Model of Fluidized Bed Elutriation: Effect of the Initial Mass of Fine Particles in the Bed

D. Santana

Universidad Carlos III de Madrid, Area de Ingeniería Térmica
Avda. de la Universidad 30, 28911 Leganes, Madrid, Spain

A. Macías-Machín[1]

Grupo EMA, ETSII de Las Palmas, Universidad de Las Palmas de Gran Canaria
Tafira Baja s/n, Las Palmas de Gran Canaria, Canary Islands, 35017, Spain

Abstract—A model is proposed to account for elutriation and attrition based on the assumption that the generation of fine particles by means of attrition depends on the percentage of the mass of fine particles in the bed. Elutriation rate constants and attrition rates were evaluated for various types of particles (TiO_2, $CaCO_3$). A decrease in the elutriation rate constant and in the attrition rate of the model was observed when the fines loaded in the bed increased. The decrease in the elutriation and attrition rates was significant when the powder cohesiveness diminished. The effect of the initial mass of fine particles on fluidized bed elutriation is also discussed.

Key Words : Elutriation, Attrition, Fluidized beds, Modelling

INTRODUCTION

Several investigators have made important contributions to our understanding of the mechanisms of elutriation and attrition in fluidized beds. Chirone *et al.* (1985), Arena *et al.* (1983) and Liu and Kimura (1993) observed that fine particles generated by means of attrition in beds with mixtures of fine and coarse particles controlled elutriation.

Bortzmeyer and Goimard (1996) investigated the relationship between the attrition tendency of agglomerates and their mechanical behaviour, and evaluated the influence of the particle characteristics. They used three $CaCO_3$ powders of different shapes and sizes, one of which exhibited a far higher attrition rate than the others. It was found that this behaviour was related to the surface properties of the agglomerates.

According to Ayazi Shamlou *et al.* (1990), the generation of fine particles through attrition in a bed is a function of the percentage of the agglomerated particles which remain in the bed. Attrition increases the number of free flowing particles and reduces the agglomeration of fines.

Therefore, a fluidized bed with agglomerated materials cannot be designed appropriately until the attrition activity is quantified (Ray *et al.*, 1987). In this work, attrition refers to the process of removing fines from the surface of the parent material so there is only a gradual decrease in the percentage of agglomerated fines in the bed. Based on experimental data obtained during the attrition process, it is suggested that a non-linear rate of increase in the mass of fines is generated as a function of the operating time.

Colakyan and Levenspiel (1984) integrated the fines generation process in the bed (attrition) into the first order equation, assuming that the attrition rate constant or fines generation constant would be constant with time. Liu and Kimura (1993) using this later model, divided the fines remaining in the bed into different types based on three states (freely moving fines, fines attached to large particles and agglomerated fines).

Recently, Santana *et al.* (1999) proposed a new model to account for the elutriation and attrition based on the assumption that the generation of fines by means of attrition is a nonlinear function of time. Thus, the purpose of this study was to examine the effect of the initial mass of fine particles in a bed on the proposed model by Santana *et al.* (1999), and also to try to find a relationship between the elutriation phenomena while taking into account the powder cohesiveness.

Studies on mixing fine powders with large particles in a fluidized bed reported by Bachovchin *et al.*

[1] To whom all correspondence should be addressed

(1981) and Yadav *et al.* (1994) found that fine powders not only formed agglomerates but also coated or attached to large particles (Bortzmeyer *et al.*, 1996; Geldart *et al.*, 1987). It has also been suggested by Liu and Kimura (1993) that the majority of fine particles in a bed agglomerate in large clusters which are easily fluidized, and that a small fraction of fine particles remain as free fines.

The aim of this investigation was to determine the effect of the initial mass of fines loaded in a bed on the model proposed by Santana *et al.* (1999).

EXPERIMENTAL

The experimental equipment used was provided by Santana *et al.* (1999). A fluidized bed with a 6.4 cm i.d. and a height of 1 m was fitted with a distributor consisting of a nylon mesh screen between two perforated plates. The top of the bed was tapered so that an abrupt increase in gas velocity was avoided. This part of the column was connected to filters by means of an anti-static tube to prevent static deposition of the elutriation dust before filtration. The effluent dust concentrations were determined by weighing particles collected with Whatman no.1 filter paper.

