FLOW CHARACTERISTICS OF A PINCHED SLUICE

By

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ABSTRACT

Pinched Sluices, in a variety of guises, are used extensively for the separation of minerals according to density. In the authors' work a pilot-scale sluice has been constructed with provision for splitting the discharge stream into a number of layers. The composition and flowrate of the stream can thus be analysed as a function of depth and the results presented graphically. The effects of such parameters as total flowrate, pulp composition and particle size on overall performance can be clearly seen from such data.

INTRODUCTION

The potential energy of a mixture of particles of different densities is at a minimum when the dense particles, regardless of size, are concentrated in a layer below those of lower density (Mayer, 1964). Stratification therefore tends to occur if the particles are free to move with respect to one another, this being the main principle upon which many gravity separation units such as jigs, tables, vanners and concentrating spirals are based.

Possibly the simplest way of reducing the interlocking and inter-particle friction which usually prevent stratification is to suspend the particles in a liquid stream flowing in an open channel or 'sluice' and crude units of this type have been used for centuries in the concentration of cassiterite and gold (minerals of high density) from placer deposits. Subsequent application of the method to lower-density minerals was at first less successful, however, and although trough-washers for coal were introduced in France and Germany 150 years ago (Richardson, 1938) it was not until the development of the Rheolaveur trough and the Battelle Launder early this century that an acceptable level of performance was achieved (Dupret, 1954; Richardson, 1938).

The success of these units lay in their elaborate refuse (i.e. sinks) removal mechanism which, by reducing the disturbance of the upper stratified layers, decreased the entrainment of the lower-density coal values. However with other, finer mineral ores, in which the valuable component was generally a minor constituent, the problem of achieving a sharp separation between the values and the gangue remained as the minerals were spread in a thin horizontal layer across the full width of the trough. The pinched sluice was developed to overcome this difficulty, pulp flow being guided by converging walls to discharge through a narrow, vertical opening.

Dupret (1954) reports that units using this principle were in successful industrial operation treating coal and heavy minerals, including gold, by the early 1930's, since which time they have become widely accepted, particularly as a primary concentrator in the heavy mineral beach sand industry. Several

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varieties exist, some of the better known being the Lamex launder, the Carpco fanning concentrator, the York tray and the Belmont sluice (Pullar, 1963; Blaskett and Hudson, 1965). Units vary from one to two metres in length, usually have an included angle of about 20^{o} to 25^{o}, a slope of 15^{o} to 20^{o} and a capacity of 0.5-1.5 tonnes/hour in a pulp of 55-60% solids by mass. Product separation may be made through an adjustable slot or slots in the base, by deflection on a spreading plate or by directing the discharge stream onto one or more splitter blades.

Higher capacities are achieved by the use of units in parallel, a convenient layout being a radial alignment of sluices to form a sector of a circle. This arrangement is carried to the ultimate in the Reichert cone (Graves, 1973) to which a 6' (1.8m) diameter, 17^{o} cone, fed uniformly about its circumference, provides the base of what may be regarded as a full ring of pinched sluices with their side walls removed. The absence of these walls reduces the turbulence evident in the more conventional pinched sluices (Pullar, 1963), possibly accounting for the high (70 t.p.h.) capacity.

As none of these units can produce a clean concentrate or tailing in a single operation it is customary to employ several stages for both cleaning and scavenging, either within a single unit (as in the Reichert cone assembly) or as a sequence of separate units. A flow-sheet matrix has recently been devised (Woodcock, 1977) which is claimed to give optimum results and which can be extended at will to give any required concentrate yield and grade. As it is clearly desirable to reduce the number of reprocessing stages to a minimum, however, it was decided to embark on a research programme to determine the effects of various changes to the usual operating conditions. With this aim, a closed-circuit test facility has been constructed, incorporating a Plexiglas pinched sluice, and preliminary testwork has been carried out. The development of this test facility, the experimental methods used and some of the results obtained are the subjects of this paper.

