Electrostatic Charging Phenomenon in Gas-Liquid-Solid Flow Systems

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Abstract

During the operation of multiphase systems such as fluidized beds, electrostatic charges are generated when the materials involved are dielectric in nature. The accumulation of electrostatic charges within the system can be operationally hazard. Work on understanding and hence preventing the electrostatic charging phenomena has mostly focused on the gas-solid media. Relatively little is performed on particulates and multiphase systems with non-conductive liquids as the medium. In this study, electrostatic charging in gas-liquid-solid fluidized beds with liquid as the continuum phase under different operating conditions is explored. Two different charge-reducing methods are also evaluated. Based on the experimental studies, it is found that the superficial gas and liquid velocities have a significant effect on the rate of the charge generation and transfer in a three-phase fluidized bed through varying the frequency and the intensity of the particle collisions. The local number density of the particles also affects the distribution of the electrostatic signal obtained. The methods of reducing electrostatic charge accumulation are also investigated by considering two approaches: adding fine powder and adding an anti-static agent such as Larostat 264A. When 15 wt% of fine glass powder is added to an air-Norpar15-HDPE (high density polyethylene) fluidized bed, the charge inside the fluidized bed is reduced by 71.4 %. The added fine powder can not only reduce the electrostatic charge but also affect interparticle forces, such as van der Waals forces, thereby altering the fluidization behavior. When, on the other hand, as little as 0.5 wt% of the anti-static agent, Larostat 264A in a liquid form, is added to the air-Norpar15-HDPE, the electrostatic level is very quickly reduced by 82.9 % and within one hour the electrostatics completely is vanished from the system.

1. Introduction

Electrostatics in particulates and multiphase systems such as fluidized beds may present serious operational problems such as particle agglomeration leading to defects in the products formation, nuisance discharge, and even vessel explosions. Since the 1950's there have been various investigations on the anomalous mishaps caused by electrostatic effects in the use of gas-solid fluidized beds. The mechanism on the static charge generation is quite complex. Factors that contribute to electrostatic charging and mechanisms that reduce electrostatic charge accumulation are still not well understood. Studies on electrostatic charges have been mainly concerned with the gas-solid media. Relatively little has been conducted on the particulates systems with liquids as the medium. Triboelectrification, ion collection, thermionic emission, and frictional charging are known to generate electrostatic charges in gas-solid fluidized beds. For a large reactor where wall effects are negligible, particle-particle interaction is the main cause of charge accumulation. The quantity of charges generated due to friction between two similar materials can be as large as that from dissimilar materials (Cross, 1987). The charging mechanism in a three-phase fluidized bed containing dielectric liquid is somewhat different from that in a gas-solid fluidized bed because the liquids can be regarded as weak electrolytes with free charge carriers (ESCIS, 1988).

In this study, the electrostatic charging effect in gas-liquid-solid fluidized beds under various operating conditions is quantified. Two different charge-reducing schemes are evaluated to yield a basis for the development of the static control method for the systems of the multiphase flow with dielectric liquids.

2. Experimental

The experiments are carried out using a Plexiglas fluidization column of 7 cm in diameter and 1.8 m in height. The schematic diagram of the experimental apparatus is shown in Figure 1. In order to detect the electrostatic charges from the fluidized bed, an electrostatic detection system is installed. The most common method used to measure the static electricity is the Faraday cup, but this method can only quantify the net charge and cannot provide the detailed on-line results (Ose, 2003). There are three major types of the on-line probes that have been used by previous researchers to measure electrostatic charges in fluidized beds – capacitance, induction and collision probes. Both capacitance and induction probes also measure the net charge, and thus, it is rather difficult to quantify the charge per particle using these probes (Park et al., 2002b). Consequently, a collision probe also known as a contacting probe is employed in the present work.

