Particuology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Particuology

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

Effects of various parameters on the attrition of bed material in a recirculating fluidized bed with a draft tube

Shivali Chourasia*, Babu J. Alappat

Department of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form 10 April 2017
Accepted 25 May 2017
Available online xxx

Keywords:
Attrition
Recirculating fluidized bed (RCFB)
Fluidization
Elutriation
Fines

ABSTRACT

We performed an experimental study to investigate the effects of various parameters on the attrition of bed material and its size distribution with increasing operation time in a recirculating fluidized bed (RCFB). The studied parameters included superficial velocity of fluidizing air, bed inventory, and spacing between the jet top and draft tube bottom (spacer height). The bed material was prepared from Indian Standard (IS) Grade I sand from sieves with a size range of 2.20–1.00 mm. Experiments were performed at ambient conditions, with the superficial air velocity ranging from 7.13–9.16 m/s, a bed inventory of 7–10 kg, spacing of 0.085 and 0.045 m between the jet top and draft tube bottom, and an operating time of 40 h. We investigated the influence of these parameters in terms of changes in the size distribution of particles, changes in the %-weight of particles of different size ranges, generation of particles with smaller diameters, the decrease of the downcomer bed height, variations in the coefficient of uniformity and coefficient of curvature, and material loss from entrainment of fines with increasing operation time. The mode of attrition was abrasion in all experiments. We found that with increasing operation time and other parameters (bed inventory, superficial air velocity, and spacer height) attrition of the bed material also increased. Generation and elutriation of fines were more pronounced at higher superficial air velocity, bed inventory, and spacer height.

Introduction

Industrial applications of fluidized bed technology include solid–fluid contact systems. For fluidization of Geldart D powders, a high gas velocity in the dense phase must be maintained, as these type of powders are relatively large and/or dense (Geldart, 1973). Geldart D particles can be made to spout by inputting fluidizing gas through a centrally positioned jet or orifice. Unlike group B particles, group D particles are difficult to fluidize in a deep bed. Therefore, spouted beds are recommended for this type of particles, in which a fluid jet enters into a solid-containing bed along its vertical axis. The limitations of spouted beds, including spouting instabilities, dispersion of gas, and non-uniform residence time, can be eliminated by introducing a centrally located vertical draft tube. The draft tube acts as a vertical transport riser, which helps to hold the spout and downward movement of particles in the downcomer. The recirculating fluidized bed (RCFB) is a modification of the spouted bed with the addition of a draft tube at the center of the bed to carry the spout (Alappat & Rane, 1996; Berruti, Muir, & Behie, 1988; Muir, Berruti, & Behie, 1990; Yang & Keairns, 1983). Some researchers (Chu & Hwang, 2002; Claflin & Fane, 1983; Milne, Berruti, Behie, & De Bruijn, 1992) have fixed the riser tube directly to the air jet to create so called internally circulating fluidized bed (ICFB) reactors, which minimizes the gas bifurcation toward the downcomer.

The maximum spoutable bed depth is limited by the energy of the fluidizing gas coming from the bottom of the draft tube (Yang & Keairns, 1983). The draft tube gives better control over the gas and solid residence time (Alappat & Rane, 2001) and further flexibility in the design (Claflin & Fane, 1983). RCFBs feature other advantages including high heat and mass transfer, compact size, uniform temperature, and high levels of mixing. Applications of RCFBs include grain drying, tablet coating, blending and mixing, incineration of liquid waste (Alappat & Rane, 2000), combustion and gasification of oil and coal (Yang & Keairns, 1974), granulation and agglomeration of fine powders among others.

Attrition is an major concern in all types of fluidized bed, which manifests as a change in the size distribution of bed particles. This change can influence the normal operation and function of fluidized

* Corresponding author. Fax: +91 011 2658 1117.
E-mail addresses: shivali.chourasia@gmail.com (S. Chourasia), alappat@civil.iitd.ac.in (B.J. Alappat).

http://dx.doi.org/10.1016/j.partic.2017.05.011
1674-2001/

Please cite this article in press as: Chourasia, S., & Alappat, B.J. Effects of various parameters on the attrition of bed material in a recirculating fluidized bed with a draft tube. *Particuology* (2017), http://dx.doi.org/10.1016/j.partic.2017.05.011

beds. Excessive attrition results a major loss of the bed inventory owing to elutriation of fine particles, or "fines," with the fluidizing gas. Other consequences of fines generation and their elutriation are clogging of downstream equipment, and the extra load on filtration and air pollution control units. Attrition negatively affects the economics of a plant and product (Merrick & Highly, 1974; Vaux, 1978). Attrition is even more critical when the generated fines are hazardous to health and/or produced in large amounts.

In any fluidized bed operation, there are several design and operating parameters that can affect the attrition of the bed material. The operating parameters can in turn be affected by the attrition of particles. Many studies have examined the attrition of particles, and effects of system parameters that can influence attrition in circulating fluidized beds and spouted beds (Bemrose & Bridgwater, 1987; Chu & Hwang, 2002; Fernández-Akarregui et al., 2012; Jiang, Zhou, Liu, & Han, 2009; Pis, Fuertes, Artos, Suarez, & Rubiera, 1991; Werther & Reppenhagen, 1999). However, few reports have described the solid circulation rate, gas bypassing, and attrition of bed particles in ICFB reactors (Chu & Hwang, 2002; Jeon, Kim, Kim, & Kang, 2008; Jia, Hughes, Lu, Anthony, & Lau, 2007; Shih, Chu, & Hwang, 2003).