EQUIPMENT

In the experimental circuit pulp gravitates from a stirred, constant level head tank through a control valve and distributor into a Plexiglas pinched sluice. The discharge from the sluice flows into a splitter, its products being collected simultaneously in nine sample compartments or recombined and directed into the sump of the recirculating pump which feeds the head tank. Overflow from the head tank flows directly to the pump sump, the flowrate being regulated by a valve between pump and tank to maintain the overflow at a constant, low level.

Details of the main components of the circuit are given below.

HEAD TANK

A cylindrical, 20 litre stirred tank mounted with the overflow approximately one metre above the pinched sluice. Feed to the sluice, controlled by a manually adjusted valve, flows out through a 30 mm pipe at the centre of the base. Incoming pulp from the recirculating pump enters near the top, a little below the pulp surface to avoid splashing. Agitation is sufficient to maintain a homogeneous distribution of particles within the tank.

DISTRIBUTION LAUNDER

A baffled rectangular launder to receive the vertical flow of fluid from the head tank and to provide a smooth, uniform feed to the sluice.

PINCHED SLUICE

A Plexiglas pinched sluice, of rectangular cross section, Figure 1, mounted at 17^{o} to the horizontal, 600 mm in length, 200 mm wide at the feed end and with a 15 mm discharge slot

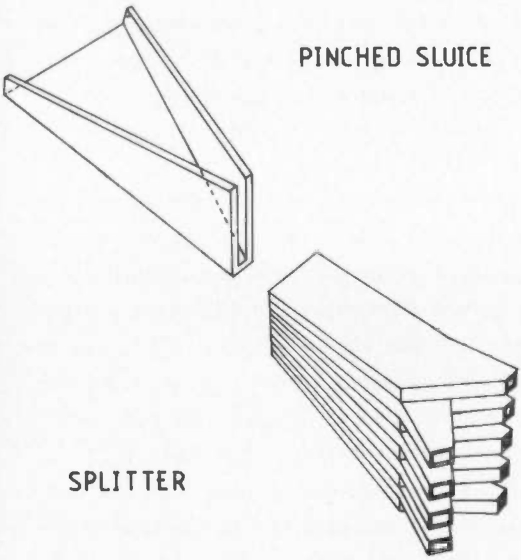

Fig. 1 - Experimental equipment.

to give a products stream, at maximum flowrate, of about 90 mm depth.

SPLITTER

Designed to divide the products stream into a number of fractions at ten mm intervals up from the bottom. The unit (Figure 1) has nine horizontal compartments separated by thin, sharp-edged sheets of Plexiglas. The compartments are angled alternately to the left and right to facilitate sample collection. Each terminates in a length of flexible tubing of approximately 25 mm internal diameter.

A 70 mm long adjustable spacer was used to align the splitter with the freely flowing pulp stream curving downwards from the sluice as direct connection of the splitter and sluice resulted in turbulence which restricted the flow. The spacer was also used to adjust the bottom of the splitter into line with the bottom of the pulp stream.

SAMPLE COLLECTOR

This unit consists of ten 2.5 litre compartments (of which only nine were used) in two rows of five on opposite sides of a sump. Flow from the splitter can be directed into the sump or into the sample compartments by manipulation of a sliding gate so that simultaneous timed samples can be collected from all levels of the sluice discharge. Flow into the sump gravitates to the recirculating pump.

PUMP

A 3kW Sala SPV180 vertical centrifugal pump is used to return the combined streams from the head tank overflow and the splitter sump to the head tank. Flowrate is controlled by a valve which restricts the flow from the pump so that the overflow from the head tank is maintained at a constant, low level, ensuring a constant head.

MATERIALS

Tests to date have been carried out with silica and ilmenite sands, individually and in combination. Samples of both materials were prepared by grinding to the size distributions shown in Table 1, the size increments shown being those used in subsequent product analysis.

Adequate quantities were prepared for the full set of planned tests and split in a rotary sampler to provide identical samples for the various tests.

