Mixing Effects in a Simple Air Classifier

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INTRODUCTION

The term air classifier is applied to a number of different types of apparatus used in the field of waste recycling. The common feature is the fact that the differing behavior of different species of solid particles in a moving stream of air is used to effect a separation.

This paper follows earlier papers (Biddulph, 1983, 1984) concerned with producing a mathematical model, based on diffusion, of a simple vertical water elutriator. The intention here is to apply the model to the much higher fluid velocity situation generally found in air classifiers, with the objective of improving the design basis of these units.

Models of air classifiers have been developed and presented by Senden and Tels (1976, 1978), Leschonski (1981), Fan (1975), Vesilind et al. (1982), and Vesilind (1984). Although models including the use of dispersion coefficients have been mentioned, no values of such coefficients appropriate to waste recycling operations have been published.

The feedstock to an air classifier in a waste recycling plant, for example comminuted municipal solid waste, is very complicated in nature. There are many particles having irregular shapes, often composed of different materials combined together. For this reason the design of air classifiers has been largely based on trial-and-error methods. Because of the complicated and largely unpredictable nature of the solid species to be separated, it probably will not be possible to apply any rigorous model involving trajectories of individual particles. However, it may be possible to establish the basic operating characteristics by using mixtures of particles of uniform and predictable behavior.

Mathematical Model

The equations which result from the eddy diffusion model have been presented previously (Biddulph, 1983). Equations 7–10 given there enable direct calculation of the rate of loss of each species from the top and bottom of the column, assuming that a value for the effective eddy diffusion coefficient is known. The model assumes no interaction of solid particles, and thus is likely to be a better representation of the behavior at low particle concentrations, that is, at high air/solids ratios. During the earlier study on the water elutriator (Biddulph, 1983), it was observed that so-called wall flow of particles was occurring. This refers to the tendency of the solid particles to prefer the slower moving fluid near the wall rather than the faster fluid near the axis of the tube. The order of fluid velocity used in the water elutriator was 0.3–0.6 m/s, whereas the air velocities used in this study are in the range 10–14 m/s. As a result of this large difference it would be anticipated that wall flow would be less of a problem in the air classifier, and it will be seen later that this is indeed the case.

Measures of Performance

There have been various ways proposed for defining the separating performance of air classifiers (Worrell and Vesilind, 1979). An attempt has been made recently to standardize the method of defining the efficiency (Vesilind, 1984).

Compositions and recovery fractions are important. If both top and bottom products are to be optimized, the criterion which has been used before (Biddulph 1983) has been the sum of the loss fractions of the species (C). A zero value for C represents perfect separation, while a value of unity represents no separation. This will again be used here for comparison with earlier studies. Other definitions are available (Vesilind, 1984).

In air classifier operations the top product composition is often called the light fraction quality, and this, together with the recovery fraction will also be used.

EXPERIMENTAL

A diagram of the equipment used in this investigation is shown in Figure 1. The main vertical duct where separation occurs is constructed from a transparent polymer sheet to make observation of the behavior possible. The dimensions of the duct are 3.60 m by 30 cm by 15 cm. The main centrifugal blower, driven by a 15 HP motor via a variable speed gearbox, provides the air flow. The solids feed comes from a hopper and a screw feeder driven by a 1/2 HP motor and a variable speed gearbox.

RESULTS

Three different mixtures of solid particles were studied, all being made up of precision polymer spheres. The three binary mixtures were made up from particles whose properties are shown in Table 1. The top and bottom products were collected and analyzed by sieving. The values of the terminal velocities (Ut) in air were predicted using the standard equations, and these agreed well with the air velocity required to just hold a species steady in the column.

Three binary mixtures were studied: A/B, B/C, and C/D. Each mixture consisted of approximately equal numbers of

