Powder Technology 319 (2017) 426–433

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Comparison of electrostatic charge generation in gas-solid fluidized beds in turbulent versus pre-turbulent flow regime

Di Song, Poupak Mehrani *

Chemical and Biological Engineering Department, University of Ottawa, 161 Louis Pasteur, Ottawa, ON K1N 6N5, Canada

ARTICLE INFO

Article history:
Received 12 February 2017
Received in revised form 25 April 2017
Accepted 5 July 2017
Available online 08 July 2017

Keywords:
Gas-solid fluidization
Electrostatics
Particle wall coating
Turbulent

ABSTRACT

In this work, the effect of gas velocity on the electrostatic charge generation in gas-solid fluidized beds was studied with a specific focus on the transition to turbulent flow regime. Experiments were conducted at a pressure of 2600 kPa (abs) with fluidizing gas velocities of 1.5, 3, and 5 times of U_{mf} (pre-turbulent regimes) and 7.5 times of U_{mf} (turbulent regime). Increasing the gas velocity and transitioning to the turbulent flow regime improved particle-wall contacts; and thus, augmented the extent of wall fouling, which indicates the increase in bed electrostatic charge generation. The amount of fouling was approximately five times larger in turbulent flow regime (7.5 U_{mf}) in comparison to that for the lowest gas velocity examined in bubbling flow regime (1.5 U_{mf}). The particles coating on the column wall consisted of a thick bottom layer which extended to a height of approximately 1 m above the distributor plate, and a thin top layer which extended to the top of the column near the outlet. The particles net specific charge in the top and bottom layers did not vary with the increase in gas velocity. However, the net charge of these particles increased. The fine particles entrained from the bed had a net negative charge resulting in a net positive charge to be left behind in the bed contributing to the increase in the magnitude of wall fouling at higher gas velocities, especially in turbulent flow regime.

1. Introduction

Gas-solid fluidized beds have been widely employed in industries such as petrochemical, oil and gas and food due to their excellent characteristics of providing a high degree of heat and mass transfer as well as mixing. In some of the gas-solid fluidization processes, such as the gas-phase polymerization of ethylene to produce polyethylene, the generation of electrostatic charge is present and results from the continuous contacts between fluidizing particles and the particles and the fluidization column wall. This leads to significant operational challenges including: particle agglomeration and particle adherence to the reactor wall and dome, resulting in a problem known as "sheeting" [1]. As the sheets grow thicker, they may dislodge from the reactor wall and fall to potentially block the fluidized bed distributor plate which necessitates reactor shutdown for clean-up and in turn imposes significant economic losses. Although attempts have been made in finding means of reducing sheeting in commercial reactors, the problem still remains [1–5]. This is due to the complexity of electrostatic charging in relation to gas-solid fluidization, and more importantly, the lack of a comprehensive understanding of the underlying mechanisms of charge generation.

One area of research that has received minimal attention is the understanding of fluid bed electrification in various fluidization flow regimes, especially those related to the commercial operations. For instance, commercial polyethylene reactors are typically operated under a wide range of gas velocities, 1.5–10 times the minimum fluidization velocity (U_{mf}) [6–10]. As the gas velocity increases beyond minimum fluidization, various fluidization flow regimes are achieved. Excess gas beyond the minimum fluidization velocity forms bubbles at the distributor plate which grow, rise to the bed surface and burst. As gas velocity is raised even higher, the bubbles grow larger to a point where they nearly take up the entirety of the column diameter and the slugging regime is reached [11]. When the fluidization gas velocity is large enough that the top surface of the bed becomes difficult to detect and the entrainment becomes significant, turbulent fluidization is reached [12]. Due to its high gas-solids contact efficiency, the turbulent flow regime is more suitable than other flow regimes for processes that require high productivity, limited axial mixing of gas, and high heat transfer efficiency [13–15].

A few works have studied electrostatic charge generation in bubbling [16–24] and slugging [25–28] gas-solid fluidized beds. Ciborowki and Wlodarski [16] fluidized multiple types of particles with size range of 300–500 μm in a 0.049 m diameter glass column at superficial gas velocities of 0.08–0.5 m/s. The authors measured the potential of the bed with an electrode and showed that the electrode potential increased with the increase of fluidizing gas velocity. Gajewski [25]

* Corresponding author.
E-mail address: poupak.mehrani@uottawa.ca (P. Mehrani).

http://dx.doi.org/10.1016/j.powtec.2017.07.013
0032-5910/

glued copper rings connected to a microammeter on the inner surface of a 0.25 m in diameter glass column to measure the electrical current inside the bed. Polypropylene particles with diameter of 2000 μm were fluidized under gas velocities of 0.1–0.5 m/s while air at 40 °C and relative humidity of 35% was used as the fluidizing gas. Their results showed that the electrostatic potential above the static bed height increased with the increase of fluidizing gas velocity. The electrostatic potential reached a peak at a gas velocity of 0.35 m/s, and then started to decrease. Revel et al. [19] fluidized polyethylene particles with an average size of 3000 μm in a 0.1 m in diameter acrylic column at gas velocities of 1.7 to 2.5 times U_{mf}. Air at room temperature with a relative humidity of less than 5% was used as the fluidizing gas. They showed that the net specific charge (q/m) of particles sampled at 0.035 m above the distributor plate increased with the increase of fluidizing gas velocity. Liu et al. [21] studied the effect of fluidizing gas velocity on the degree of electrostatic charge generation in a 0.15 m in diameter carbon-steel gas-solid fluidization column. Polyethylene particles with an average size of 646 μm were fluidized at 138 kPa and at excess gas velocities of 0.05, 0.10, 0.15, 0.20 m/s. Air at room temperature with a relative humidity of 8–11% was used as the fluidizing gas. The measurements from three current collision probes located at different radial and axial positions in the column showed that the electrostatic charge increased with the increase of fluidizing gas velocity. Alsmari et al. [24] used the same apparatus as Liu et al. [21], and conducted free-bubbling experiments. They fluidized a binary mixture of large glass beads (425–600 μm) and 5 wt% fine glass beads (25–50 μm) at 207 kPa and a range of gas velocities of 0.2–0.6 m/s (1–3 times minimum fluidization velocity). Air at 20 °C with a relative humidity of 12% was used as the fluidizing gas. The particles charge densities were determined by current collision probes. The results showed that as the superficial gas velocity increased, the degree of electrostatic charge measured locally at the probe tip increased.