Densities of the quartz and ilmenite were 2650 and 4320 kg/m^3 respectively.

Table 1.

Size distributions of silica and ilmenite feed sands

Size range	Percentage by mass in size range	
µm	Quartz	Ilmenite
+ 180	79.2	24.6
- 180 + 90	9.5	41.8
- 90	11.3	33.6
	100.0	100.0

EXPERIMENTATION

The objective of this initial study was to determine the flow characteristics of the test sluice over a range of conditions. Accordingly, a series of experiments have been carried out with water only and with suspensions of quartz, ilmenite, and a mixture (50:50 by mass) of the two minerals. Each suspension was tested at two concentrations, 4.0% and 27.4% by volume and all tests run at three flow rates, 0.33, 0.67 and 1.0 litres per second.

The higher pulp density for the mixture (27.4% by volume, 55.3% by mass) is towards the lower end of the optimum concentration range quoted for industrial sluices (Pullar, 1963). The lower concentration level was chosen to give a practical approach to free settling conditions, i.e. conditions in which the individual mineral particles could move with negligible interference from other particles. Pulp compositions were standardised on the basis of volume as this is the most important factor determining pulp rheology.

Eighty-four runs have been made (four replications of seven feed compositions at three flowrates) and the flowrate (ℓ/s), solids concentration (g/ℓ), size distribution of solids and grade (% ilmenite) of each size fraction measured, where appropriate, for each of the splitter products.

In each case, samples were collected over a period of ten seconds. Results were rejected and a run repeated if the total volume of the splitter products differed from the expected value by more than five percent. Pulp volumes were measured in calibrated cylinders, solids concentrations by weighing after decantation and drying and size distributions by screening using mechanically shaken 200mm test sieves. Ilmenite grade was determined using a Frantz Isodynamic (magnetic) separator after a preliminary test using the 50:50 quartz:ilmenite mixture established that a complete separation of the minerals was achieved in a single pass.

RESULTS AND DISCUSSION

Selected results are presented graphically in Figures 2-5.

The incremental flowrate for water alone and for each of the suspensions passed through a maximum at about half the total depth for each overall flow value and decreased sharply towards the free surface. Figure 2 shows the data for the extreme cases of water alone and high ilmenite concentration. The velocity distribution thus differs from that in parallel-sided channels in which the maximum flowrate is encountered within the upper 25% of the stream, the difference being attributed (Chow, 1959) to an exchange of velocity head for potential head as the stream 'piles up' behind the discharge slot. The resultant backwater rise was clearly visible through the transparent walls of the sluice.

The flow regime for a liquid in an open channel may be evaluated on the basis of the dimensionless Reynolds number using the definition:

$$Re = VL\rho/\mu$$

where V = Mean fluid velocity, m/s

L = Hydraulic radius of fluid[1], m

ρ = Fluid density, kg/m^3

and μ = Fluid viscosity, Pa.s

Assuming a pulp viscosity equal to that of water for the low concentration suspensions and a value three times larger for the higher concentrations (Green et al., 1978) and substituting appropriate density, flowrate and flow cross sections for the various sets of data, values for Re are found to range from about 1200 (50% quartz, 0.33 ℓ/s) to over 5000 (water only, 1.0 ℓ/s). Corresponding flow

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[1] $L = A/P$

where A = cross sectional area of flow

and P = wetted perimeter of channel.

