THE INTERDEPENDENCE OF CANE PREPARATION, PARTICLE SIZE, DISPLACEABILITY, AND LIQUID HOLDUP IN FIXED BED DIFFUSERS

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Abstract

Observations on the use of Displaceability Index and sieve analysis as a means of characterizing cane preparation are given. Data on liquid holdup in fixed beds of bagasse are presented; both dynamic and static holdup are shown to be dependent on flow rate and the degree of cane preparation.

Introduction

It is now a well-established fact that the degree of cane preparation has a considerable effect on diffuser extraction. Moreover, cane preparation affects the maximum obtainable percolation rate, and juice holdup and retention time. There is, therefore, a need for some quantitative means of characterizing cane preparation. This is no easy task, due to the nature of bagasse particles, which constitute a wide range of complex shapes and sizes.

Markham[4] recently investigated Displaceability Index as a measure of cane preparation, and demonstrated a relationship between bagasse particle size as obtained by sieve analysis and Displaceability Index. Further observations on these two methods of particle characterization are presented, as well as liquid holdup data in a fixed bed diffuser.

The subject of this paper forms part of a much wider investigation into sugar diffusion; thus only preliminary results are presented.

Sieve Analysis

Sieve analysis is a well-established and widely applied procedure, and it was a logical step to apply it to the analysis of bagasse samples.

Bagasse samples were sieved in two stages; firstly in a sieving box containing three coarse screens for two minutes, after which the residue was transferred to smaller sieves and sieved for ten minutes. The methods of preparation of bagasse samples are given in Appendix I.

A typical cumulative size distribution is shown as curve A in figure 1, on log normal probability coordinates. The inflection in the curve corresponds to the change from large to small screens. In order to assess whether the inflection was due to sieving technique or to some sudden change in shape factor at that point, the following procedure was carried out: any particle retained on one of the coarse screens which could have passed through that screen was pushed through by hand; sieving of the smaller particles was then continued for a further 30 minutes. The resulting size distribution is marked B in figure 1; this plots as a straight line and thus follows the log normal distribution law. In such cases, the mean size is obtained from the 50% point. In order to obtain a characteristic particle size from the sieve test, the straight portion of the curve A was projected as shown by the dotted line in figure 1. The point where this crosses the 50% horizontal was taken as the characteristic particle size. This procedure was applied to all the sieve tests, and characteristic sizes closer to the mean of the true distribution are obtained.

It is unlikely that anything other than relative values of bagasse particle size can be obtained by sieve analysis. As with all sieving operations, results depend on the time of screening, method of shaking, and screen loading. In sieving bagasse, further difficulties are encountered due to the fibrous nature of the bagasse; tangling between particles, sticking of particles to the screens, and high values of particle length to breadth ratios all lead to low sieving efficiencies.

It is only possible therefore to compare particle size in this way when identical sieving procedures are adhered to.

Displaceability Index

The use of the Displaceability Index (DI) was first reported by Payne[6] as a direct measure of the availability of sugar in bagasse. Since then, Markham[4] has reported some results which show that DI depends on bagasse particle size.

The method of determining DI as proposed by Markham has been used here, except that brix values measured by means of a precision refractometer have been used instead of pol measurements.

Figure 2 confirms that a direct relationship exists between characteristic particle size and DI, which may be written in the form:

$$\mathrm{DI} = k d_c^{\,n} \qquad (1)$$

where n has the value -0.275 and k is 88.0. It should be noted that these values of k and n hold only when d_c is determined as described in the previous section.

The determination of DI is more accurate and reliable and less dependent on experimental technique than the determination of d_c, and thus it is felt that DI is a better method of characterization of cane preparation. Once again, the value of DI depends to some extent on the procedure employed; it is suggested that the procedure described by Markham[4] be standardized.

Liquid Holdup

Liquid holdup in a packed bed may be considered as consisting of two parts, static holdup and dynamic holdup. Thus we may write:

$$H_T = H_S + H_D \qquad (2)$$

Dynamic holdup may be thought of as a measure of the amount of liquid flowing through the bed. Static holdup has been identified with stagnant pockets of liquid in the bed[11], but perhaps a better idea is obtained by referring to observations by Shulman et al.[7] on the flow of dye injected into a packed bed. He observed semi-stagnant pockets of liquid, and splashing and the random motion of liquid over the packing surfaces deposited or removed dye from pockets by means of a slow random dilution process. Thus a certain amount of exchange of liquid between the flowing liquid and stagnant regions occurs.