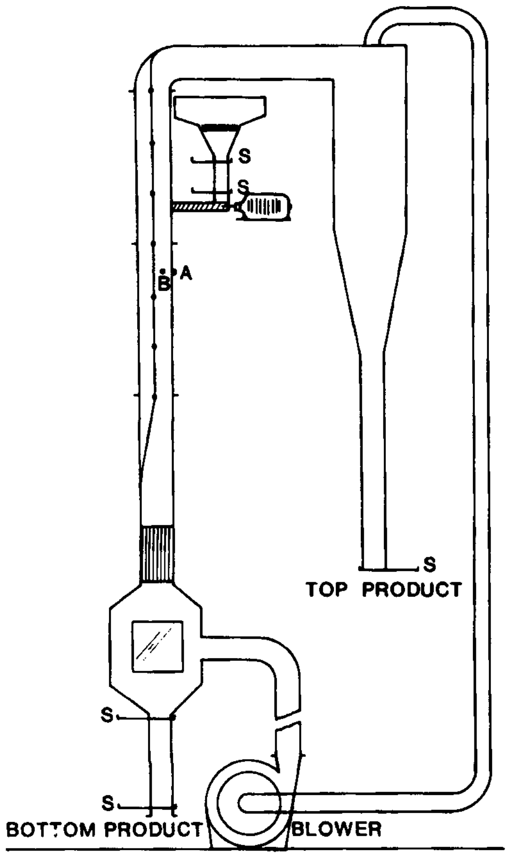

Figure 1. Experimental air classifier.

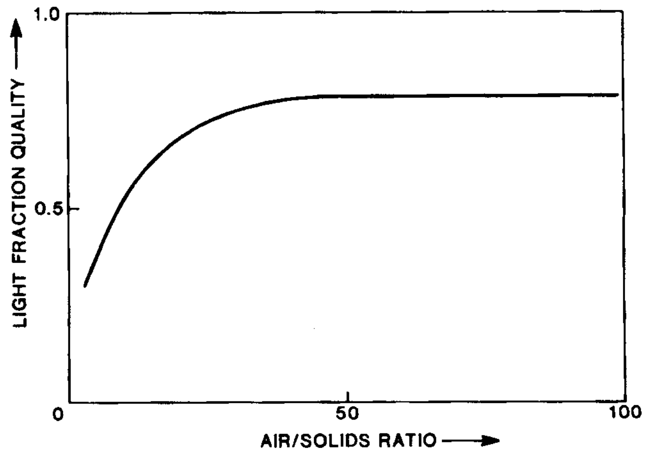

Figure 2. Typical dependence of performance on air/solids ratio.

particles of each species, and the runs were made at high air/solids ratios, Figure 2 (Vesilind and Rimer, 1981).

The experimental separation results from the three mixtures studied are presented as light fraction quality, light species recovery fraction, and the sum of the loss fractions of both species (C).

Figure 3 shows a comparison between the experimental separations, expressed as C values, and the predictions from the model for mixture A/B. Values of effective diffusivity for each species were adjusted to obtain the best fit, these diffusivities being related to the appropriate free stream dispersion coefficients based on the data of Levenspiel (1972). The slight skew to the right shown by the curve indicates greater mixing of the light species downwards than of the heavy species upwards, bearing in mind that the feed point is above the middle of the column, a fact that would give a curve skewed to the left if the diffusivities were equal. Both effective diffusivities are quite close to the free stream value ($Defs$), the light species requiring 1.27 $Defs$ while the heavy species requires 0.63 $Defs$. This is a similar but less pronounced effect to that observed in the water elutriator, and is due to the slight wall flow assisting the light species to penetrate downward. It is reasonable that the heavy species should require a diffusivity slightly lower than the free stream value, since presumably only zero mass particles could exhibit a value equal to the free stream value in this situation.

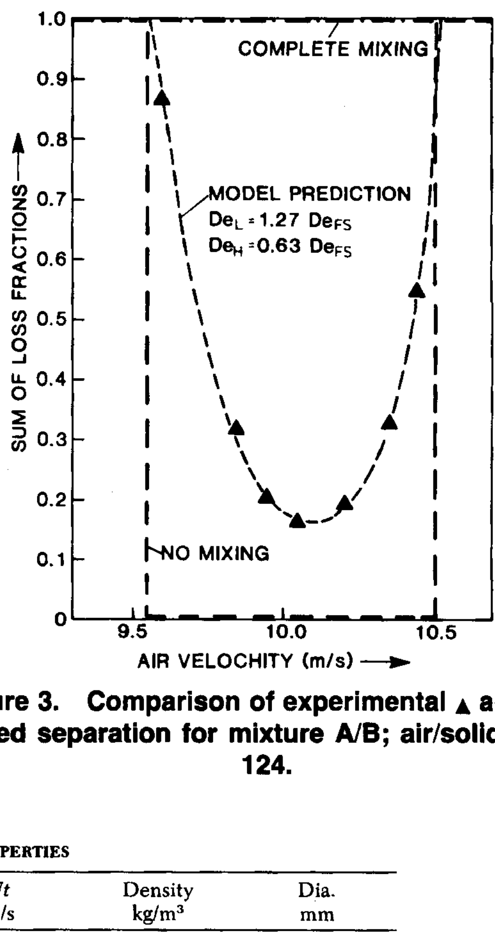

Figure 3. Comparison of experimental ▲ and predicted separation for mixture A/B; air/solids ratio 124.