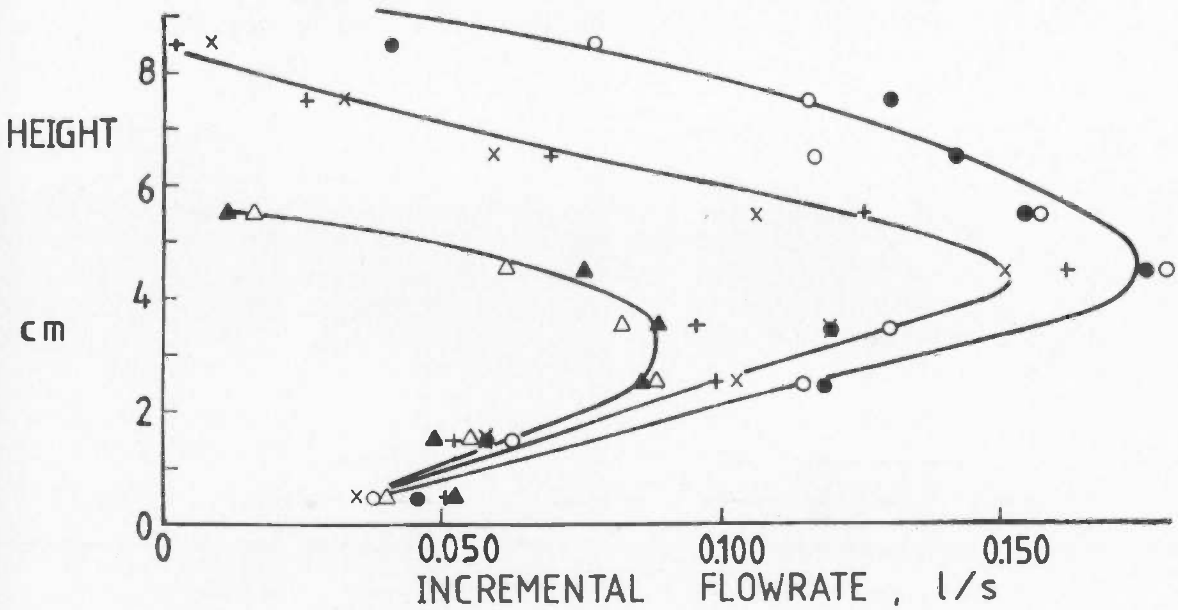

Fig. 2 - Flowrate vs. height. Total flowrates 0.33, 0.67 and 1.0 litre/sec.
Water only: △ , X , O ; High ilmenite concentration: ▲ , + , ● .

conditions, taking the lower limit for turbulent flow as 2000 (Chow, 1959), thus vary from upper transitional to fully turbulent and, in view of the converging nature of the flow, it is probably reasonable to assume turbulent flow under all test conditions.

The relative concentrations (product concentration/feed concentration) for each of the three size fractions are shown as a function of depth in Figure 3 for the maximum flowrate at both levels of concentration. Curves of similar form were obtained at the lower flowrates. In all cases the concentration increases towards the bottom of the stream, the effect being most evident with coarse, dense particles under free settling conditions (Figure 3a). The curves are similar to those derived theoretically (Raudkivi, 1967) for particles in channels of constant cross section on the basis of a simple equilibrium between local turbulence and the settling velocity of the particles. A greater degree of vertical mixing is expected with a pinched sluice, however, due to the backwater rise so that the vertical distribution of even the coarsest particles is more homogeneous than would be the case for the same sized particles in a parallel-sided sluice. Of particular interest is the way in which the differences in the vertical concentrations of the three size fractions almost vanish in the high density pulp (3c,d) although being very considerable with low concentration feeds (3a,b), reflecting the relative effects of hindered and free settling conditions respectively. Clearly, therefore, the choice of high pulp densities (at or a little above the upper level used in the experiments) in industrial practice permits