A brief description of some of the published work on holdup follows, in the light of which the present holdup data may be discussed.

Static Holdup

The static holdup is normally taken as being equivalent to the adherent holdup, i.e., the residual liquid which remains in the bed on draining. This implies that H_S is independent of flow rate; however, one can envisage the volume of stagnant regions decreasing as the flow rate increases.

Gelbe[3] states that the adherent holdup is equal to the highest value of H_S at zero throughput. If the influence of the flowing film on the static holdup is taken into account, the value of H_S decreases with increasing flow rate, approaching zero at a high enough flow rate. This is a more plausible point of view.

Published data on static holdup are characterized by a considerable amount of scatter. This data shows that H_S is strongly dependent on packing material, shape and size[7,9], and also when adherent holdup is considered, on conditions in the packed bed before draining[10].

It has been shown that static holdup should depend on We/Fr, i.e., the ratio of Weber to Froude numbers[3,10]. This ratio represents the ratio of gravity to surface tension forces.

Dynamic Holdup

Dimensional analysis leads to the following relation for H_D[5]:

$$H_D = f(Fr/Re, Re) \qquad (3)$$

where Fr and Re are the Froude and Reynolds numbers respectively. The most general correlations which have been proposed for H_D are of this form[2], but scatter is still up to approximately 20%.

Shulman et al.[7,8] found dynamic holdup to be independent of packing shape and material. This supports a theory proposed by Davidson[2] that all random packings of a given size are equivalent to a series of sloping surfaces which are indistinguishable from one another. According to Davidson's model, for liquid in laminar flow.

$$H_D = f\left[\frac{(Re)^{\frac{1}{3}}}{Gr}\right] \qquad (4)$$

where Gr is a modified Grashof number.

Gelbe[3] reduced the scatter in correlation of dynamic holdup data by assuming that H_S varies with flow rate. He proposed the following correlation:

$$H_D = S \left(\frac{We}{Fr}\right)^{1/7} \left(\frac{Re^2}{Fr}\right)^{-0{\cdot}3} Re^n \qquad (5)$$

where S is a shape factor. For $Re \leq 1$, where the influence of inertia is negligible, $n = 1/3$ (cf Davidson[2]), and for $Re > 1$, where inertia increases and viscous drag decreases, $n = 5/11$.

A number of other correlations have been proposed. These will not be discussed here, save to point out that the dependence of H_D on flow rate has not been established satisfactorily.

Experimental Liquid Holdup Results

A brief description of the pilot plant diffuser is given in Appendix II.

Dynamic Holdup

This was calculated as the product of mean residence time and flow rate once steady state flow conditions were achieved. Mean residence time was taken as the time interval between injection of a dye into the top of the bagasse bed to the peak in outlet dye concentration. Experimental results are shown in figure 3. These data were obtained with bagasse bed heights varying from 30" to 35". The temperature of the percolating juice was 75°C; a few points obtained at 60°C and 90°C are included in figure 3 as they showed no significant variation. Flooding occurred at values of H_D = ca. 300 lb.

A marked effect of cane preparation can be seen. and four curves can be drawn through the data for the four types of preparation used (see Appendix I). A certain amount of scatter can be observed, which is to be expected as significant variations between bagasse samples occur even with the same method of preparation.

It is clear from the preceding discussion that if constant liquid properties are assumed, H_D is a function of flow rate and particle size only. Asssuming DI to be a measuring of particle size, a correlation of the following form is indicated:

$$H_D = A\, L^n\, DI^m \qquad (6)$$

where A, n and m are constants. Multilinear regression analysis showed L and DI to be significant at the 0.5% level. Values of A, n and m, and their standard deviations are given in Table I.

A more general form of correlation was obtained as:

$$H_D^1 = A^1\, L^{n1}\, DI^{m1} \qquad (7)$$

where H_D^1 is defined as holdup per lb. fibre. The corresponding value of the constants are given in Table I. In both cases dynamic holdup can be predicted with a standard deviation of 15%. Thus a usable correlation for dynamic holdup has been obtained, but indicates perhaps that DI alone is not sufficient to specify the dependence of H_D on particle size.

The values of n and n^1 as given in the Table lie in between the values of exponents on flow rate (or Re) of 5/11 proposed by Gelbe[3] and 0.75 proposed by Mohunta and Laddha[5].