As mentioned previously, many industrial fluidized beds including that of polyethylene reactors are operated in turbulent flow regime. However, to the authors' knowledge, no work has been carried out to investigate the electrostatic charge generation and wall fouling in turbulent flow and its comparison with pre-turbulent flow regime. Moreover, industrial gas-solid fluidized bed polyethylene reactors are operated at high pressures close to 3000 kPa [29]. Therefore, the goal of this work was to investigate and compare the degree of electrostatic charge generation in pre-turbulent and turbulent fluidization flow regimes at pressurized conditions, similar to that of commercial polyethylene reactors.

2. Experimental setup and method

Experiments were conducted in a pilot-scale pressurized gas-solid fluidization system, detailed previously [30,31]. The system contained a 0.15 m in diameter stainless steel fluidization column. Two copper inner Faraday cups were placed in the bottom and top expanded sections of the column. The two inner cups were electrically isolated from the expanded sections. The top and bottom expanded sections of the column acted as the outer Faraday cups. The Faraday cups were connected to digital electrometers for measuring the net electrostatic charge of fluidizing particles. The distributor plate was a modified knife-gate valve which allowed the in-bed particles to dislodge into the bottom Faraday cup without any particle handling. A filter bag was placed inside the top Faraday cup to capture the entrained particles and to help measure their cumulative charge during fluidization. In all experiments, the fluidization system was pressurized to the desired operating pressure with nitrogen gas from a gas cylinder. The gas was circulated at the desired fluidizing gas velocity with a centrifugal compressor having a variable speed drive. A plate type heat exchanger was used to maintain the temperature of the gas at room temperature. Linear low-density polyethylene (LLDPE) resin directly received from a commercial reactor was fluidized in this work with properties summarized in Table 1.

Table 1
Particles properties.

Particle type	Geldart group	Particle density (kg/m^3)	Particle size distribution (μm)	Particle mean diameter (μm)
LLDPE	B	918	20–1500	560

The experimental conditions in this work are summarized in Table 2. Experiments were conducted with various gas velocities at factors of minimum fluidization velocity and at an elevated pressure, similar to the operating pressures of typical commercial polyethylene reactors. Experiments at 1.5–5 U_{mf} represented pre-turbulent flow, while those at 7.5 U_{mf} were at the turbulent flow regime. Since significant mass of particle entrained from the bed in 5 and 7.5 U_{mf} experiments, the fluidization period was limited to 15 min for all trials in this work.

2.1. Detection of minimum fluidization velocity and turbulent flow transition velocity

First the minimum fluidization velocity and the transition gas velocity to turbulent flow regime were established at the operating pressure of 2600 kPa. The minimum fluidization velocity, found by measuring the pressure drop across the bed at various superficial gas velocities, was 0.08 m/s.

The transition velocity to turbulent flow regime was found by monitoring the standard deviation of differential pressure signal across the bed at various superficial gas velocities. As the fluidizing gas velocity is increased, the resulting pressure fluctuations amplitude increases. However, beyond a certain superficial gas velocity, known as turbulent flow transition velocity (U_c), the amplitude of pressure fluctuations begins to decline and the large voids in the bed begin to disappear [14,32]. To find the turbulent flow transition velocity, in this work, the fluidizing gas velocity was elevated in increment of one U_{mf}, up to 8 U_{mf} which was at the limit of the compressor power. A fresh batch of polyethylene resin was used for each fluidizing gas velocity and the fluidization was carried out for 15 min, similar to the electrostatic trials. Since a significant amount of particles entrained from the bed when the fluidizing gas velocity was raised to 5 U_{mf} and higher, the bed particle size distribution and the turbulent transition velocity were influenced. Therefore, to determine any deviations in the U_c measurement, the differential pressure signal was measured for various fluidization periods including: 2, 6, and 12 min. The signal was recorded for 30 s for each time period, except for the 12 minute run where the signal was recorded for 3 min giving a total run time of 15 min. The results presented in Fig. 1 indicate that the turbulent transition gas velocity was between 6 and 7 times of U_{mf}. Thus, it was established that the system was operating in the turbulent flow regime at a fluidization velocity of 7.5 U_{mf}.

2.2. Experimental procedure

In all trials, as received particles (referred to as “initial” or “initial particles”) were poured into the fluidization column after taking their initial net charge. The desired fluidizing gas velocity was then reached by adjusting the speed of the centrifugal compressor after pressurizing the fluidization system to the desired operating pressure. During fluidization, the cumulative charges of entrained fine particles were measured by the top Faraday cup, containing a filter bag (referred to as “fines” or “fine particles”). After 15 min of fluidization, the compressor was gradually stopped and the system was depressurized. Then, the

Table 2
Experimental conditions.

Gas velocities	1.5, 3, 5 U_{mf} (pre-turbulent); 7.5 U_{mf} (turbulent)
Fluidization period	15 min
Operating pressure	2600 kPa (abs)