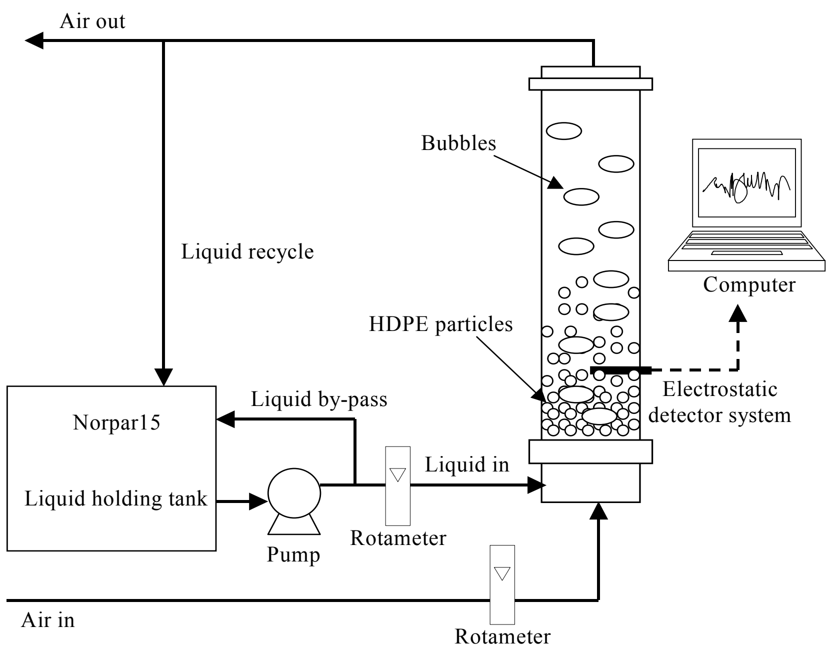


Figure 1. Schematic of multiphase apparatus

The particles used throughout the experiments are high-density polyethylene (HDPE) particles. In the latter portion of the studies, fine glass powder is used to reduce the electrostatic charges in the fluidized bed. The physical properties of these materials are summarized in Table 1. Two different hydrocarbon fluids, Norpar15 and Paratherm, are initially considered for this study based on their low dielectric constants. However, it is found that for the given experimental conditions, less electrostatic charges are generated in Paratherm due to its higher viscosity. When the same amount of energy is applied to agitate the multi-phase systems with non-conductive liquids, collisions between particles do not yield adequate impact to transfer electrons in liquids with higher viscosity due to the presence of the lubricating liquid layer between the particles. Thus, Norpar15 is selected for the subsequent experiments of this study.

Table 1. Physical properties of the materials used in this study

Material	Mean particle size	Density [g/cm^3]	Viscosity [mPa·s]	Dielectric constant
HDPE	4.1 mm	0.926	NA	2.3
Glass powder	26.2 μm	2.458	NA	3.1
Norpar15	NA	0.752	1.3	2.5

3. Quantification of Electrostatic Charges in Fluidized Beds

In order to investigate the electrostatic charging phenomenon in fluidized beds, accurate quantitative information on the static charge is necessary. First, single bubble injection experiments are carried out in a fluidized bed containing Narpar15. Traces of voltage and charge versus time are obtained and plotted in Figure 2. The voltage output in Figure 2 (a) is very similar to the voltage trace obtained by Dastoori et al. (2005) who used a vertical drop test rig (i.e. inductive probe) to measure the charge.

