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EFFECTS OF PARTICLE SIZE AND FLUIDIZING VELOCITY ON THE CHARGE DENSITY OF ENTRAINED FINES

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ABSTRACT

A previously-developed Faraday cup fluidized bed unit was modified to facilitate the *in-situ* monitoring of the transient entrainment rate and net charge of entrained fine powders. This enabled the determination of the transient charge density as a function of particle size and residence time of entrained fine particles. The results showed that the charge density increased significantly with increasing size of entrained fines, but was not very sensitive to the residence time and the fluidizing gas velocity for the finest entrained particles at gas velocities of 0.24 and 0.36 m/s. At U_g=0.48 m/s, the charge density of larger particles increased with increasing particle residence time.

INTRODUCTION

One of the known phenomena associated with triboelectric charging is that most powders are capable of bi-polar charging behaviour. Bipolar charging of particles is a common occurrence in gas-solid fluidized bed processes where particles often have wide size distributions. As a result, fine particles acquire charges of a polarity opposite to those acquired by larger particles of the same material. When charged fine particles are entrained from a fluidization column, they leave a net charge behind, with the quantity and polarity depending on the physical and chemical properties of the particles and on the operating parameters. The mechanisms responsible for bi-polar charging are not clearly understood, often confounding attempts to assess the charging behaviour of powder samples. In a previous study (1), we developed a Faraday cup fluidized bed unit to study the charging behaviour of entrained fine particles from fluidized beds of binary particles or particles of wide size distributions. A fine particle injection system was also installed to emulate catalyst injection into a commercial fluidized bed gas phase polymerization reactors.

To elucidate the effect of size and residence time of fine particles entrained from fluidized beds on the charge density, we have modified our Faraday cup fluidized bed unit by installing a sensitive *in-situ* particle-weighing load cell. The current paper presents *in-situ* charge data and the weight of entrained fine powders, as well as interpreting the calculated charge density of entrained powders.

EXPERIMENTAL

Figure 1 shows the modified novel on-line fluidized bed Faraday cup unit. The column is made of copper with Teflon sections for electrical insulation. When particles of a size distribution are placed in the reactor, the fine particles tend to be charged oppositely to the coarse ones due to charge separation between fine and coarse particles during their contacts. The entrainment of charged fine particles from the top of the column leaves opposite charges in the bed, which are measured by an electrometer connected to the Faraday cup fluidized bed. To monitor the weight of fine particles entrained from the fluidized bed, a sensitive load cell was installed beneath the cycle dipleg. The degree of triboelectrification of fine powders at given time *t*, defined as the specific charge or charge density, can thus be obtained by differentiation of the instantaneous charge recorded by the Faraday cup divided by the instantaneous weight of entrained powders collected by the *in-situ* load cell.

