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Review

Electrostatics in gas-solid fluidized beds: A review

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HIGHLIGHTS

- The characterization methods of electrostatics in fluidized beds are outlined.
- Charge generation and distribution phenomena in fluidized beds and the underlying mechanisms are discussed.
- The interplay between electrostatics and hydrodynamics in fluidized beds is reviewed.
- Practical applications of tribocharging fluidized beds are presented.
- The CFD simulations of fluidized bed systems including electrostatic charges are compared.

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ABSTRACT

Gas-solid fluidized beds, by their nature, are associated with intense and frequent collisions of solid particles with each other and with the vessel wall, causing tribo-electrification. Accumulation of electrostatic charges in fluidized bed reactors can result in severe problems such as agglomeration, wall fouling, nuisance and hazardous discharge, all reducing the process performance and raising significant safety concerns. Tribo-charging of particles in fluidized beds has also been exploited in a number of useful applications. In this review, the characterization methods of electrostatics and the mechanisms of charge generation and distribution in fluidized beds are presented, followed by an account of the interplay between the hydrodynamics and electrostatic phenomena. Furthermore, techniques of electrostatic charge control in fluidized beds are reviewed, and applications of tribo-electrostatic fluidization systems are summarized. Finally, computational fluid dynamics simulations of the electrostatic effects on the hydrodynamic characteristics of fluidized beds are outlined.

Contents

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Nomenclature

Symbols

A_p	probe tip surface area, m^2
d	particle diameter, m
D	fluidized bed diameter, m
D_b	bubble size/diameter, m
d_p	particle diameter, m
E_d	breakdown potential in air (3×10^6 V/m)
F_d	drag force, kg m/s^2
F_e	electrostatic force, kg m/s^2
F_g	gravity force, kg m/s^2
I	total current, A
q	particle electrostatic charge, C
q_m	charge density or specific charge on particles, C/kg
t	time, s
U_b	bubble velocity, m/s
U_g	superficial gas velocity, m/s
U_{jet}	jet velocity, m/s
U_{mf}	minimum fluidization velocity, m/s
U_t	terminal settling velocity of particles, m/s
W_s	entrainment flux of solid particles, kg/m^2 s
x_i	weight fraction of fine particles having d_i as average diameter, dimensionless
z	distance between tips of a dual-tip probe, m

Greek letters

α_i	fitted parameter in Eq. (5), kg/m
β_i	fitted parameter in Eq. (5), C s^2/kg m^2
γ_i	fitted parameter in Eq. (5), C/kg
Δt	time lag between peaks from two tips, s
$\Delta\tau$	time difference between maximum and minimum peaks from one tip, s
ε	voidage, dimensionless
ε_0	vacuum permittivity (8.854×10^{-12} F/m)
ρ_b	fluidized bed density, kg/m^3
ρ_p	particle density, kg/m^3

Subscripts

1	upper probe tip
2	lower probe tip
max	maximum
min	minimum
mf	minimum fluidization

1. Introduction

Fluidization is associated with solid particles being transformed into a fluid-like state by a flowing fluid. It arrived on the industrial scene in a major way in the early 1940s with Fluid Catalytic Cracking (FCC) (Jahnig et al., 1980) and has since been implemented in many other industrial applications, including solid-catalyzed gas-phase reactions, non-catalytic reactions and physical processes. Advantageous features of gas-solid fluidized beds such as excellent gas-solid contacting, efficient and uniform heat transfer, temperature uniformity, and suitability for processing a wide range of feedstocks, have led to widespread industrial applications including coal/biomass combustion/gasification/pyrolysis, drying, coating, ore roasting, catalytic processes such as acrylonitrile, aniline and Fischer-Tropsch synthesis, and gas-phase polyolefin production (Grace et al., 2006; Kunii and Levenspiel, 1991).

Electrostatic charging of particles in gas-solid fluidized beds was first reported about 60 years ago in connection with anomalous behavior encountered in experiments on subjects as diverse as heat transfer (Miller and Logwinuk, 1951), elutriation (Osberg and Charlesworth, 1951), and characteristics of fluidized particles (Lewis et al., 1949). Problems associated with fluidized bed electrification include particle-wall adhesion, inter-particle cohesion and electrostatic discharges. The charged particles can coat vessel walls, requiring frequent cleaning. The electrostatic charges on particles and vessel walls, as well as the high-voltage electrical fields arising from them, can affect hydrodynamics and cause the formation of undesired byproducts (Cheng et al., 2012a). They can also interfere with sensors and bed internals, leading to malfunction of measurement instruments and operation (Zhang et al., 2013). For instance, when electrical capacitance tomography (ECT) is applied in a particulate process, electrification can result in measurement errors and even malfunction of some ECT systems (Gao et al., 2012; Zhang et al., 2014). Electrostatic charges are also responsible for potentially severe problems in commercial gas-solid fluidized bed facilities due to agglomeration (Ciborowski and Wlodarski, 1962), sheeting (Hendrickson, 2006), shank (fusion of solid particles into solid shapes resulting from overheating particles residing on the reactor wall in a reactive environment) (Moughrabiah, 2009), nuisance discharges and product handling (Chen et al., 2003a, 2003b). All of the obstacles owing to electrostatics, especially sheeting in fluidized bed polymerization reac-