Discharge times of ultrafine and superfine powders in a short riser circulating fluidized bed at different humidification conditions

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Abstract

Discharge times, t_D, of sub-micron ultrafine and micron-size superfine powders from a circulating fluidized bed (CFB) with the cyclone upside stream were investigated using a Geldart A-C mixture of ultrafine and superfine $Al(OH)_3$ powders and coarse FCC particles. t_D which refers to the time needed for complete depletion of the fine powders contents from the fluidizing system.
Variation of discharge times of ultrafines and superfines with the equilibrium water content of FCC particles was investigated at a 5 wt% maximum loading of ultrafines and superfines. The superfines discharge times decreased noticeably using bed particles humidified with gas of higher (larger than 50%) relative humidity. Bed particles humidified using lower (35%) relative humidity showed very high discharge times at higher contents of fines. Relatively larger discharge times of the cohesive ultrafines were measured compared with those of the less cohesive superfines.

Key words: circulating fluidized bed; discharge times; equilibrium water content; ultrafine powders, superfine powders

1. Introduction

Practical applications of Geldart-C powders (Geldart, 1973) are increasing widely due to their extreme specific surface area per unit volume. It is concluded that fine powders, <10µm, have strong adhesion and cohesion characteristics (Jacques, 2002). Motion of superfine powders of few microns and sub-micron ultrafine powders in fluids is rather difficult due to poor aeration (Bruni et al., 2007). They tend to form bridges, adhere to surfaces, form agglomerate, clumps and solid aggregates when flowing (Wang & Kwauk, 1998). However, cohesive fine powders still exist in fluidized beds as individually dispersed particles.
Extensive studies have been made on the cohesive forces and other various forces affecting fluidizing systems in presence of fine powders. Factors affecting formation of agglomerates, clumps and solid aggregates, such as the particles density, superficial gas velocity, etc. were presented by Chaouki et al. (1985). Interparticle adhesion forces were found to reduce the entrainment rate during fluidization of fine particles (Santana et al., 1999). Experiments studying effects of liquid bridge forces (Mc Laughlin & Rhodes, 2001) and magnetic forces (Rhodes et al.,

2001) showed that changes of the interparticle force directly affects transition of Geldart-B particles to A, and from Geldart-A to C (Molerus, 1982). Mechanical interlocking, local sintering, liquid bridging and electrostatic force might become important under certain circumstances (Xu & Zhu, 2005; Castellanos, 2005). Furthermore, Since van der Waals force acts across a distance of 0.2–1 nm (Visser, 1989). Lauga et al. (1991) pointed out that only particles on the surfaces of agglomerates contribute to inter-agglomerate force.

After repeated fluidization, ultrafne powders usually show improved fluidizability (Wang & Kwauk, 1998). The experimental results showed that the average agglomerate size decreases with increasing superficial gas velocity (Zhou & Shinohara, 2006). Thus, CFBs are strongly suggested to overcome the cohesiveness of the bed particles. But, higher gas velocities and larger interactions amongst particles and between particles and internal surfaces will result in an increase of triboelectrification. CFBs is also affected by the amount and size of the particles, especially fine powders (Chian et al., 2010). Presence of such fines will affect the performance of gas distributor as well as the bubble formation, activity and bubble expansion in bottom zone of the riser column in CFBs (Werther & Wein, 1994). The mass balance of fines and coarse particles flowing to the cyclone will control its efficiency (Trefz & Muschelknautz, 1993). Axial solids distribution and elutriation will also be altered (Colakyan & Levenspiel, 1984).

Literature studies covering qualitative and quantitative analysis of CFBs in presence of ultrafine and superfine powders are not available and still incomplete, hence extended investigations are necessary (Abdelghany et al., 2014).

The current study fluidizes a binary mixture of two types of Geldart-C cohesive powders in small fractions with the non-cohesive Geldart-A particles. This system results in an efficient gas-solid mixing caused by the turbulence promoter Geldart-A particles. The objective of this work is to investigate the changes of the discharge times of fine powders at different equilibrium moisture contents of the bed particles. Discharge time refers to the time needed for all the fine contents in the CFB to be carried entirely out of the system.