Static Holdup

Consideration of the nature of bagasse leads one to expect significantly higher values of the static holdup in a bed of bagasse than in a bed of conventional packing materials used in absorption or distillation; to which most data on holdup refer. This is due to the complex shapes of the bagasse particles and the affinity of bagasse for water, and the error involved in assuming H_S equal to the adherent holdup is greater in this case than with conventional packing materials.

Values of H_S were calculated by subtracting the dynamic holdup from the total holdup, which could be readily obtained from the weight of the contents of the diffuser. Experimental data are shown in figure 4. Again a dependence on flow rate and cane preparation can be observed. The scatter is more pronounced in this case, which on the basis of the preceding discussion is not unexpected; static holdup is a function of particle shape and size.

Values of the ratio of adherent holdup to fibre varied from 5 to just over 6. No significant trends could be discerned, other than a slight dependence on cane preparation. It can be seen from figure 4 that extrapolation to zero flow rate leads to a value between 5 and 6, thus supporting the contention that adherent holdup is equal to H_S at zero throughout[3].

A correlation of static holdup/fibre ratio in terms of flow rate and DI was obtained by multilinear regression:

$$H_S{}^1 = B\, L^p\, DI^q \qquad (8)$$

Values of the constants B, p and q are given in Table I. It was found that DI is significant at the 0.5% level, and L at the 5% level. The standard deviation in predicted values of $H_S{}^1$ is 19%.

Discussion

The relations given above for holdup will be influenced by the density of packing and bed height. Nevertheless, it is probable that the relationship between holdup, L and DI will still have the same form. Further, in the case of different liquid properties, different holdup values will be obtained. The effect of varying properties on liquid holdup has been thoroughly investigated by Shulman et. al.[7,8].

Residence time of juice in diffusers has assumed a new importance recently; high residence time systems are associated with the production of more molasses and a consequently higher loss of sugar. The implications of a high static holdup are that some of the juice may remain in the bed for a long period of time, and have a far greater than average residence time in the bed. Higher static holdups are associated with coarser preparations; however, the total holdup of juice is less than that obtained with finer preparations. Higher flow rates significantly reduce the static holdup.

Conclusions

1. The fact that a relationship exists between DI and particle size has been confirmed. Values of the constants in this relationship will depend on the method used to characterize particle size.
2. DI is a more reliable measure of cane preparation than particle size. Since it is still a relative measure of cane preparation, values of DI depend on the method of determination.
3. Static and dynamic holdup exhibit a strong dependence on cane preparation.
4. Both static and dynamic holdup depend on flow rate. The ratio H_D/H_S increases markedly with flow rate.
5. DI has been used as a measure of cane preparation to provide working correlations to predict holdup in fixed bed diffusers.

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Nomenclature

DI = displaceability index
d_c = characteristic particle size (mm or ft)
d_p = particle size (mm or ft)
Fr = Froude Number = $\dfrac{V^2}{gd_p}$
g = acceleration due to gravity (ft/sec²)
Gr = modified Grashof Number = $\dfrac{gd_p{}^3\,\rho^2}{\mu^2}$
H_T = total holdup (lb)
H_D = dynamic holdup (lb)
H_S = static holdup (lb)
$H_D{}^1$ = H_D/lb fibre
$H_S{}^1$ = H_S/lb fibre
L = liquid mass velocity (lb/min ft²)
Re = Reynolds Number $\dfrac{d_p\,L}{\mu}$
V = Velocity of liquid based on empty column (ft/sec)
We = Weber number = $\dfrac{V^2\,\rho d_p}{\sigma}$
μ = liquid viscosity (lb/min ft)
ρ = liquid density (lb/ft³)
σ = surface tension (lb/ft)

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TABLE I

Values of regression coefficients and standard deviations for equations (6), (7), and (8).

	Regression Coefficient	Standard Deviation
A	0.010	—
n	0.472	0.048
m	1.887	0.153
A^1	0.00052	—
n^1	0.494	0.048
m^1	1.728	0.155
B	1780	—
p	-0.154	0.059
q	-1.306	0.189

APPENDIX I

Preparation of bagasse samples

Bagasse samples were taken from the milling tandem at Mount Edgecombe after the first mill. The bagasse could then be further prepared by the use of a small Hippo Mill, a fixed hammer shredder, with provision for the introduction of screens on the outlet in order to attain finer preparation.