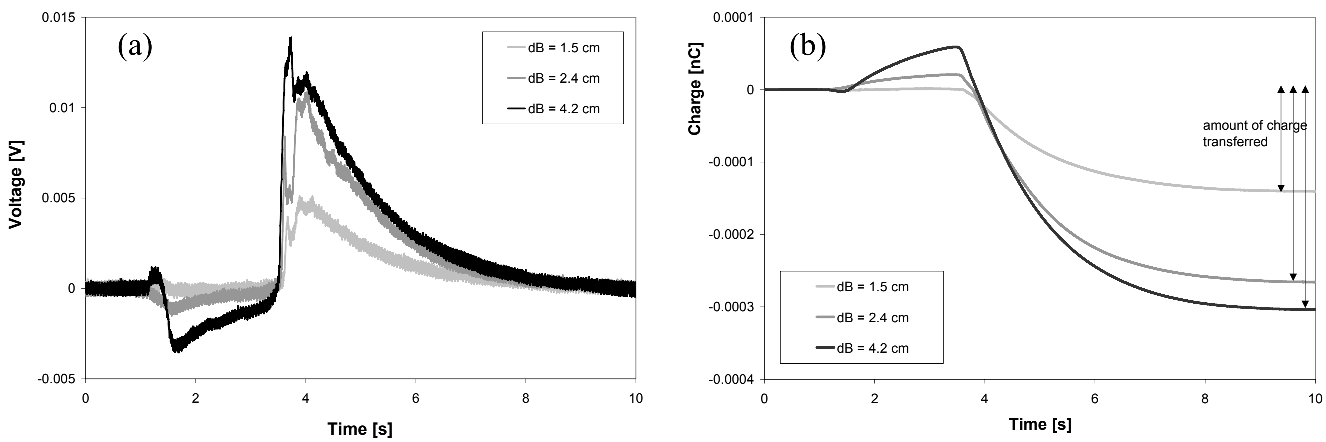


Figure 2. Effect of injected bubble volume on (a) voltage output and (b) charge inducement and transfer for single bubble injection into a fluidized bed of Norpar15 in absence of particles

The large value of the positive peak in Figure 2 (a) leads to a speculation that Norpar15 is charged positively and electrons are transferred from the ground to the liquid inside the column. As shown in Figure 2 (a), the magnitude of the voltage output increases with an increase in the injected bubble size. The effect of the bubble size is more significant when the bubble size is smaller (< 2.5 cm).

The raw voltage data in Figure 2 (a) is processed to calculate the discrete total current in the direction from the probe to the ground using the following equation:

$$I_{total} = \frac{V}{R}\frac{1\times10^{-9}\ \mathrm{A}}{0.016\ \mathrm{A}} \qquad (1)$$

where V is the voltage output and R is the resistor installed to convert the initial current output to the voltage output before being sent to the data acquisition system.

I_{total} is then converted to the accumulated amount of the charge on the probe, Q_p, using Equation (2). The negative sign is used to account for the direction of the current that is opposite to the direction of electron motion.

$$Q_P = -\int I_{total}\, dt \qquad (2)$$

As discussed by Park et al. (2002a), there are two components of the voltage registered by an electrostatic probe inserted into the fluidized bed: one caused by charge induction and the other caused by direct charge transfer. Thus, I_{total} is also a result of both the induced charge on the probe and the charge directly transferred to the probe.

$$Q_{total} = Q_{induced} + Q_{transferred} \qquad (3)$$

By integrating I_{total} using Equation (2), the induced portion of the current is eliminated, because the net change of the charge on the probe caused by the induced current would be zero ($Q_{induced}$ = 0) (Park et al., 2002a). Thus, the asymptotic values in Figure 2 (b) correspond to the actual amounts of the charge transferred from the bed material to the probe. The negative amount of the charge transfer in Figure 2 (b) indicates that electrons are transferred from the ground to the system inside the fluidized bed via the electrostatic probe. The greater amount of charge is transferred as the bubble size becomes larger, because the motion of the larger bubble creates increases the liquid movement in the fluidized bed. This observation agrees with those of previous researchers who found that maximum charging occurred near the bed surface, which is also where the largest bubbles are observed (Boland and Geldart, 1971).

Typical voltage outputs for both the gas-liquid (air-Norpar15) and the gas-liquid-solid (air-Norpar15-HDPE) fluidized bed are shown in Figure 3. The experimental conditions are identical for the two cases, except the latter including 29.1 vol% of HDPE particles. In both cases a large number of bubbles exist in the fluidized bed, and it is not feasible to distinguish the voltage output for each bubble. However, it is clear that there is a greater charging effect in the system with HDPE particles. The accumulated charge transferred to the probe for the three-phase fluidized bed is calculated using Equation (2). The net change in the amount of charge transferred then gives the rate of direct charge transfer, I_{transfer}, between the probe and the fluidized bed. The positive value of I_{transfer} indicates that the probe is charged positively and accepts electrons from the particles, while the HDPE particles in the fluidized bed are generally negatively charged.