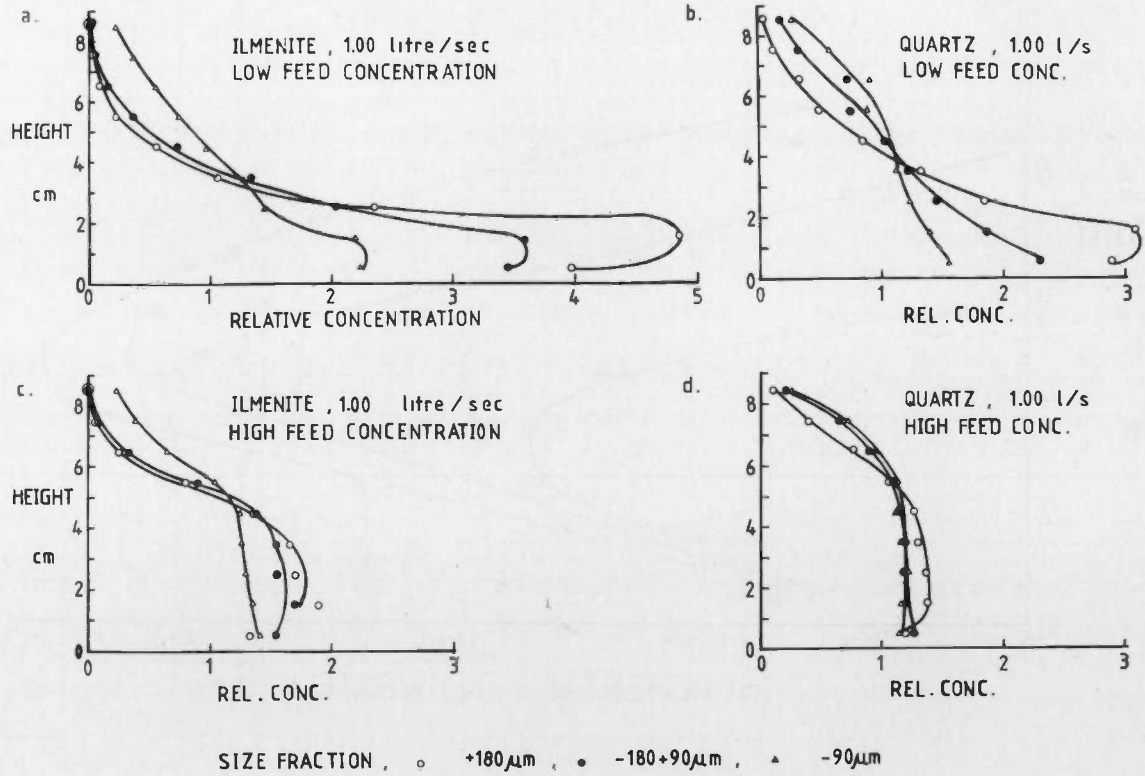

Fig. 3 - Relative concentration (Incremental concentration/Average concentration) vs. height. (Selected examples. Minerals tested separately.)

the processing of unsized feeds.

Examples of the combined effects of the pulp flow pattern and the relative concentrations of particles are shown (Figure 4) in terms of minerals distribution (i.e. percentage of specified feed fraction reporting to each level). In most cases the flow pattern dictates the form of the curves and it is only at low pulp concentrations and flowrates, notably in the case of ilmenite at 0.33 ℓ/s, that the different settling behaviour of the three size fractions results in significant changes in the distribution curves for those fractions.

In Figure 5 the distribution in the product stream of each of the minerals from a 50:50 ilmenite:quartz feed is shown for the full range of conditions tested. As before, each point is plotted at the mid-point of the increment to which it applies and is the mean of four experimental values. A bar through each point indicates plus or minus one standard deviation (n - 1 formula).

For perfect separation the curves for the two minerals would form discrete peaks above and below a distinct level at which a split could be made. No such stratification is seen for any size fraction or flowrate with low concentration feeds (Figure 5a), the distribution of the two minerals being closely similar in each case. This result is in accordance with the already noted requirement of high feed concentrations for effective separation.