The various degrees of preparation referred to in the text are:

P1	First mill bagasse.
P2	First mill bagasse, after passing through the Hippo mill without a screen.
P3	As above, but with a coarse screen in the Hippo mill.
P4	As above, but with a fine screen.

APPENDIX II

Description of the pilot plant diffuser

The diffuser consisted of a 2 ′ D. mild steel column 6 ′ high. The bagasse bed rested on a screen located towards the bottom of the column. The diffuser itself rested on three knife edges; two of them rested on a rigid supporting framework on one side of the column, and acted effectively as a pivot. The third knife edge was attached to a Phillips PR 6101P/02HK load beam; any increase in weight in the diffuser increased the force on the load beam. This produced a signal proportional to the force, which was led to a recorder. Thus the weight of the contents of the diffuser could be continuously monitored.

The weight of the vessel itself was counter balanced by means of a weight-and-pulley system. A fine tare adjustment on the power supply to the load beam enabled accurate elimination of the weight of the vessel for recording purposes.

In operation, water or juice was pumped from a stirred thermostatistically controlled tank through a flow controller and into a flow distributor, suspended independently of the diffuser just above the bagasse bed.

At the commencement of a run, the weight was observed to increase; after a few minutes, the weight tended to a constant value, indicating steady state flow conditions. All holdup data reported here referred to steady state operation only.

Discussion

Mr. Bruijn (in the chair): Do you favour a coarse or fine preparation for diffusion?

Mr. Rein: I suggest somewhere in between. If it is too fine, the maximum flow rate is limited. On the other hand, if it is too coarse the extraction will be low.

Mr. Bruijn: Is not the flow rate connected with the type of diffuser, or does this apply to all diffusers, i.e. does it only apply to a percolation diffuser.

Mr. Rein: This applies mainly to percolation diffusers.

Mr. Jullienne: No mention is made in the paper of the effect of air locks. Was this investigated.

Mr. Rein: This was not investigated. It is more important when flooding occurs but as these data were taken when the bed was not flooded, air locks should have little effect.

Mr. Renton: Mr. Rein says that in the case of static hold up some of the juice may remain in the bed for a long time, i.e. longer than the usual residence time.

Percolation bed diffusers have a higher juice retention than fibre retention. Therefore, if there is static hold up, does this juice have less residence time than juice that is percolated.

Mr. Rein: The boundary between static and dynamic hold up is not absolutely defined, and there is interchange between the two.

Some parts of static hold up will be more firmly held in bagasse beds than others and it is those parts which are most firmly held that might be caught in the bed near the beginning of the diffuser, be taken to the end, and recirculated to the beginning.