The experiment was started and allowed to run at minimum fluidization velocities until the added dust particles ($CaCO_3$, TiO_2), which were between 2.5 and 5 % of the bed weight, reached a good degree of mixing with the bulk (sand) bed material while carryover of particles in the bed did not occur.

When a run was started, the gas velocity was increased. The test duration varied from 60 to 90 min with superficial gas velocities of 0.24 to 0.61 m/s respectively. To prevent adherence of fines to the wall of the unit, the freeboard section was constantly and gently vibrated.

To measure the extent of the experimental error, runs with the powders were repeated at three velocities under identical conditions. The difference in the elutriation rates was negligible at low velocities and less than 9% at high fluidization velocities.

MODELLING

A number of models have been proposed by Wen *et al.* (1960), Colakyan and Levenspiel (1984) and Liu and Kimura (1993), based of a first order equation used to describe elutriation from a fluidized bed. Santana *et al.* (1999) presented the following model:

$$-\frac{dW_f}{dt} = k \cdot A_b \frac{W_f}{W_b} - R\frac{W_a}{W_b}, \qquad (1)$$

$$-\frac{dW_a}{dt} = R\frac{W_a}{W_b}, \qquad (2)$$

$$\frac{dW_e}{dt} = k \cdot A_b \frac{W_f}{W_b}, \qquad (3)$$

where W_f is the mass of elutriable freely moving fines, W_a is the mass of agglomerated fines that remain in the bed at time t, W_e is the cumulative mass of fine particles carried out of the bed, A_b is the cross-sectional area of the bed, and W_b is the total mass of particles which are initially charged in the bed. R is the rate of attrition and k is the elutriation rate constant.

At this moment, we should point out some important aspects of the above three equations. The mass of free fines which remain in the bed decreases due to elutriation and increases due to the production of fines resulting from the breaking up of agglomerates as described in Eq. (1). The left side of Eq. (2) is the rate of decrease in agglomerates or the rate of generation of free fines by means of attrition. Free fines generation follows a first order equation used to model the attrition in fluidized beds in the bubble regime (Fan and Srivastava, 1981) and for fluidized beds in the slugging regime (Kokkoris and Turton, 1995). It is important to note that, the attrition rate constant regulates the mass transfer of agglomerated fines to free fines.

Tasirin and Geldart (1998) discussed a new correlation for the elutriation rate constant and have suggested that the elutriation rate (the left side of Eq. (3)) is proportional to the percentage of free fines in the bed, to the elutriation rate constant and to the cross-sectional area of the bed. On the other hand, it is important to point out that the reduction of agglomerate particles by means of attrition is not linear but proceeds according to exponential decay.

Integrating Eqs. (1)-(3) with the initial conditions $W_f = W_{f,0}\,; W_a = W_{a,0} = W_b - W_{f,0}\,; W_e = 0$ for $t = 0$, we obtain

$$W_e = W_{f,0}(1 - e^{-k^* t}) + \frac{W_b - W_{f,0}}{R^* - k^*}[R^*(1 - e^{-k^* t}) - k^*(1 - e^{-R^* t})], \qquad (4)$$

where k^* and R^* are defined in Eqs. (5) and (6), respectively

$$k^* = \frac{k \cdot A_b}{W_b}, \qquad (5)$$

$$R^* = \frac{R}{W_b}. \qquad (6)$$

The above initial conditions are only true if the process involves the removal of cluster fines or lar-

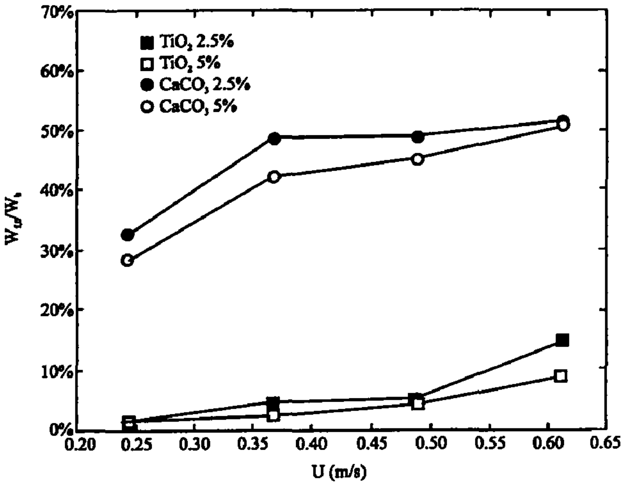

Fig. 1. Effect of the percentage of loaded fines on the percentage of free fines.