Even at high concentrations (Figure 5b) it can be seen that the turbulence at high

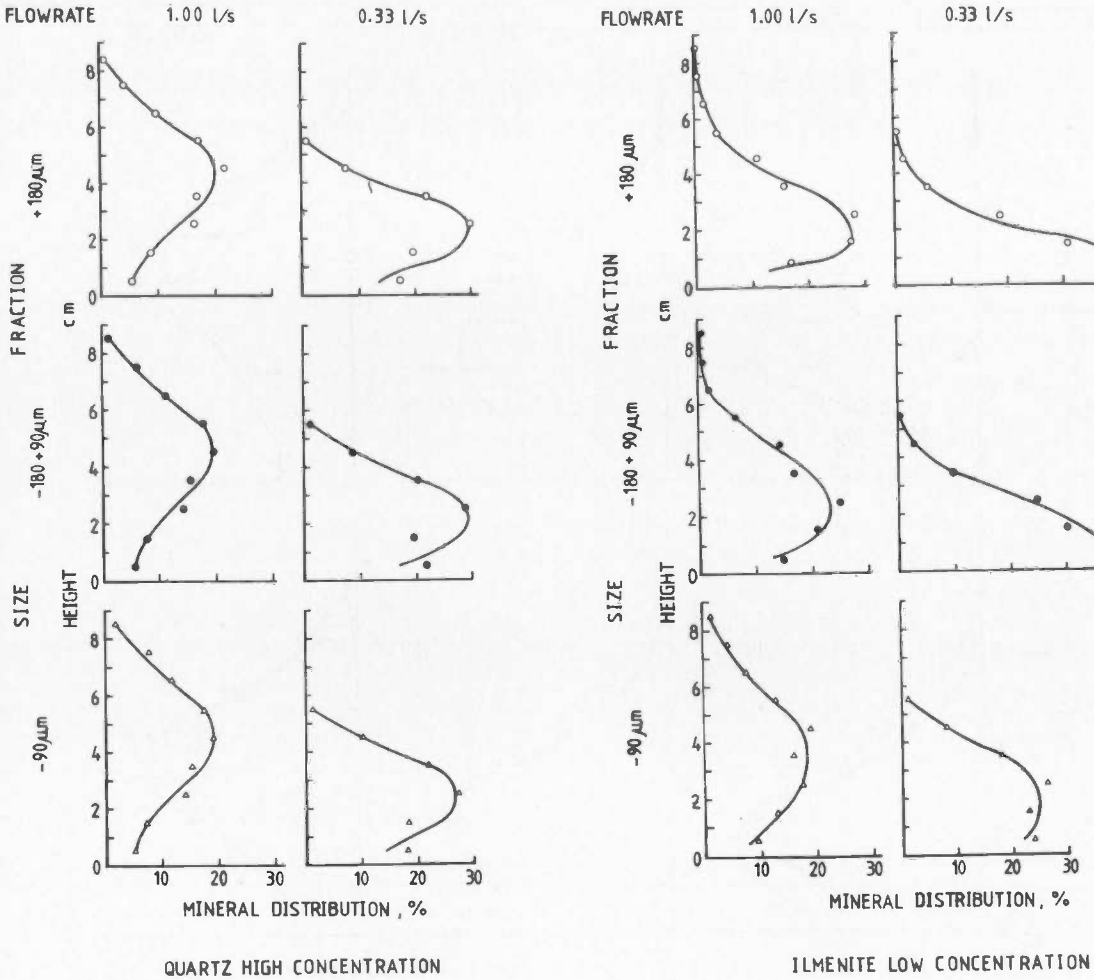

Fig. 4 - Examples of the distribution of mineral in product (percentage reporting to each height increment). Minerals tested separately.

flowrates results in mixing, especially of the fine fraction. It is only at the lowest flowrate (0.33 litres/sec) that a clear separation becomes evident, being especially marked in the coarser fractions.

SUMMARY

Equipment has been constructed which permits the analysis of the product stream from a small pilot-scale pinched sluice as a function of depth. Results are presented which are in agreement with industrial observations, namely that separation efficiency improves with increased feed concentration, with increased particle size and with reduced flowrates. These data should provide a good basis for comparison in a planned series of experiments involving modifications to the equipment and mode of operation aimed at an ultimate improvement in performance.