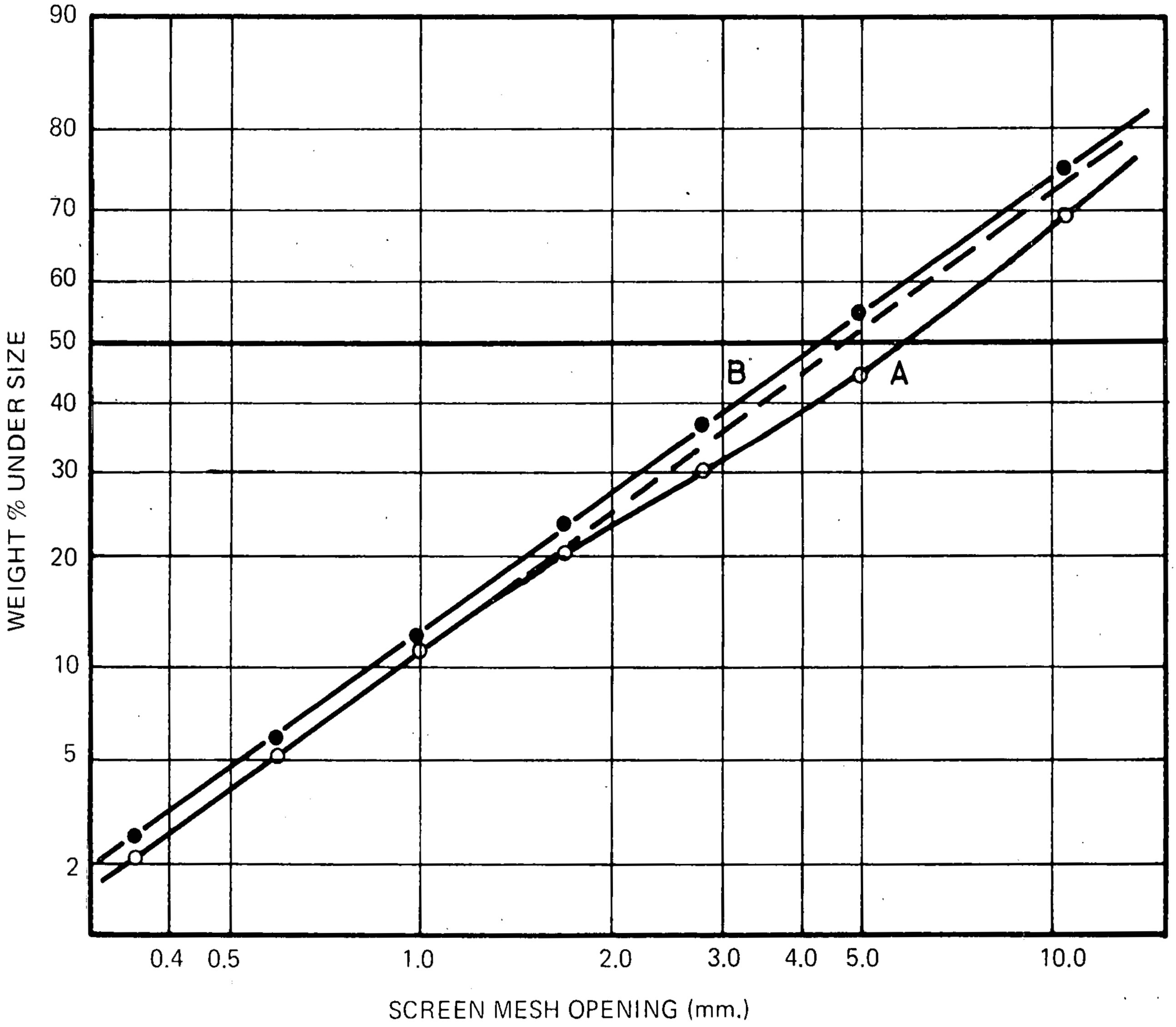

FIGURE 1

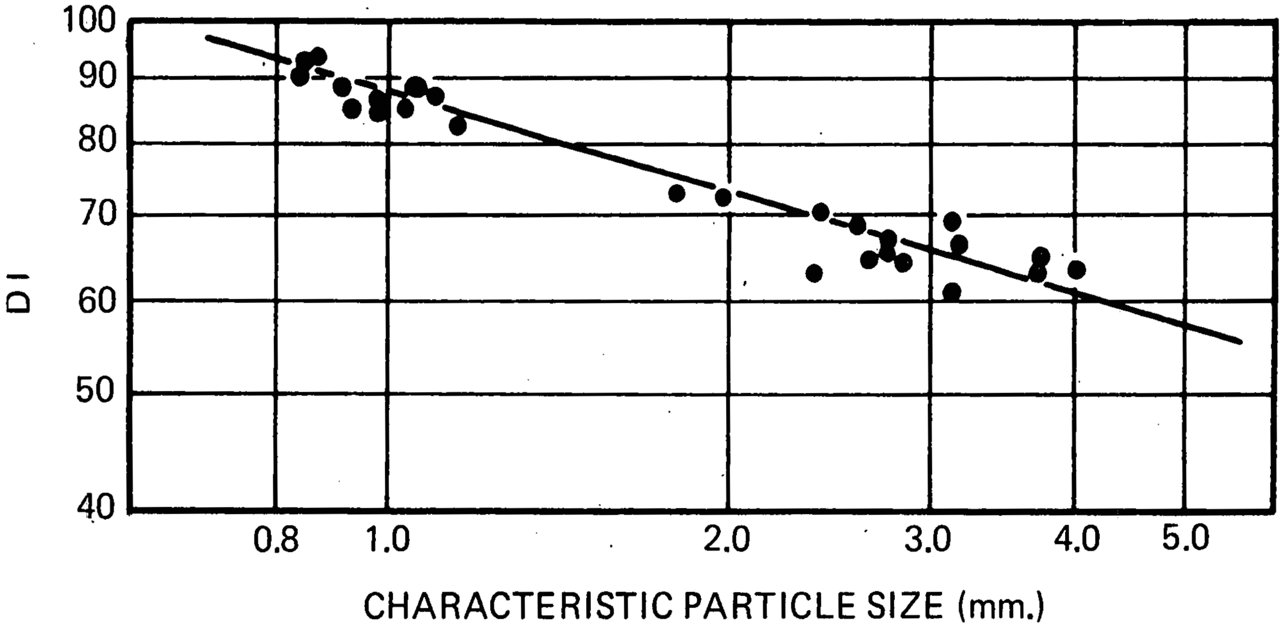

FIGURE 2