2. Experimental

2.1. Experimental setup

The CFB experimental setup is shown in **Figure 1**, where the riser column is an experimental 2.0 m long transparent vinyl chloride column of 0.052 m internal diameter. A sintered metal plate (Mott Corp., 20 micron orifices, and open area of 40%) is located at the bottom of the riser in order to evenly distribute the air. A 100 litre capacity damping chamber was placed on the bottom of the plenum chamber to improve reproducibility. A stainless steel cyclone, 2D2D type, was installed as a particle collector. A flexible vinyl chloride hose is used as a downcomer and connected at the bottom of the cyclone. Pre-humidified bag filters were used to collect fine powders discharged at the top of the cyclone.

One column filled with silica gel and another column filled with Rashing rings and water, are used to control the relative humidity of the air feed stream. Two air flow meters (KI corp., FR2000 model, and range from 100 to 1400 litre/min) are used to measure the flow of dry and humid air.

The Fluid Catalytic Cracking, FCC particles, mean size 66 μm are used as coarse particles and ultrafine and superfine $Al(OH)_3$ powders (0.5 μm and 8.0 μm mean sizes, respectively) are used as fine powders.

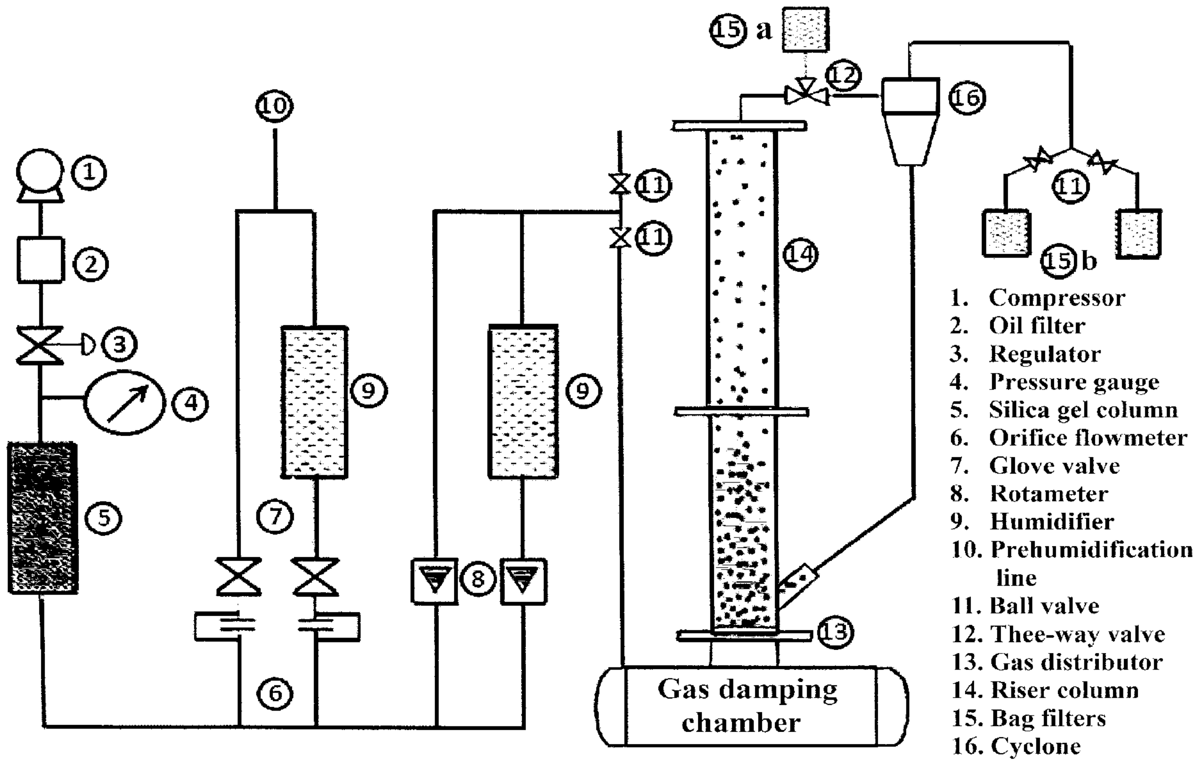

Fig. 1. Schematic diagram of experimental setup

2.2. Experimental procedures

Before experiments, FCC particles were humidified with air at different relative humidities for sufficiently long time to attain saturation and the results are shown in Table 1.

Table 1 Equilibrium water contents of FCC particles at different air relative humidities.

