SUMMARY

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Separation of materials into two or more fractions depending upon their rates of flow through the fluid is called classification. In classification particles of varying sizes, shapes and densities are separated and it is a very useful operation in the concentration of minerals. One recent development in the classification of solids is the application of fluidized bed technique, using a medium of liquid (hydraulic) or gas (pneumatic).

During classification the solid particles are acted upon by gravitational, buoyant and drag forces. The particles varying in size and/or density behave differently in the fluid medium and a separation is possible using a proper fluid velocity. It is commonly believed that the minimum velocity required for the carry-over of particles (finer/lighter component), should be equal to or greater than U_T. In calculating U_T it is assumed that (i) free-fall condition exists and (ii) the particles are spherical in shape. None of these conditions is, however, met in actual practice and it is in this context that the determination of actual carrying velocity of particle becomes so important.

In an ideal batch classifier using air as the fluid, it should be possible to separate completely any mixture of

particles (say binary) into its respective constituents, namely, the lighter/finer (overflow or elutriated fraction) and the heavier/coarser (underflow or bed mass) components. It has, however, been found in course of the present investigation that the bed has a retentive capacity for the lighter/finer constituent and a state of 'equilibrium concentration' is reached beyond which no further separation is possible. This equilibrium bed concentration again depends on the conditions of classification. It is equally important to know how fast the equilibrium is reached and, therefore, a kinetic model for the rate of elutriation has to be considered for the design of a fluidized bed classifiers.

In conventional fluidizers slugging is a very common phenomenon. The formation of slugs increases the amount of carry-over of particles, but the quality of separation deteriorates. Accordingly, a classifier with internal baffles has been developed and its performance assessed in terms of conventional separation indices.

It is, however, observed that many of these indices fail to satisfy the prescribed requirements. For this purpose, a new index, denoted by 'Classification Factor' (C.F.), has been proposed to evaluate the performance of the classifier.

In view of the fact that a batch classifier has a low capacity and also because data on continuous classification are rather meagre, the urge for developing a continuous classifier and investigating its performance has been strongly felt. Accordingly, some studies have been carried out in this direction and suitable design equations suggested.

The thesis has been presented in eight chapters.

Chapter I : LITERATURE SURVEY

An intensive literature survey has been made outlining the principle of separation of solid mixtures in conventional classifiers (hydraulic as well as pneumatic) and their performance characteristics. A review dealing with the entrainment of particles has been included. The effects of operating conditions on the extent of separation have been discussed. Informations about the so called 'equilibrium' concentration or 'retentive capacity' of the bed have been given. It is revealed that a first order 'kinetics' fits the data on the rate of elutriation. To improve the quality of fluidization use of baffles was suggested in literature and the work related to this aspect is reported.

Chapter II : EXPERIMENTAL ASPECTS

A detailed description of the batch as well as the continuous classifiers, method of calibration, preparation of feed, experimental procedure and method of analysis has been given. Air at about 32°C and relative humidity of about 40% has been used as the fluidizing medium. The batch fluidizing column is made of perspex tube of 5.7 cm i.d. and 60 cm height. The equipment used for continuous classification is also made of perspex tube (5.7 cm i.d. and 95.5 cm height) and has four feeding ports at different heights inclined at 45°. The feed rate is controlled by means of a cup-and-cone feeding arrangement.

The materials investigated include coke, coal, salt, sand, chalcopyrite, graphite, ammonium-sulphate, magnesite, hametite and magnetite. Size ranges used are 20/30, 30/40, 40/52, 52/60, 60/72, 72/80, 80/100, 100/120 and 120/150 BSS.

Experiments have been conducted in the following ranges of different parameters :

H/H_s : 4.8 - 10.6, G/G_{me} : 1.5 - 2.66
w/W : 0.3 - 0.8, ρ_2/ρ_1 : 1.35 - 4.30
d_2/d_1 : 1.28 - 2.93 G/G_{mf} : 7 - 12
G_s/G : 0.09 - 0.36 H/H_f : 1.30 - 3.75

Chapter III : MINIMUM ELUTRIATION VELOCITY

The minimum velocity required for elutriation (G_{me}) in a heterogeneous system has been found to depend on the system variables like the sizes and densities of the particles and the density and viscosity of the fluid.

The correlation developed for predicting G_{me} is of the form :

$$Re_{me} = 0.11\ (Ga)^{0.61}$$

or,

$$G_{me} = 7.45\ d_p^{0.83}\ \rho_g^{0.61}\ (\rho_s - \rho_g)^{0.61} / \mu^{0.22}$$

The equation has a correlation coefficient, $r = 0.97$ and $S_{y,x} = 0.12$.