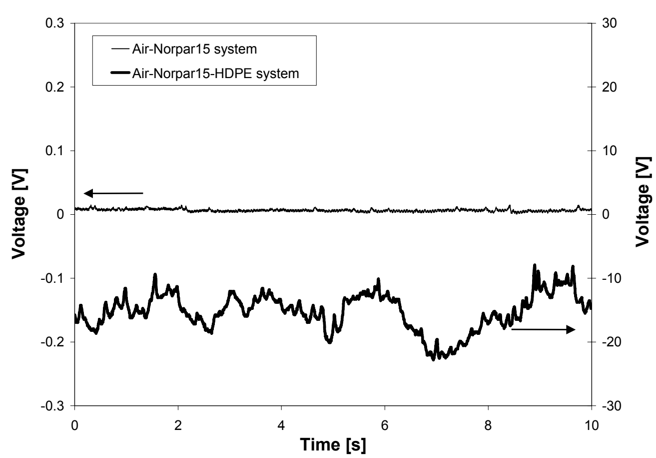


Figure 3. Typical electrostatic signals for bubbling two-phase and three-phase fluidized beds (batch Norpar15, U_g = 2.04 cm/s, three-phase solids loading = 29.1 vol% HDPE)

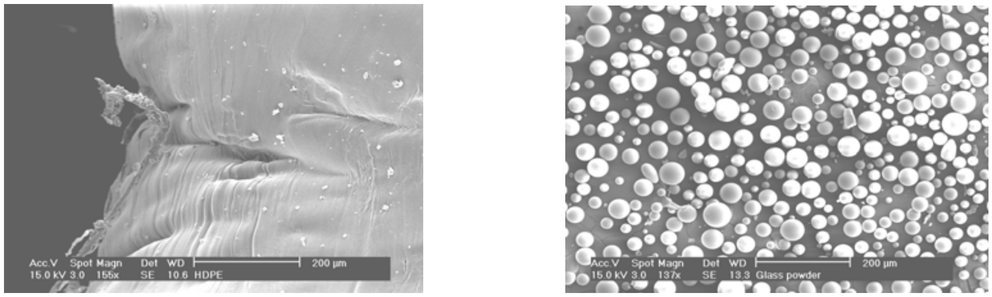
Next, the effect of the superficial gas velocity on electrostatic charging phenomenon in a fluidized bed is investigated with four different solids loading conditions (0, 12.5, 20.8 and 29.1 vol%). According to the experimental results, increasing the superficial gas velocity reduces the measured local electrostatic charges by lowering the particle density near the probe. On the other hand, for a given superficial gas velocity, as the solids loading increases, the electrostatic charge generation and charge transfer are also intensified. This comparison indicates that the effect of the superficial gas velocity on the electrostatic charging behavior is approximately linear, while it is exponential with respect to the solids loading. The effect of the solids loading on electrostatic charging is much greater in magnitude than the effect of the superficial gas velocity. Therefore, without using other charge reduction methods, such as anti-static agents, solid concentration should be considered as the primary means for charge reduction with the gas flow rate as the secondary means.

In case of the superficial liquid velocity, as the velocity increases, the magnitudes of both mean and standard deviation of the voltage output increase. In addition, the rate of the direct charge transfer is also amplified with respect to the liquid flow rate. The speculated reasons for this behavior are that HDPE particles are better fluidized at higher liquid velocities leading to greater bed expansion. Therefore, when the electrostatic probe is initially located at a level higher than the fixed bed height, a higher solid concentration near the probe is achieved as the superficial gas velocity increases, and the increased interaction between particles and liquid phase results in enhanced charge generation within the system. Furthermore, the operation of the pump may have contributed to the increased charging activity in the overall fluidized bed setup. From these results, it is concluded that to avoid electrostatic charge accumulation and electrostatic discharge, it will be useful to reduce the superficial liquid velocity if possible in order to reduce the frequency and the impact energy of the particle collisions. However, in many cases, this is not feasible due to reactor operational requirements in the process (Kiss et al., 2005).

4. Reduction of Electrostatic Charge Accumulation

A review of the literature suggests that there are five common methods of preventing electrostatic charge accumulation in fluidized beds: grounding the column, coating the inner wall of the column, increasing the humidity of the fluidizing gas, and adding fine particles or an anti-static agent. In this study, methods of adding fine powder or an anti-static agent are selected to evaluate their effectiveness in reducing static charges in a three-phase fluidized bed of air-Norpar15-HDPE.