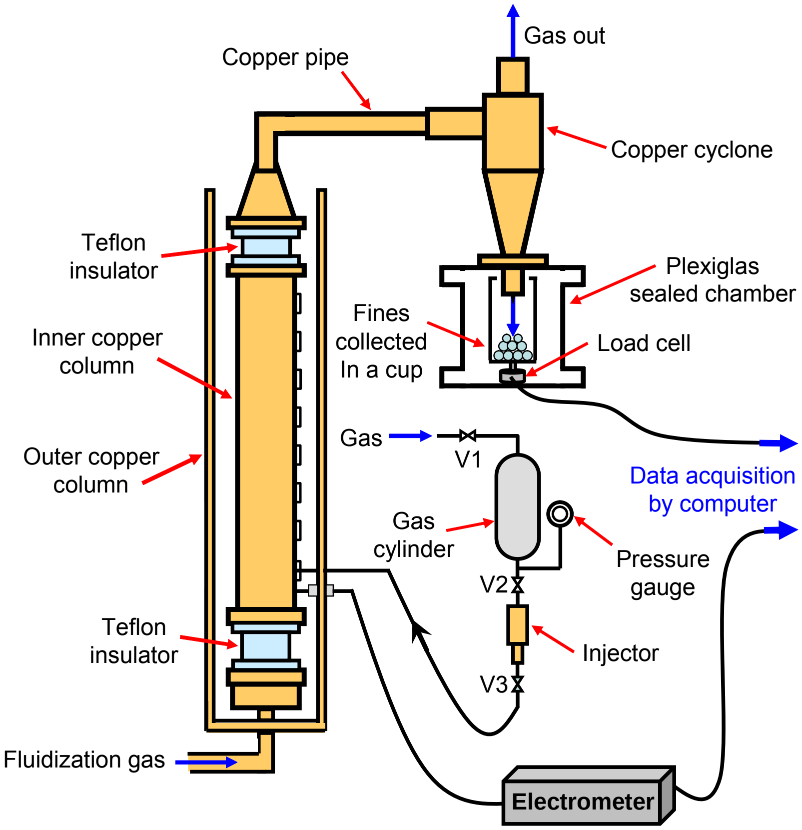

Figure 1 Schematic of the novel Faraday cup fluidized bed apparatus.

A commercial grade of polyethylene resin was the test material. The particles had a density of 944 kg/m^3, a mean particle size of 585 μm, and a wide size distribution. For each run, 700 g of powder were loaded into the column and then fluidized by pure nitrogen of industrial grade. The reactor was operated at ambient temperature and pressure in all cases.

RESULTS AND DISCUSSION

Charge density of entrainment fines

Typical results from the modified Faraday cup fluidized bed unit are shown in Figure 2 for the selected PE powder. The tests were carried out by loading 700 g of fresh polyethylene powders into the Faraday cup fluidized bed unit, with the initial charge (Q_0) being measured. The bed was then fluidized at a superficial gas velocity (U_g) of 0.36 m/s for about 21 minutes. The net change in charge from the system was measured by the fluidized bed Faraday cup at the same time as the entrainment rate was measured by the load cell. There were four repeated runs, as shown by the different lines.