TABLE 1. PARTICLE PROPERTIES

Species	Material	Color	Ut m/s	Density kg/m^3	Dia. mm
A	Nylon	White	9.55	1,134	3.175
B	Polypropylene	Green	10.50	875	4.763
C	Polystyrene	Red	12.30	987	6.00
D	Polypropylene	Green	13.25	875	7.94

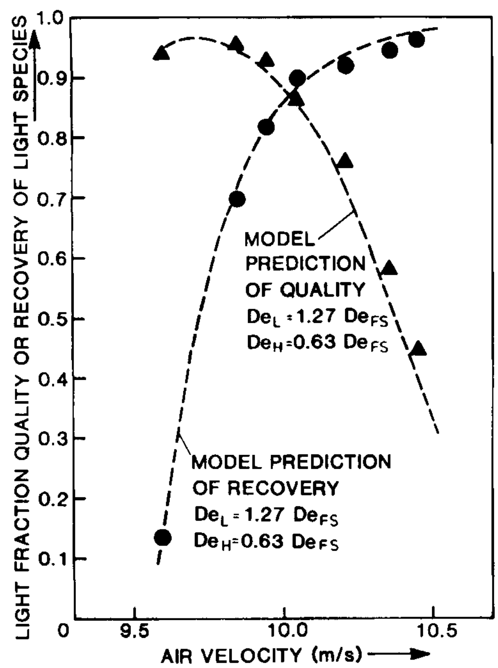

Figure 4. Comparison of experimental ▲● and predicted quality and recovery for A/B; air/solids ratio 124.

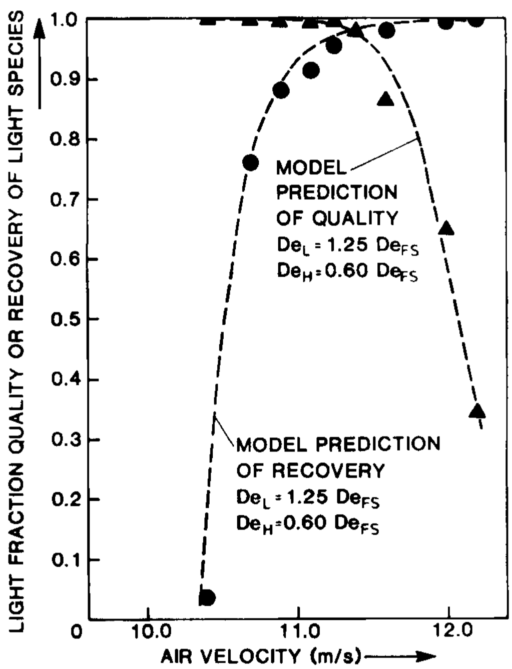

Figure 6. Comparison of experimental ▲● and predicted quality and recovery for B/C; air/solids ratio 120.

Figure 4 shows the comparisons of top product composition (weight fraction) or light fraction quality, and the recovery fraction of the light species as measured experimentally and predicted by the model. It can be seen that quite a good match is achieved. Figures 5, 6, 7 and 8 show the equivalent comparisons for mixtures *B/C* and *C/D*.

The absolute values of the effective diffusivity deduced by this method are shown in Table 2, each at optimum separation conditions. In this range of air velocities, commonly used in waste recycling operations, and under the conditions employed in these experiments, the values of the effective diffusivities remain fairly constant. With increasing velocity there may be a tendency for the diffusivity relative to the free stream value to decrease slightly.

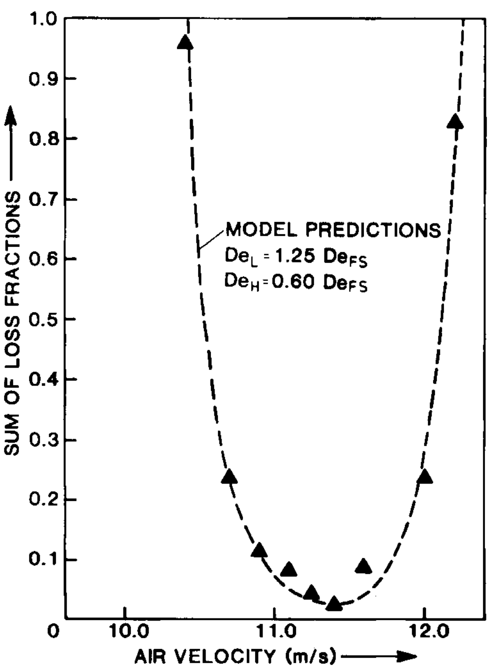

Figure 5. Comparison of experimental ▲ and predicted separation for mixture B/C; air/solids ratio 120.