In calculating Re_{me} and Ga the average particle size, d_p and the average particle density, ρ_s have been computed using the harmonic and arithmetic mean respectively.

Chapter IV : EQUILIBRIUM BED CONCENTRATION

An analysis of the data reveals that for a given set of experimental conditions of classification, the concentration of the lighter/finer particles in the bed decreases gradually (asymptotic nature) with the time of elutriation, reaching thereafter a specific value beyond which no further separation takes place. This limiting concentration, C_E (termed as 'equilibrium bed concentration') has been found to depend on dimensionless parameters like, d_2/d_1, G/G_{me}, H/H_s, w/W and ρ_2/ρ_1. Accordingly, the following correlation for cylindrical classifier has been obtained.

$$C_E = 15.81\,(H/H_s)^{0.28}\,(G/G_{me})^{-3.69}\,(w/W)^{2.04}\,(\rho_2/\rho_1)^{-0.51}\,(d_2/d_1)^{-0.80}$$

correlation coefficient, $r = 0.74$, $S_{y,x} = 0.412$.

Chapter V : RATE OF ELUTRIATION

The kinetics of elutriation has been investigated and it is found to follow a first order equation of the type,

$$-dC/d\theta = k(C - C_E)$$

Integrating between the limits,

$$\ln\left[(C_o - C_E)/(C - C_E)\right] = k\theta$$

The rate constant, k has been evaluated from the slope of straight line obtained by plotting $\ln(C_o-C_E)/(G-C_E)$ against time, θ. The value of k has been found to depend on parameters identical to C_E. The correlation developed is as follows :

$$k = 0.11(H/H_s)^{-0.07}(G/G_{me})^{2.88}(w/W)^{-2.14}(\rho_2/\rho_1)^{0.67}(d_2/d_1)^{-2.72}$$

The correlation coefficient, r = 0.93, $S_{y,x} = 0.15$.

The values of rate constant, k so obtained, have been compared with those of Osberg and Charlesworth[75], Wen and Hashinger[119] and Yagi and Aochi[122].

Chapter VI : CLASSIFICATION IN ANNULAR VESSEL

To reduce slugging in the fluidizer, baffles of conical shape have been inserted into the column and their effects on elutriation have been studied. Three baffles of effective diameter, D_e (calculated by equating the volume of the baffle to that of a cylinder of the same length) as given below, have been used.

Baffle	Size, cm.		
	Top end	Bottom end	D_e
B1	1.27	1.90	1.55
B2	1.27	2.54	1.92
B3	1.27	3.18	2.27

The introduction of baffle within the column leads to fluidization in the annular space. Since the fluid velocity decreases gradually upwards, the top product gets enriched more and more with the lighter/finer particles (analogous to rectification in a distillation column). Also, the tendency of formation of slugs of the size of column diameter is minimised. Consequently, the quality of separation improves, though the capacity gets little reduced. In general, it is observed that the bigger is the D_e , the better is the quality of separation.

The equilibrium bed concentration, C_E for the three baffles have been experimentally found and correlated as below :

$$C_E = 26.12(H/H_s)^{0.08} (G/G_{me})^{-2.88} (w/W)^{1.67} (\rho_2/\rho_1)^{-2.26} (d_2/d_1)^{-2.42} (D_t/D_e)^{0.12}$$

Correlation coefficient, $r = 0.88$, $S_{y,x} = 0.276$.

Chapter VII : PERFORMANCE OF FLUID BED CLASSIFIER

The performance of conventional classifiers is adjudged using various separation indices as described in literature. A pneumatic classifier of the present type has unique advantages in that the settling velocity of heavier/coarser particles is roughly about one hundred times greater than in hydraulic classifier, because of manifold decrease in the apparent specific gravity and the viscosity. It is, therefore, felt proper to assess the maximum separation achieved (corresponding to the bed concentration C_E) in the fluid bed classifier by using separation indices like efficiency, performance index and concentration index. Empirical correlations have been obtained and these are summarised in Table I.

One important criterion of separation is the selectivity index (S.I.), which gives the geometrical mean of the relative recoveries and relative rejections of two minerals or metals. This concept being analogous to relative volatility in distillation, has been successfully applied to the classification of materials in the gas-solid fluidized bed. Accordingly, the S.I. values for the data with and without baffle have been calculated and correlated empirically as follows :

Without Baffle

$$S.I. = 7.94 \times 10^{-3} (H/H_s)^{0.68} (G/G_{me})^{2.47} (w/W)^{-0.68} (\rho_2/\rho_1)^{2.41} (d_2/d_1)^{5.27}$$

Correlation coefficient, $r = 0.884$, $S_{y,x} = 0.40$

With Baffle

$$S.I. = 0.095 (H/H_s)^{0.61} (G/G_{me})^{3.19} (w/W)^{-0.14} (\rho_2/\rho_1)^{2.43} (d_2/d_1)^{3.27} (D_t/D_e)^{-1.0}$$

Correlation coefficient, $r = 0.93$, $S_{y,x} = 0.18$.