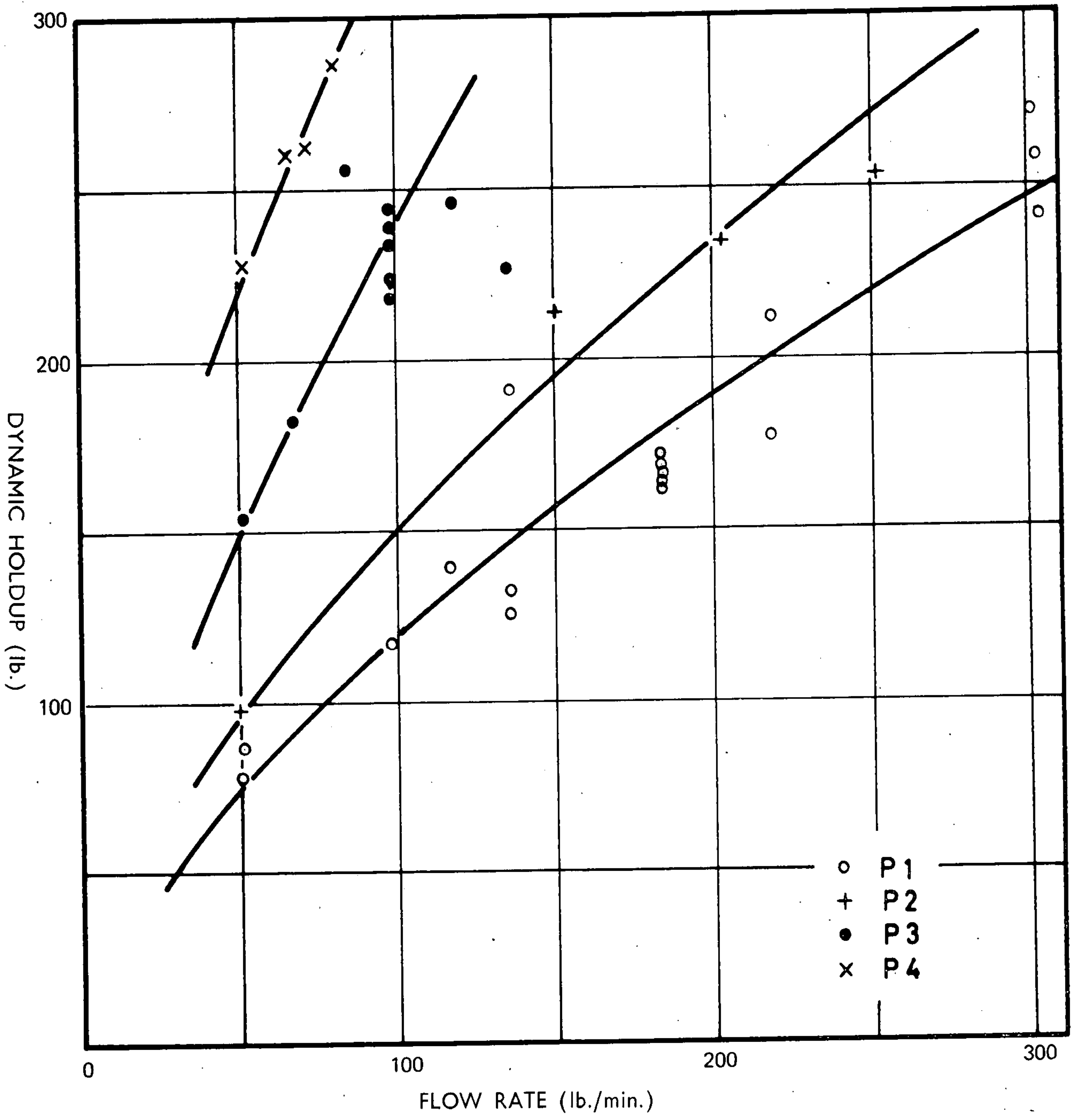
300
200
100
0
100
200
300
DYNAMIC HOLDUP (lb.)
FLOW RATE (lb./min.)
○ P1
+ P2
● P3
× P4