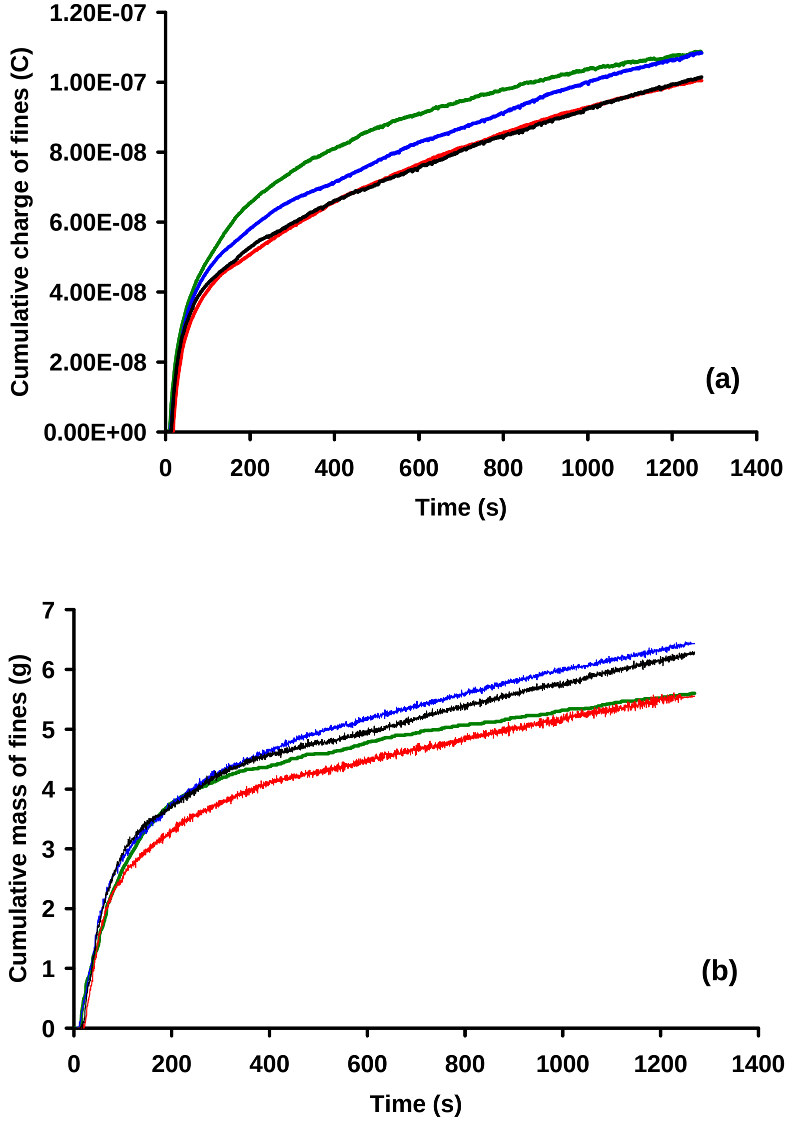

Figure 2. (a) Cumulative charge and (b) fines entrainment rate measured simultaneously as functions of time for a superficial gas velocity of 0.36 m/s.

The change in cumulative net charge in the column is plotted versus the cumulative mass of entrained fine powders in Figure 3. If all the fine particles entrained from the column had the same mass charge density, the charge density (represented by the slope of the curve) would remain constant, independent of the residence time in the column before being entrained. An approximately linear relationship is observed in Figure 3, especially for those data at the middle section. At the beginning of the experiment, there was a sharp increase in the slope, implying a higher charge density, likely associated with the entrainment of very fine particles from the fluidized bed. In the later stage of the test, the charge density, reflected by the slope of the curve, slightly increased, likely related to the longer residence time of particles entrained later from the fluidized bed column.

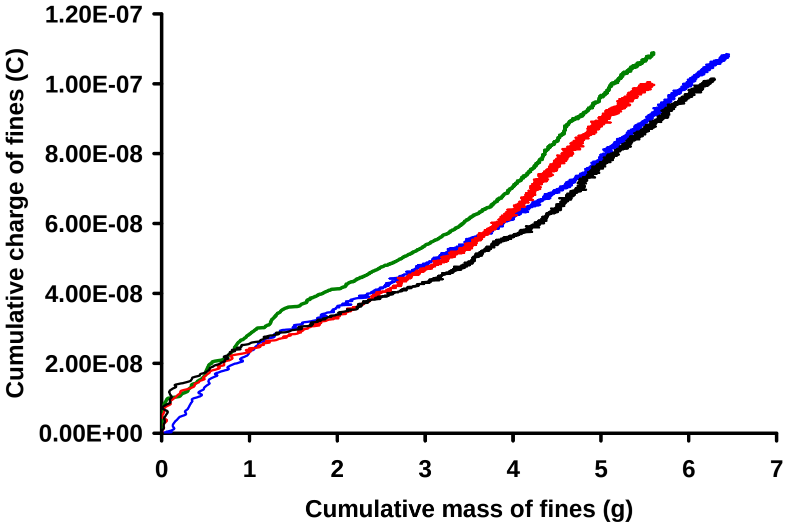

Figure 3. Cumulative charge of fines as a function of cumulative mass of entrained fines at U_g=0.36 m/s.

Effect of fluidizing gas velocity on the charge density of fines

Both particle size and particle residence time may affect the charge density of entrained fine particles, whereas the mean particle size of entrained powders is primarily determined by the fluidizing velocity. The effect of superficial gas velocity on the charge density of entrained fine particles was investigated by operating the column at three different gas velocities using fresh PE powders for each run at a different gas velocity. For each run, 700 g of fresh polyethylene were loaded into the Faraday cup column, and the initial charge was measured. The particles were then fluidized at a certain gas velocity, U_g=0.24, 0.36 or 0.48 m/s, for 21 minutes, with the cumulative charge and mass of fines being measured simultaneously in real time.

Figure 4 shows the cumulative charge and mass of entrained fine powders for three runs at different gas velocities. It is seen that there is an initial sharp increase in entrainment rate and changes in cumulative net charge for each run, followed by a gradual increase. This behaviour is what one would expect for a batch fluidized bed without the return of entrained fines.