Attrition is unwanted degradation and/or breakage of particles from the original particles occurring over time. The mechanism and degree of particle attrition depend on a number of factors including properties of the bed material such as size, shape, surface, porosity, hardness, roughness, and cracking; properties of the surroundings such as process conditions, gas velocity, temperature, and pressure; and the configuration of the particular fluidized bed, such as jet alignment, jet diameter, number of orifices (Boerefijn, Gudde, Ghadiri, & Tw, 2000; Chen, Grace, & Lim, 2008; Choi, Moon, Yi, & Kim, 2010; Li, Briens, Berruti, & McMillan, 2012; McMillan, Briens, Berruti, & Chan, 2007; Pougatch, Salcudean, & McMillan, 2010; Stein, Seville, & Parker, 1998; Tardin, Goldstein, Lombardi, & Pagliuso, 2001; Thon & Werther, 2010; Thon et al., 2011; Tomeczek & Mocek, 2007; Valverde & Quintanilla, 2013; Zhang, Jamaleddine, Briens, Berruti, & McMillan, 2012).

In some fluidized beds, the minimum bubbling velocity, interstitial gas velocity, and bed expansion increase as the amount of fines increases (Yates & Newton, 1986). Attrition of particles occurs through two main modes; surface abrasion and/or particle fragmentation (Chen, Grace, & Lim, 2011; Choi et al., 2010; McMillan et al., 2007; Ray, Jiang, & Jiang, 1987; Stein et al., 1998; Tardin et al., 2001; Teng, 2008; Thon & Werther, 2010). Abrasion of particles generates fines from the surface of the original particles, while the size distribution of the particles only slightly changes or remains same. Conversely, fragmentation causes the original particle to break into smaller particles of similar size. Therefore, the resultant size distribution curve of the particles becomes broader (Pis et al., 1991). Shih et al. (2003) investigated the effects of different designs and operating parameters on solid circulation, attrition rates, and gas-bypassing fractions in an ICFB reactor. Jeon et al. (2008) determined the effects of gas velocities to the draft tube and annulus section on the solid circulation rate and gas bypassing fractions in a square ICFB reactor with an orifice-type square draft tube.

In any fluidized bed operation, the bed material is in dynamic motion, and unavoidably subjected to mechanical stress owing to particle–particle collisions and other surrounding impacts. In fluidized bed operations, attrition takes places mainly because of abrasion mechanisms rather than fragmentation with increasing operation time (Boerefijn et al., 2000; Chen et al., 2008; Choi et al., 2010; Li et al., 2012; McMillan et al., 2007; Pougatch et al., 2010; Stein et al., 1998; Tardin et al., 2001; Thon & Werther, 2010; Tomeczek & Mocek, 2007; Valverde & Quintanilla, 2013; Zhang et al., 2012).

Although RCFBs are widely used, there have been only a few studies on the attrition of bed material and the effects of attrition on the RCFB performance. In the present study, attrition of bed material and the influence of the different factors on the attrition were investigated experimentally, by varying parameters including operation time, bed inventory, superficial air velocity, and spacer height in an RCFB.

Experimental

Setup and bed material

For our attrition studies of the bed material in an RCFB, we used an experimental setup based on a semi-circular cold model RCFB made of transparent Perspex as presented in Fig. 1. The draft tube was 1.00 m long with an inner diameter of 0.050 m and made of aluminum. The downcomer tube had a 0.150-m inner diameter and was made of transparent Perspex. The diameter of the air jet was 0.023 m. The spacings between the jet top and the bottom of the draft tube (spacer height) were 0.085 or 0.045 m. The fluidizing air used was supplied by an air compressor. The air flow rate was measured with a gas rotameter and regulated by a gate valve. The bed material used for the experiments was prepared by sieving Indian Standard (IS) sand. Particles able to pass through a 2.20 mm sieve but retained by a 1.00 mm sieve were used as the bed material (Table 1). The particle size distribution of original bed material (before attrition, i.e., at time = 0 h) is presented in Section "Particles size distribution, %-weight of particles of different sizes, and material loss" (Fig. 2, obtained by sieve analysis).

Experimental procedure

The reactor was filled up with the weighed bed material. The air flow was started at a high air velocity to ensure steady circulation of solids. Then, the air flow was reduced to the required level. The upwards air flow, with the sand particles, through the draft tube created a fountain above the draft tube. The sand fell down into the downcomer (annulus region) moving downward to the bottom of draft tube to be picked up again. All experiments were performed under steady operation of the reactor with stable solid circulation (i.e., continuous circulation of the bed material without any slugging in the draft tube or downcomer and minimal fluctuations in the spout height above the draft tube). The details of the different sets of operation conditions are given in Table 2. The range of different operating parameters for the reactor included superficial air velocity 4.5–12.5 m/s, bed inventory 4–10 kg, spacer height of 0.045, and 0.085 m.

These values show the range of the individual operating parameters of the reactor. However, only specific combinations of these operating parameters were examined. For example, the maximum bed inventory of the system was 10 kg, without submerging the draft tube. With a spacer height of 0.085 m and a bed inventory of 10 kg, the reactor could be operated at a maximum superficial gas velocity of approximately 9.5 m/s without any slugging. Thus, the maximum limit of bed inventory and superficial air velocity were determined by the spacer height of 0.085 m. For a spacer height of 0.085 m, the reactor could be operated with a minimum inventory of 7 kg and a superficial velocity of around 7 m/s. Below these ranges slugging of material occurred. The problem of slugging occurred mainly with higher spacer heights. At a spacer height of 0.045 m, the reactor could be operated over a wide range of bed inventories (4–10 kg) and superficial gas velocities (5.0–11.0 m/s). However, for comparison and observation of the effects of the spacer height on the attrition, the same ranges were chosen for spacer 2, i.e., 0.045 m. It was not possible to operate the reactor with a spacer height of 0.110 m owing to continuous slugging of the bed material. The ranges of superficial air velocity and bed inventory were selected