R.H. %	Equilibrium moisture content, $W_{eq.H_2O}$ [$wt_{H_2O}/wt_{dry\ FCC}$]
20.0	0.0380
50.0	0.0610
80.0	0.0670

A semi-batch CFB was used to fluidize mixtures of fine powders and coarse particles at different loadings, mass percent, of fine powders in the bed. Certain fractions of fine powders were discharged entirely out of the bed with air then collected by a bag filter at different time intervals. Thus, loadings of fines in the bed were decreasing with time.

It was confirmed that no FCC particles were carried out with air going out from the cyclone upside stream. Only fractions of fine $Al(OH)_3$ powders were carried out of the CFB at any of the experimental operating gas velocities. To prevent catalysts attrition, run time was limited to one hour.

For maintaining good fluidization, a solid mixing vessel ('V' cone shaped model: CEN-MKII-11-Armfield) was used to mix particles before experiments.

2.3. Parameters and calculations

Weight percent of fine powders in the bed is referred to as loading, *X*, and defined as

$$X = [Wfp / (Wcp + Wfp)] \times 100 \qquad (1)$$

Where, W_{fp} and W_{cp} are the weights of fine powders and coarse particles in the bed, respectively. W_{fp} can be calculated using the difference between the initial weight of fines and the total weight of fines discharged from the system.

The average discharge time of fine powders, t_D, refers to the time required for the fines to be discharged entirely out of the bed, and it is calculated from Eqs. (1) and (2) as follows:

$$t_D = W_{fp} / \acute{r}_D \qquad (2)$$

The mass discharge rate of fine powders, $\acute{r}_D$, from the CFB per run is calculated as follows:

$$\acute{r}_D = W_{dfp} / \theta_R \qquad (3)$$

where, W_{dfp} is the weight of fines discharged out from CFB per run and θ_R is the run time (10 min).

The solid circulation rate of the binary particle mixture, R_C is calculated as follows:

$$R_{C,\,FCC} = W_{EM} / (A * \theta_S) \qquad (4)$$

where, W_{EP} is the weight of elutriated FCC particles collected in the bag filter (block 15.a. in Fig. 1) per run. θ_S is the sampling period for FCC circulation rate measurements, which was fixed to 20 ~ 30 s.

3. Results and discussions

In the series of experiments, desirable starting loadings was limited to 5 wt% to avoid severe agglomeration. Thus, current study presents 2, 4 and 5wt% as typical examples at 1 m/s maximum gas velocity to avoid attrition and loss of FCC particles with the cyclone upside stream.

3.1. Selection of the suitable conditions for smooth fluidization

Figure 2 shows the variation of the solid circulation rate, $R_{C,\,FCC}$, at different water contents of the FCC particles in absence of fine powders at two different gas velocities. Solid circulation rates of FCC particles increased with increasing the weight of FCC particles safely up to 1.2 kg, where no FCC particles were noticed at the top of the cyclone. At larger weight of FCC particles, fluidization was not running smoothly and larger fractions of FCC particles were discharged at the top of the cyclone which is not accepted as it directly changes the discharge rates of ultrafine and superfine aluminium hydroxide powders. For the current study 0.8 kg of FCC particles were used for the main study of measuring fine discharge rate, where no FCC particle were collected at the top of the cyclone. Besides, smooth fluidization were noticed irrespective of the fractions of fine powders in the bed.