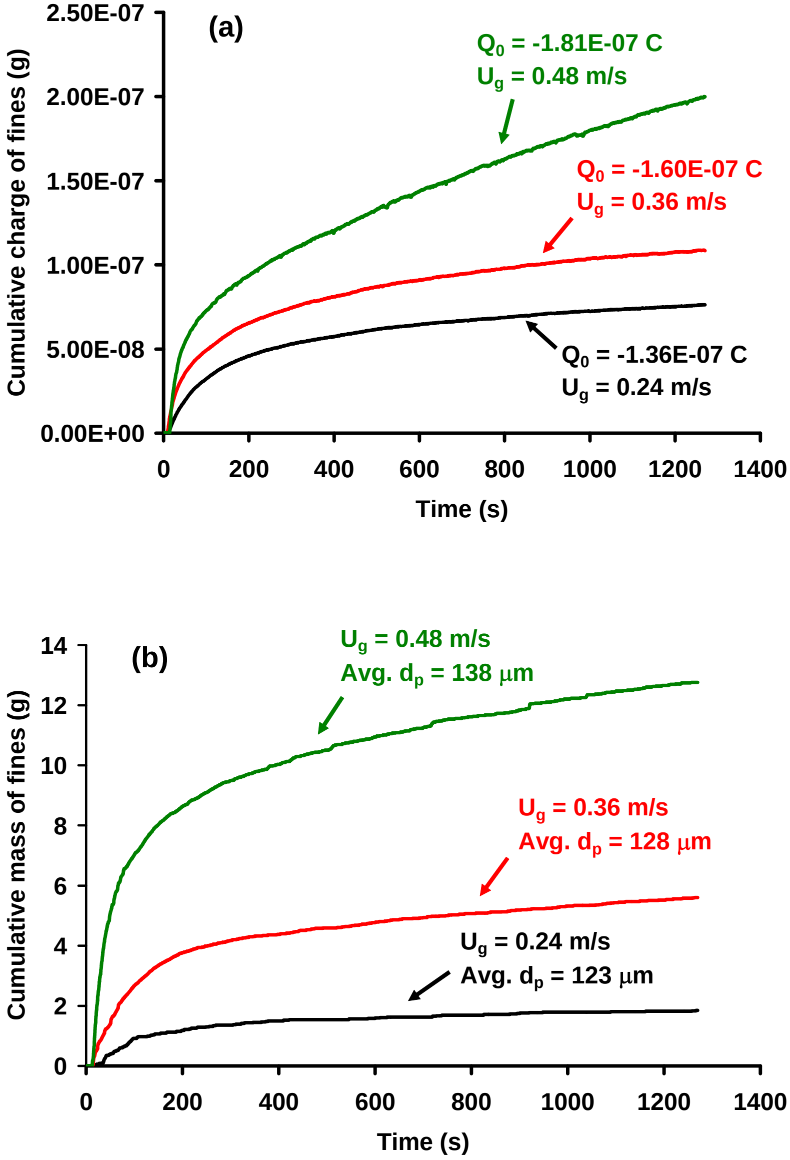

Figure 4. (a) Transient cumulative net charge and (b) cumulative mass of entrained fines as functions of time for three superficial fluidizing gas velocities.

The relationship between the cumulative net charge and the cumulative entrained mass of fines is shown in Figure 5. It is seen that a nearly linear relationship exists for the runs at U_g=0.24 and 0.36 m/s. For U_g=0.48 m/s, the initial slope is almost linear, but then tends to increase in the late stages of the test period. Again, the probable explanation is that the particles entrained in the later stage had spent more time being fluidized, likely gaining higher charge densities than the particles which had been entrained earlier.

It is also observed that the charge density, reflected by the slope of the curve, during the initial stage of entrainment (corresponding to lower cumulative masses of fines for each run) is almost the same for the runs at three different gas velocities. Since the same kind of fresh PE powders were used in each run with similar fraction of fines, the result implies that the fluidizing gas velocity has only a marginal effect on the charge density of entrained fine powders.