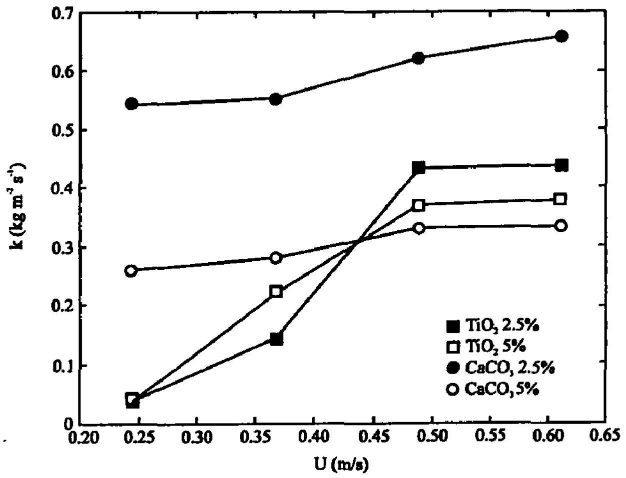

Fig. 2. Effect of the percentage of loaded fines on the elutriation rate constant.

ger particles. When this model is used with a different type of attrition, due to the breaking up of asperities of larger particles or due to fragmentation, it is necessary to use it cautiously because the weight of fines which are finally elutriated may be unknown. The variables of the model $(W_{f,0}, k, R)$ are determined using the least squares method (according to Eq. (4)) and the corresponding experimental values of the cumulative mass of fine particles in the bed (W_e).

RESULTS AND DISCUSSIONS

From Fig. 1, one can observe the effect on the percentage of free fines when the percentage of loaded fines increased from 2.5% to 5% in weight. However, in spite of the doubling of the weight of loaded fines in the bed, the percentage of free fines is slightly lower for the mixture with a higher concentration of fines. This means, that the weight of initial free fines, $W_{f,0}$, in the bed for a 5% is slightly inferior to double the weight of initial free fines for a percentage of 2.5% for both $CaCO_3$ and TiO_2. For this reason, an increase in the weight of loaded fines in the bed produced, for the range studied, an increase in the weight of free fines on the order of the increase of the loaded weight. Thus, the percentage of free fines keeps remained independent of the percentage of loaded fines in the bed, but this percentage was slightly lower for a mixture with a higher concentration of fines.

From Fig. 2, unlike the percentage of fines, one can see a different behaviour for the elutriation constants for $CaCO_3$ and TiO_2 with the increase in the loaded fines in the bed. While the elutriation constant for $CaCO_3$ increased slowly with the velocity, it increased quickly for TiO_2 and was slightly higher for less concentrated mixtures of fines. While the effect of the increase in fines on the elutriation constant was clear for $CaCO_3$, the elutriation constant was twice as high for a less concentrated mixture. However, this increase is not as marked as in the case of TiO_2. The different behaviour can be seen at the end and resulted from the effect of the increase in the percentage of loaded fines on all the parameters used in the proposed model.

This behaviour of the elutriation constant with the increase in the percentage of loaded fines may be due to the fact that this model assumes that the cumulative mass of fine particles carried out of the bed is proportional to the percentage of free fines in the bed. As previously seen, this behaviour does not vary in a significant way with the increase in loaded fines in the bed. This process occurs due to a higher attrition velocity of the agglomerates particles. Consequently, we get a percentage of freely moving fines which can be easily elutriated. The decrease in the elutriation rate constant with the increase in the number of loaded particles in the bed does not result in lower elutriation of particles. Furthermore the percentage of elutriated particles depends on the percentage of freely moving fines in the bed and increases with the attrition rate constant.

The difference in behaviour between TiO_2 and $CaCO_3$ will be discussed in the following because it is a result of the attrition constant which controls the transference between elutriated free fines and non-elutriated agglomerated fines according to the model.