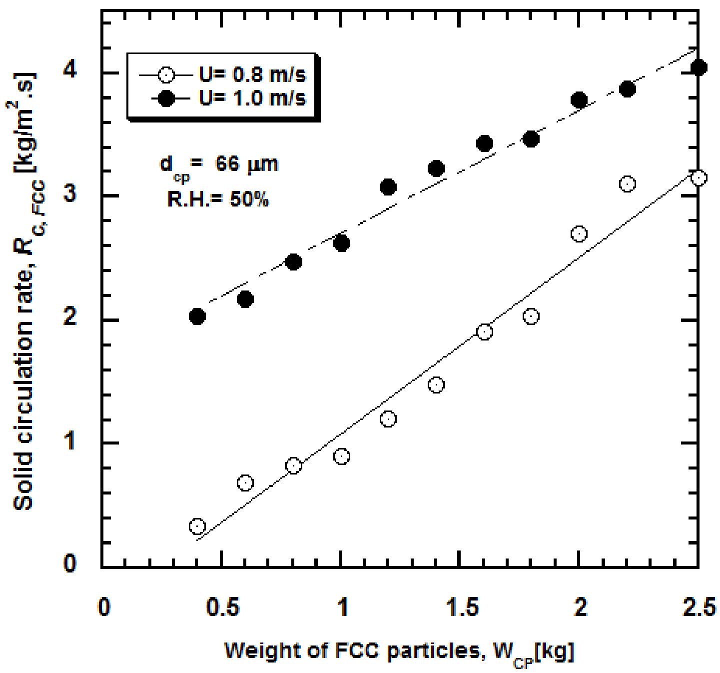

Fig. 2. Variation of the solid circulation rate of FCC particles, $R_{C,\,FCC}$, with the weight of FCC particles in the bed at U= 0.8 m/s and U= 1.0 m/s

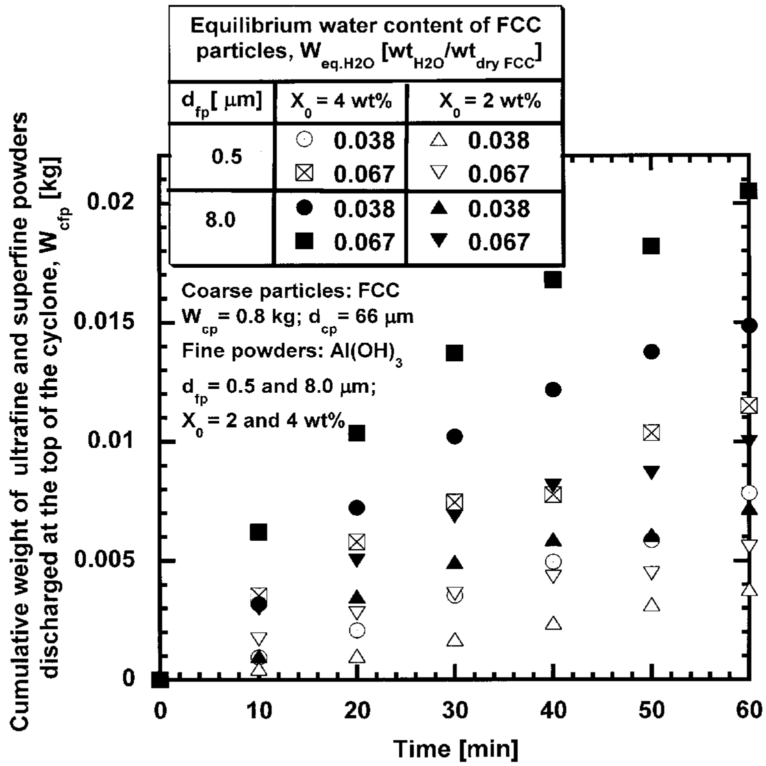

Fig. 3. Change of the cumulative weights of discharged ultrafine and superfine powders with time at different equilibrium moisture contents of the bed particles starting with X_0= 2 wt% and X_0= 4 wt%

3.2. Evaluation of cumulative discharged fines with time

Figure 3 shows a typical example of the changes of the cumulative discharged amounts of fines from CFB, W_{cfp}, for 0.5 μm ultrafine and 8.0 μm superfine powders at 1.0 m/s gas velocity and 2 and 4 wt% starting loading of fine powders. Irrespective of the type of fine powders, the cumulative discharged weights of fines was found to increase with time and with the loading of fines, and therefore, their residual loading in the bed decreased, as shown in Fig. 3. However, discharged fractions of superfine powders increased with increasing the water contents of the FCC particles and these discharged superfines were relatively larger than the discharged fractions of ultrafines.

At lower moisture water contents of FCC particles, accumulation of electrostatics charges in the bed was believed to prevail and results in strong cohesion and adhesion forces. Thus, for the two types of fines in this study, the amount of fines discharged noticeably decreased with decreasing moisture contents of FCC particles.