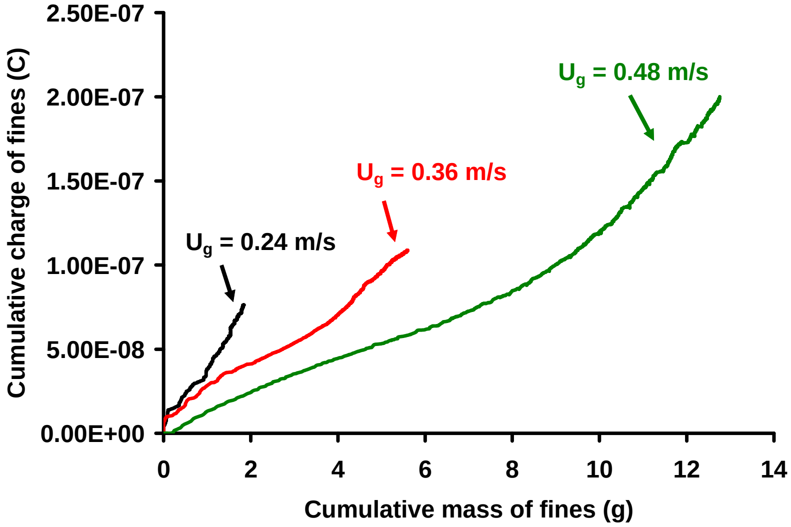

Figure 5. Cumulative charge of fines as a function of cumulative mass of fines at three fluidizing gas velocities.

Effect of fluidizing velocity without changing the original bed material

To study the effect of particle size on the charge density of entrained fines, another set of tests was carried to better segregate bed fines into the collected entrained samples for a given batch of fresh PE powders. In the test, 700 g of fresh polyethylene powders were loaded into the Faraday cup column, and the initial charge was measured. The column was then fluidized at three different superficial gas velocities (U_g = 0.24, 0.36, 0.48 m/s) from low to high for about 8 minutes each, i.e. in three stages. At each velocity, the net change in charge of the system was measured by the fluidized bed Faraday cup, while the entrainment rate was measured by the sensitive load cell as a function of time. At the end of each stage, the fluidizing nitrogen was turned off, and fines were removed from the collecting cup and stored for particle size distribution measurements. After the electrometer and load cell were reset to zero, nitrogen was turned on for the next stage and the same procedure was repeated for the second and third stages.

Figure 6 shows typical results for three repeated runs. At U_g=0.24 m/s, only the finest particles were expected to be entrained. When U_g was increased to 0.36 m/s, particles of larger size would be entrained. Figure 6(a) shows that more charges were removed from the fluidized bed unit as more fines were entrained from the column at lower gas velocities. The entrainment rate became more significant at higher gas velocities because of the entrainment of larger particles which were present in higher mass percentage than the finest particles in the original PE sample.