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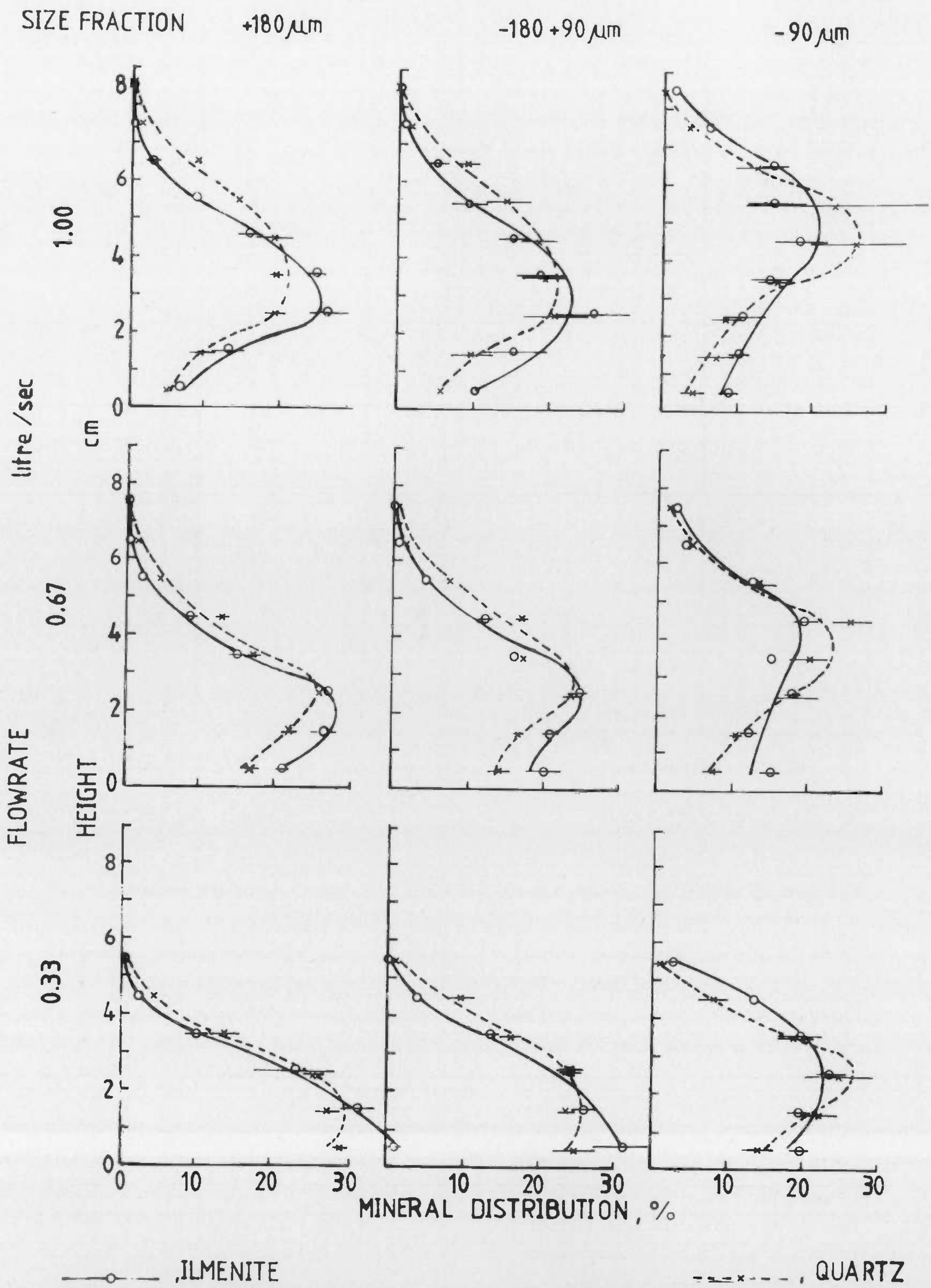

Fig. 5a - Distribution of minerals from a mixed feed. Low feed concentration.