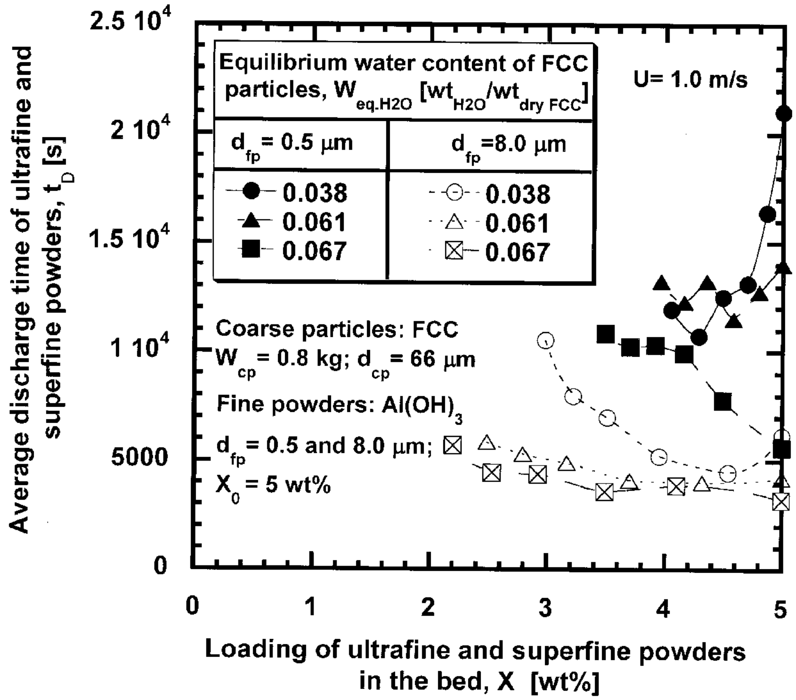

Fig. 4. Change of the average discharge time of ultrafine and superfine powders with their loading at different equilibrium water contents of FCC particles

3.1. Evaluation of average discharge times, t_D, at different moisture contents

Results for discharge rates of ultrafine and superfine powders presented elsewhere (Abdelghany et al., 2014), are used for evaluation of the average discharge times of fine powders. Changes of the average discharge times of ultrafine and superfine powders with loadings of fines at various humidification conditions is shown in **Figure 4.** The average discharge times of fine powders decreased with increasing the water contents of the bed particles. In presence of superfine powders, the average discharge times were lower at the beginning and then increased with decreasing the loading of fines in the bed. This was not the case using ultrafine powders, where, the average discharge times were almost the same, except two data point due to uncontrolled premixing. Irrespective of the loading of fines, the average discharge times for superfines were much smaller than ultrfines. Using a long distance focus microscope (Hatano et al., 1990), due to adhesion forces of the superfine powders, large flocculates of FCC were confirmed to produce for the gas-solid two-phase flow of a mixture of 70 μm FCC and 7 μm $Al(OH)_3$. They concluded that concentration of fine powders directly affects the size of flocculates. At lower moisture contents of the bed particles, up to one third from the bottom of the riser was covered by layers of the naturally cohesive/adhesive ultrafine powders. Layers of fines were expected to form due to accumulation of static electrification. At larger moisture of bed particles, lower average discharge times were measured, especially for the individually dispersed superfine powders.

4. Conclusions

The fluidization quality of a binary Geldart A-C mixture in a CFB was studied by evaluating the average discharge times of fine powders at differed equilibrium water contents of FCC particles. Fluidization phenomenon improved using superfine powders which showed low average discharge times than ultrafine cohesive powders using bed particles humidified of larger moisture contents. Bed particles humidified of lower water contents showed large average discharge times of superfine powders. Natural cohesion and adhesion properties of ultrafine powders were found to control fluidization quality rather than water contents of the bed particles.

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Biographies

Emad A.M. Abdelghany, hold a Ph.D. in Chemical Engineering from Gunma University, Japan in 2004 in the field of fluidization engineering. He is interested in research focusing on particle technology, specifically fluidization engineering of ultrafine and superfine. The circulating systems including submicron (superfine and ultrafine) powders are fluidized in a new circulating fluidized bed with coarse particles as a turbulent promoter in a circulating powder-particle fluidized bed, this system is very useful in the field of petrochemicals and catalytic cracking systems. Currently, Dr. Emad is interested in tribo-electrification and electrostatic generation in fluidized beds, oil-shale studies, solid grindability, and besides, he is involved in the research in modelling, simulation and optimization of gas-liquid reactors, especially in the field of natural gas treating. Dr. E. Abdelghani, recently has a recent research in the field of water treatment and boiler technology.
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