One major difficulty experienced in using many of the separation indices has been that the desired product has to be well-defined. The S.I. is a good criterion but has drawback in the sense that in case one of the products is hundred percent pure, the value becomes an indeterminate. Some of the indices

TABLE I : CORRELATIONS FOR DIFFERENT SEPARATION EFFICIENCIES

Authors	Correlation	Corr.coeff., r	Std. error of est., $S_{y,x}$
1. Truscott[115]	$e = 0.13(H/H_s)^{-0.36}(G/G_{me})^{3.92}(w/W)^{-3.91}(\rho_2/\rho_1)^{0.30}(d_2/d_1)^{1.08}$	0.94	0.19
2. Gaudin[31] Hancock[42] Taggart[118] Valentik[117]	$Ef=1.63x10^{-2}(H/H_s)^{-0.65}(G/G_{me})^{7.01}(w/W)^{-4.89}(\rho_2/\rho_1)^{0.70}(d_2/d_1)^{1.81}$	0.93	0.27
3. Edser[19]	$n=4.86x10^3(H/H_s)^{0.64}(G/G_{me})^{-7.46}(w/W)^{5.21}(\rho_2/\rho_1)^{-0.93}(d_2/d_1)^{-1.76}$	0.94	0.26
4. Anderson[3]	$Ef=4.98(H/H_s)^{-0.17}(G/G_{me})^{1.72}(w/W)^{-2.30}(\rho_2/\rho_1)^{0.22}(d_2/d_1)^{0.44}$	0.97	0.07
5. Lemke et al[59]	$F.I.=0.22(H/H_s)^{0.65}(G/G_{me})^{7.01}(w/W)^{-6.69}(\rho_2/\rho_1)^{0.70}(d_2/d_1)^{1.81}$	0.95	0.27
6. Stevans & Collins[106]	$I_c=2.3x10^{-5}(H/H_s)^{-0.65}(G/G_{me})^{7.10}(w/W)^{-7.72}(\rho_2/\rho_1)^{0.71}(d_2/d_1)^{1.83}$	0.96	0.27

again do not depend on the product qualities. Considering these difficulties the author has postulated a new index, the 'Classification Factor (C.F.)' [equal to $W_c(C_d-f_d)/100$], which is easily conceivable and can satisfy all the characteristics of a separation index. The correlation developed for C.F. is as follows :

Without Baffle

$$C.F. = 2.025\times10^{-2}(H/H_s)^{-0.23}(G/G_{me})^{5.23}(w/W)^{-1.33}(\rho_2/\rho_1)^{0.99}(d_2/d_1)^{2.98}$$

The correlation coefficient, $r = 0.723$, $S_{y,x} = 0.48$.

With Baffle

$$C.F. = 0.11(H/H_s)^{-0.22}(G/G_{me})^{4.55}(w/W)^{-1.23}(\rho_2/\rho_1)^{0.88}(d_2/d_1)^{2.7}(D_t/D_e)^{-0.88}$$

The correlation coefficient, $r = 0.89$, $S_{y,x} = 0.26$.

Chapter VIII : CONTINUOUS CLASSIFICATION IN FLUIDIZED BED

The continuous classifier has been operated under different conditions by varying the particle sizes, feed composition, rate of feed, location of the feed point and the velocity of air, and their effects on the overall performance have been investigated. Various materials like coal, sand, hametite, graphite and magnetite have been used.

Based on the data, the following correlations have been developed.

The relationship proposed for C.F. is as follows :

$$C.F. = 2.92 \times 10^{-9} (H/H_f)^{0.32} (G/G_{mf})^{7.0} (w/W)^{-4.16} (\rho_2/\rho_1)^{0.245} (d_2/d_1)^{4.76} (G_s/G)^{-0.146}$$

The correlation coefficient for the above equation is 0.77.

A correlation has been developed for predicting the rate of carry-over of particles which is applicable for both batch and continuous classifiers :

$$E/G = 1.31 \left(\frac{u^2}{gd_1} \cdot \frac{\rho_g}{\rho_1} \cdot \frac{w}{W} \right)^{2.95}$$

The correlation coefficient has been found to be 0.82 and the standard error of estimate is 0.59.

APPENDIX : This consists of all the programmes used in IBM 1620 computer along with the results.

The thesis also contains the NOMENCLATURE and the REFERENCES.