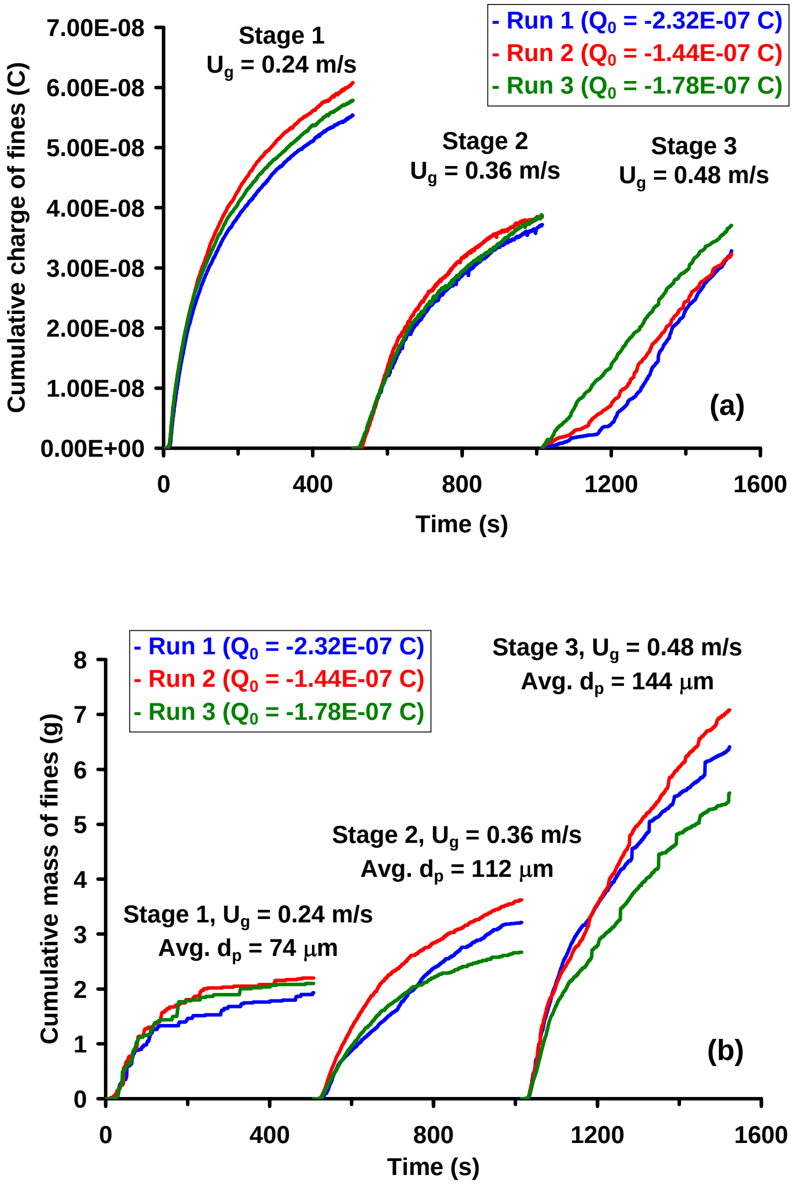

Figure 6. (a) Cumulative net charge and (b) cumulative mass of entrained fines as a function of time in three repeated runs of a 3-stage test.

The plot of change in cumulative net charge in the column versus the cumulative mass of entrained fine particles in Figure 7 shows the effect of powder residence time in the column and the particle size on the charge density of entrained fine powders. The charge density, reflected by the slope, is seen to be higher for fines entrained at lower fluidizing gas velocities. Since the mean particle size collected at low gas velocities was smaller than that collected at high gas velocities, the results indicate a strong particle size effect, confirming that smaller particles carried higher charge density, i.e. charge per mass. An approximately linear relationship is again observed at both U_g=0.24 and 0.36 m/s, indicating little effect of particle residence time in the column. However, the charge density at U_g=0.48 m/s appears to have increased with time, indicating that larger particles residing longer in the column tend to give higher charges.

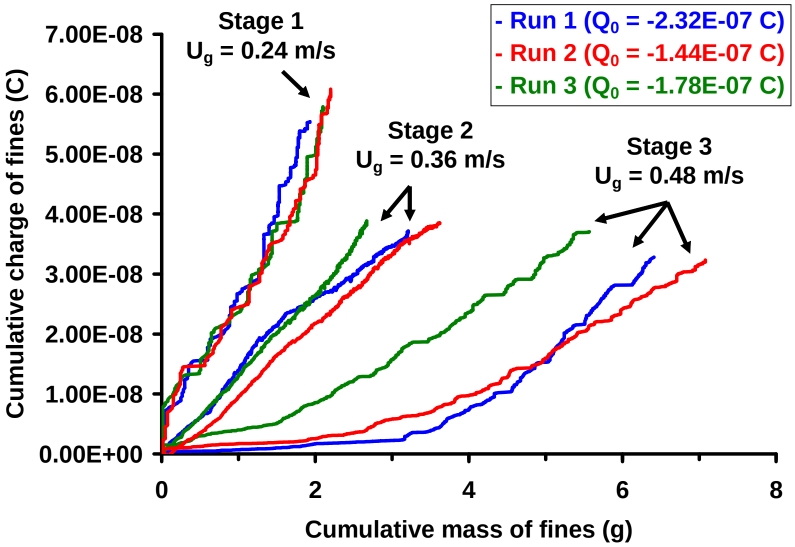

Figure 7. Cumulative charge of fines versus cumulative mass of entrained fines in three repeated runs of 3-stage tests.

CONCLUSIONS

Experiments in a novel Faraday cup fluidized bed unit with *in-situ* monitoring of transient net charge change and the transient mass of entrained fines revealed that the particle residence time had little effect on the charge density of entrained fine powders, while particle size had a strong effect on the charge density of entrained fines, with a higher charge density for finer powders. The fluidizing velocity also appeared to have little effect on the charge density of the finest entrained particles.

ACKNOWLEDGEMENT

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(1) Mehrani, P., H.T. Bi and J.R. Grace, Electrostatic charge generation in gas-solids fluidized beds, J. of Electrostatics, 63, 165-173, 2005.