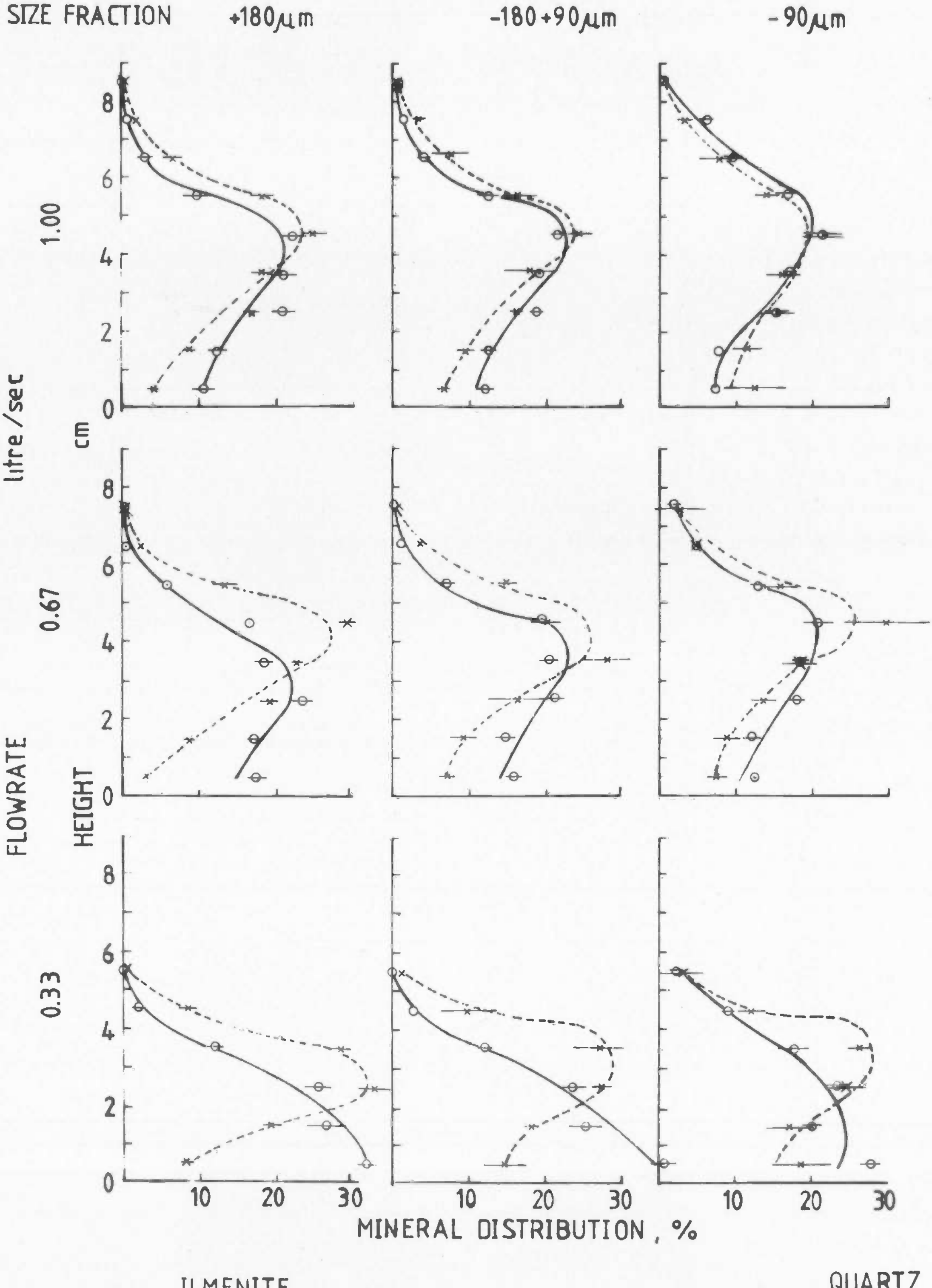

Fig. 5b - Distribution of minerals from a mixed feed. High feed concentration.

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