FIGURE 3

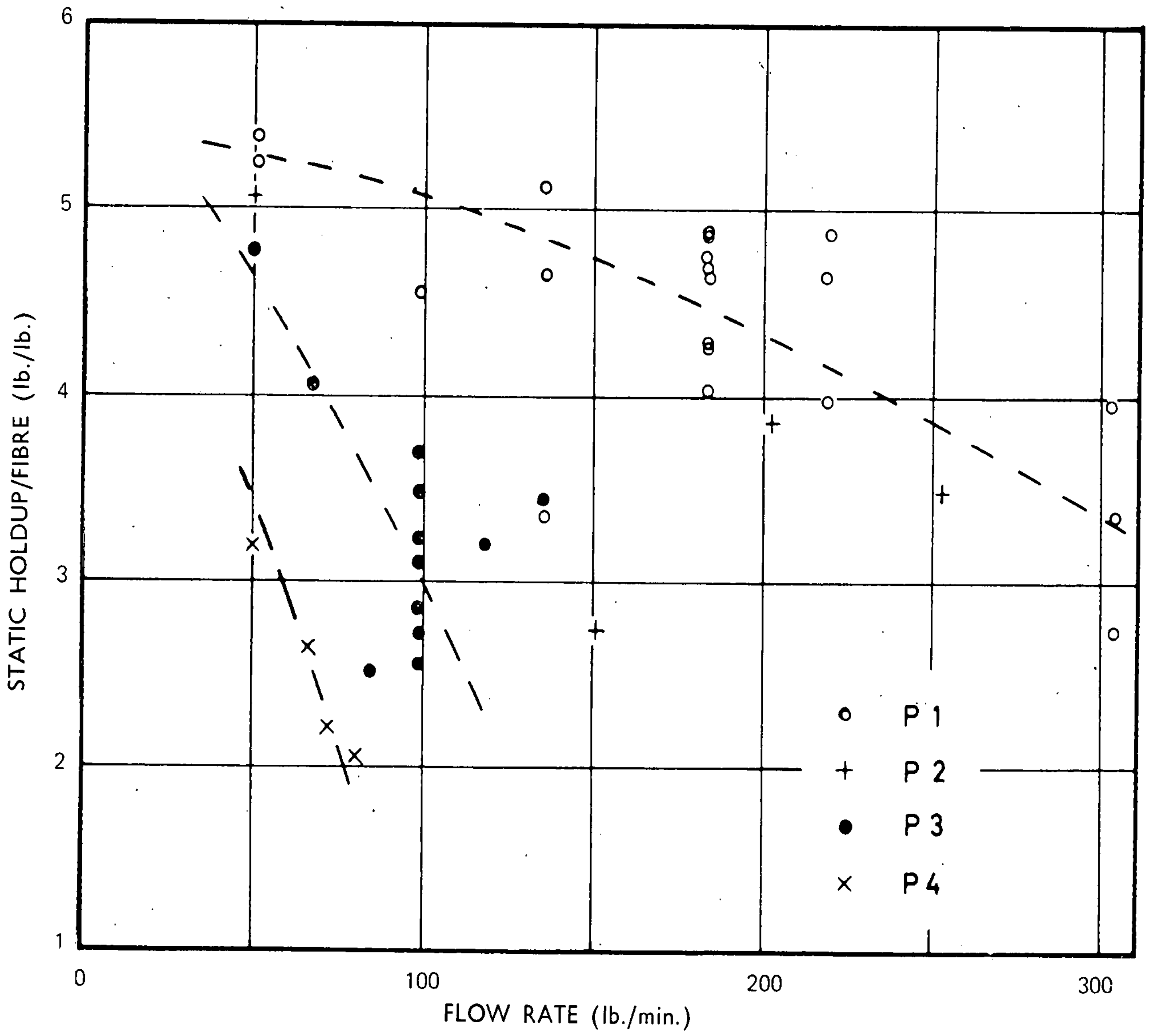
6
5
4
3
2
1
STATIC HOLDUP/FIBRE (lb./lb.)
0
100
200
300
FLOW RATE (lb./min.)
○ P 1
+ P 2
● P 3
× P 4

FIGURE 4