The effect of the attrition constant can be observed in Fig. 3. As can be seen, the slope of the attrition constant with velocity increased from the higher concentrated mixtures of fines of TiO_2 to the less concentrated fines of $CaCO_3$. As the slope can be taken as an indicator of the mixture cohesiveness, it can be seen that the increase in the percentage of loaded fines in the bed reduces the slope, so it can be deduced that the less cohesive mixture of the two is that of $CaCO_3$ because the slope of the attrition con-

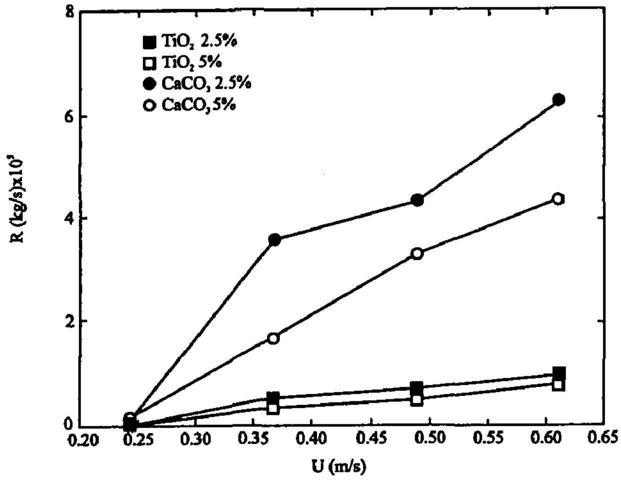

Fig. 3. Effect of the percentage of loaded fines on the attrition rate constant.

stant with velocity is higher than that for TiO_2.

We need to take into account the fact that attrition rate constant controls the transfer between agglomerates particles and freely moving fines because the percentage of those fines in the bed depends on the elutriation constant rate. As a result, the decrease in the attrition rate constant with the increase of loaded fines (at least those of $CaCO_3$) is due to the dragging capacity of the bed, mainly at the beginning of the fluidization process. This fact would explain the obvious difference between the less cohesive particles, which produce more freely moving fines, and the highly cohesive particles like TiO_2. In Fig. 3, it can be observed that the attrition constant increases, for the same velocity, with the decrease in the percentage of loaded fines in the bed. This increase becomes greater as the fluidization velocity increases. This increase in the attrition constant together with the decrease in the percentage of loaded fines in the bed can be explained by results obtained by Ayazi Shamlou *et al.* (1990). As the decrease in the percentage of fines makes the mixture less cohesive due to the fact that the interaction between larger particles is much more efficient in the separation of fine particles adhered to larger particles, higher attrition constants for mixtures with lower percentages of fines will be obtained.

In Fig. 3, it can be observed that the attrition constant that controls the transference between free and agglomerated fines, did not vary in excess for TiO_2 with the percentage of fines, so similar elutriation constants for the same fluidization velocity and different percentages of loaded fines resulted, whenever the percentage of loaded fines was not too high.

A similar situation occurred for $CaCO_3$, but in this case, as observed in Fig. 3 an increase in the attrition constant, so significant increases in the elutriation rate constant (Fig. 2) with the increase in the percentage of loaded fines was obtained in spite of the fact that the percentage of free fines did not vary significantly.

CONCLUSION

A decrease in the elutriation constant and in the attrition constant of the model together with an increase in the fines in the bed was observed. From this, it can be deduced a slower transfer velocity between free and elutriated fines and between free and agglomerated fines respectively, as well as an increase in the weight of loaded fines in the bed, due to the cohesive behaviour of the mixture when the percentage of fines in the bed increased.

NOMENCLATURE

A_b	cross-sectional area of a fluidized bed, m^2
k	overall elutriation rate constant, $kg \cdot m^{-2} \cdot s^{-1}$
k^*	elutriation velocity constant, s^{-1}
R	overall attrition rate constant, $kg \cdot s^{-1}$
R^*	attrition velocity, s^{-1}
t	time, s
U	superficial velocity of fluidizing gas, m/s
W_a	mass of agglomerated fines remaining in the bed at any time, kg
$W_{a,0}$	initial mass of agglomerated fines, kg
W_b	initial mass particles in the bed, kg
$W_{b,f}$	initial mass of fine particles in the bed, kg
W_e	cumulative mass of fine particles carried out of the bed, kg
W_f	mass of elutriable freely moving fines remaining in the bed at any time, kg
$W_{f,0}$	initial mass of elutriable freely moving fines, kg

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