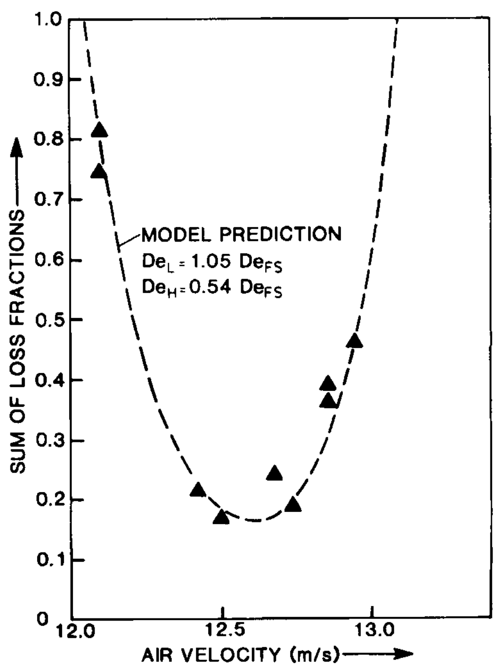

Figure 7. Comparison of experimental ▲ and predicted separation for mixture C/D; air/solids ratio 130.

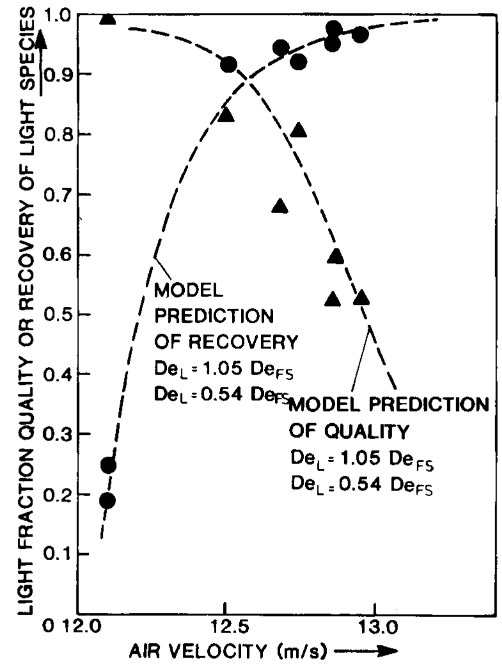

Figure 8. Comparison of experimental ▲● and predicted quality and recovery for C/D; air/solids ratio 130.

TABLE 2. EFFECTIVE DIFFUSIVITY VALUES

Mixture	Air Veloc. m/s	*Del* m^2/s	*Deh* m^2/s
A/B	10.1	0.51	0.26
B/C	11.4	0.57	0.28
C/D	12.7	0.54	0.28

IMPLICATIONS FOR DESIGN

As in the case of the water elutriator, it is beneficial to locate the solids feed point noticeably above the middle of the column. The exact location could be established by using the model under the required conditions. This is a feature that has emerged by trial and error in many air classifier designs, but this model provides a means of locating the best feed point.

The best total length of column can be found for a given set of conditions—the optimum length, which can be established in the same way as before (Biddulph, 1984).

The results obtained here apply to ideal mixtures under ideal conditions of no particle interaction. Real mixtures contain particles with a range of sizes and shapes, and which are likely to interfere with each other. The model can be used to study a mixture having a range of terminal velocities by dividing the mixture into notional slices and summing the separation achieved for each slice (Biddulph, 1984). It is better to operate air classifiers of this type at high air/solids ratios if possible, giving better, and more predictable, separation. The estimated performance at lower air/solids ratios might be obtainable by using the model to effectively locate the curve of the type shown in Figure 2.

ACKNOWLEDGMENT

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NOTATION

C	= sum of the loss fractions of species
$Defs$	= free stream fluid diffusivity, m^2/s
Deh	= effective eddy diffusivity for heavy species, m^2/s
Del	= effective eddy diffusivity for light species, m^2/s
Ut	= terminal falling velocity in air, m/s

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