5, 10, and 15 wt % of fine glass powder with an average diameter of 26.2 μm is added to the fluidized bed of 4.1 mm HDPE particles. The HDPE particles used in this study are quite smooth in most areas but rough in certain parts as shown in Figure 4 (a). On the other hand, the glass powder in Figure 4 (b) is very smooth and spherical. Since Figures 4 (a) and (b) are in the same scale, it is easy to compare the sizes of the HDPE particle and glass powder. The glass powder has a wide particle size distribution, and thus, a fraction of the powder is small enough to access the areas of potential charge entrapment on the large HDPE particles. According to the experimental results, the addition of 5 wt% glass powder does not suppress the electrostatic charging in the three-phase fluidized bed; instead more negative charges are accumulated. The amount of the fine glass powder seems to be insufficient to act efficiently as spacers for large HDPE particles. Meanwhile, glass particles are also negatively charged during fluidization, causing higher static electricity buildup in the system. On the other hand, as the added amount of the fine glass powder is increased to 10 and 15 wt%, the amount of the electrostatic charges in the system begins to decrease. With the addition of 10 wt% fines, the electrostatic charge in the fluidized bed is reduced by approximately 21.4 %. When 15 wt% of fine glass powder is added to the fluidized bed, up to 71.4 % of the initial static charge is eliminated within a few minutes, and this effect is maintained for at least 180 minutes.



(a) Rough surface structure of HDPE particle (b) Fine glass powder

Figure 4. Scanning Electron Microscopy (SEM) photos of high-density polyethylene particle and fine glass powder.

Next, an anti-static agent, Larostat264A (an alkyl dimethylethyl ammonium ethosulfate quat), from BASF is selected as a potential candidate to reduce the electrostatic charging in a three-phase fluidized bed. Larostat264A is made from naturally occurring soybean oil, and it is compatible with various complex systems due to its unique molecular structure containing a high degree of unsaturation (BASF, 2004). Larostat 264A is completely soluble in both aqueous and hydrocarbon systems.

First, 29.1 vol% HDPE particles are fluidized in Norpar15 with air at a superficial gas velocity of 2.04 cm/s. The system is fluidized for 30 minutes to ensure sufficient electrostatic charge generation. Once the electrostatic behavior of the fluidized bed stabilized, 0.5 wt% of Larostat264A is added to the system. There is an initial abrupt increase in both voltage output and its standard deviation. This may be due to a rapid change in the chemistry of the liquid phase immediately after the addition of Larostat264A. Once Larostat264A is completely dissolved into Norpar15, the electrostatic level in the fluidized bed is reduced significantly. Within a few minutes, the electrostatic charges in the three-phase fluidized bed are reduced by 82.9 % of its initial value. The rate of direct charge transfer is also reduced to an insignificant level. Within one hour, the static in the air-Norpar15-HDPE system is completely eliminated. This effect is monitored for 24 hours and its effectiveness is maintained during this period.

5. Conclusion

The experimental study of electrostatic charges in gas-liquid-solid fluidized beds is conducted under various operating conditions. High-density polyethylene (HDPE) particles are found to be negatively charged in a three-phase fluidized bed of air-Norpar15-HDPE. Norpar15 is selected due to its low dielectric constant and low viscosity. As the superficial gas velocity increases, the measured electrostatic level in the three-phase fluidized bed decreases, whereas the superficial liquid velocity exhibits the opposite effect. The effect of the solids loading on the electrostatic charging phenomenon is much greater than those of the superficial gas and liquid velocities. As expected, at higher solids loading, a greater amount of static is generated within the system. Further, the methods of reducing electrostatic charge accumulation, in particular by adding fine powder or an anti-static agent such as Larostat 264A, are examined. When 15 wt% of fine glass powder is added to the air-Norpar15-HDPE system, the electrostatic level is reduced by 71.4 % of its initial values within a few minutes. For the same system, 0.5 wt% Larostat264A is added and this method is found to be even more effective than the method of adding fines. The electrostatic charges in the fluidized bed are quickly reduced by 82.9 % and eventually are completely eliminated within one hour. Once the static is eliminated from the air-Norpar15-HDPE system, its condition can be maintained for more than 24 hours.

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