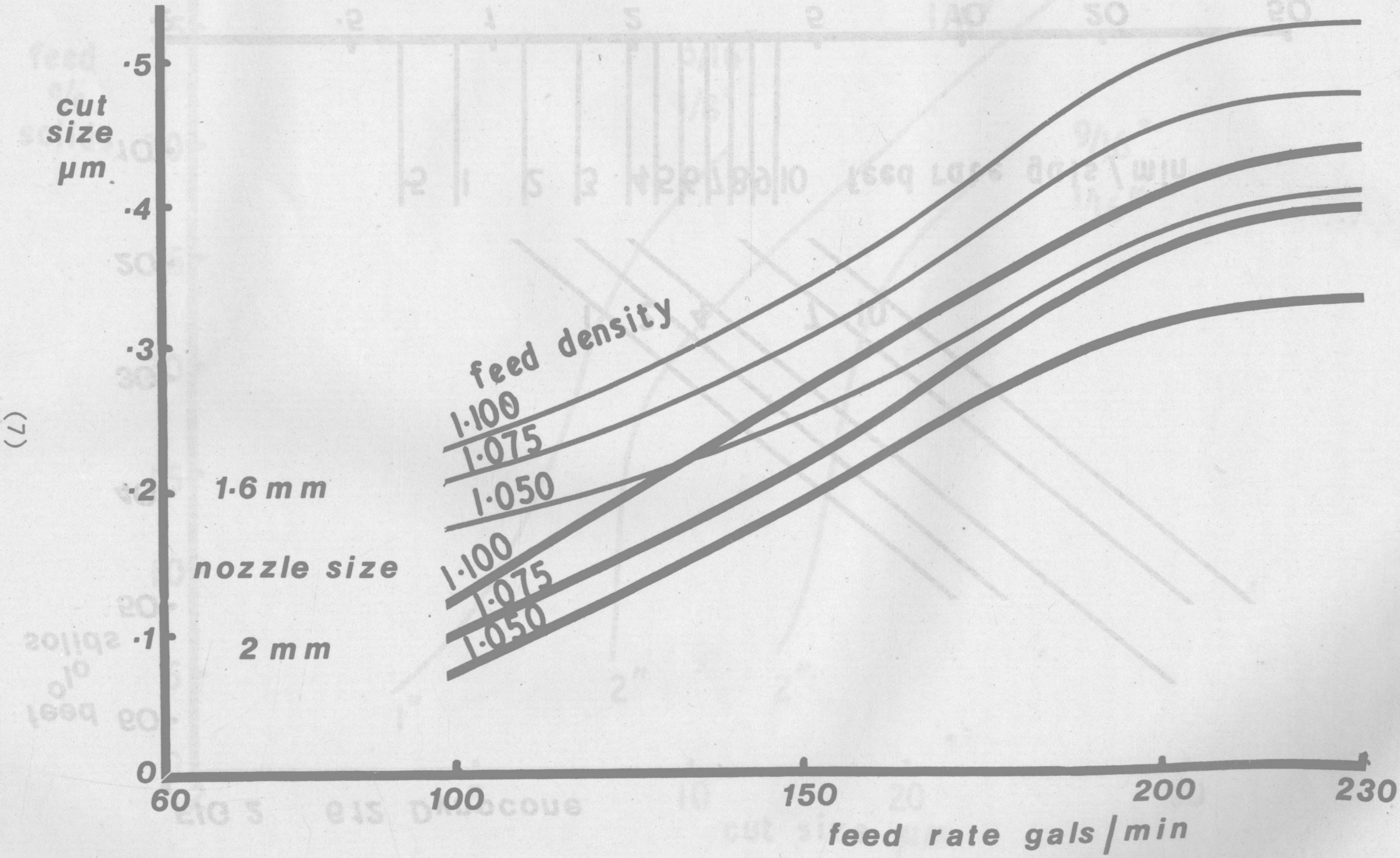


FIG 2 612 Dynocone

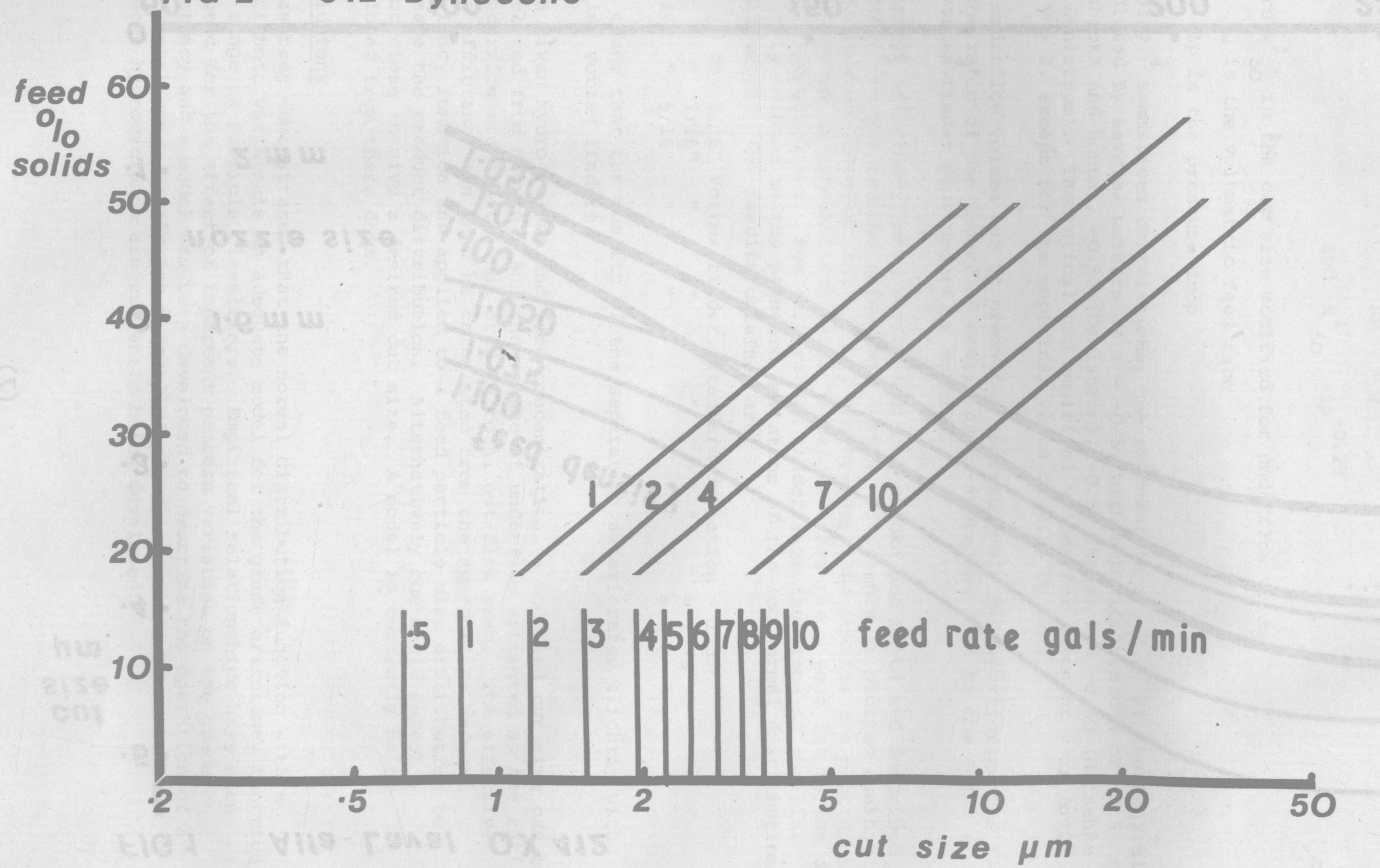
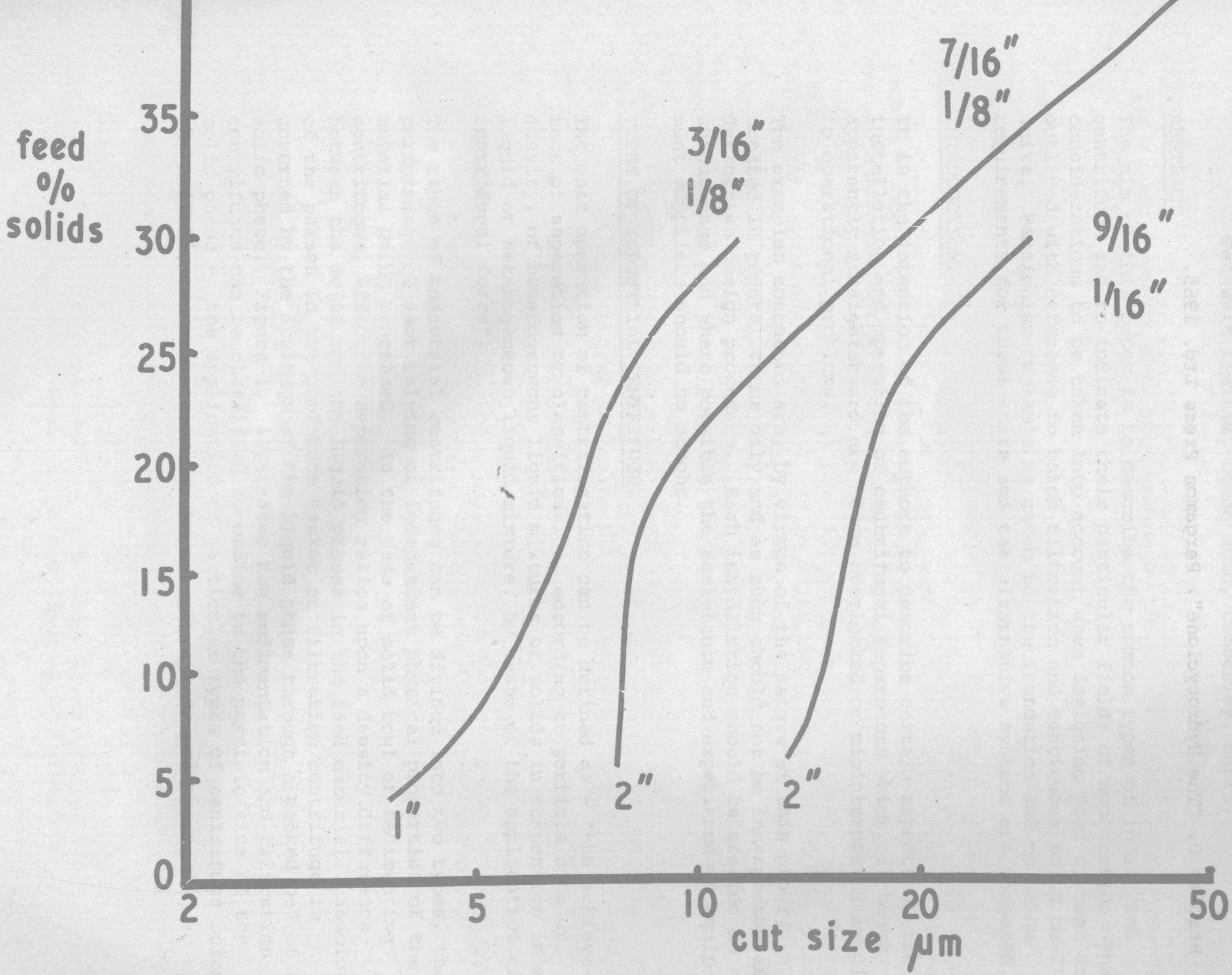


FIG 3 Hydrocyclones



References

1. Svarovsky, L. (Ed) "Solid Liquid Separation", Butterworths 1977.

2. Gibson, K.R. "Particle Classification Efficiency Calculations by Geometry". Powder Technology, 18 (1977) 165-170.

3. Mining Journal, August 11, 1978, p.p. 97,98.

4. Bradley D, "The Hydrocyclone", Pergamon Press Ltd. 1965.