Bioresource Technology 119 (2012) 339–348

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Hydrodynamics of a fluidized bed co-combustor for tobacco waste and coal

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HIGHLIGHTS

- A pioneering study of fluidization of binary mixtures containing tobacco stems.
- Three fluidization velocities are identified for different tobacco stem fractions.
- Four hydrodynamic stages are experienced with the increase of gas speed.
- High speed gas jet should be used to improve the mixing and fluidisation effect.

ARTICLE INFO

Article history:
Received 20 January 2012
Received in revised form 27 April 2012
Accepted 25 May 2012
Available online 1 June 2012

Keywords:
Tobacco waste
Herbaceous biomass
Co-combustion
Fluidization engineering
Mixing behavior

ABSTRACT

The fluidization characteristics of binary mixtures containing tobacco stem (TS) and cation exchange resin (a substitute for coal) were studied in a rectangular bed with the cross-section area of 0.3×0.025 m^2. The presence of herbaceous biomass particles and their unique properties such as low density and high aspect ratio resulted in different fluidization behaviors. Three fluidization velocities, i.e. initial, minimum and full fluidization velocities, were observed as the TS mass fraction increased from 7% to 20%, and four hydrodynamic stages were experienced, including the static, segregation, transition and mixing stages, with increasing operational gas velocities. The results suggest that the operational gas velocity should be in the range of 2.0–5.0 times of the minimum fluidization velocity of the binary mixtures, and less than 7% TS mass fraction should be used in an existing bubbling fluidized bed. Higher TS fraction inclusion requires the introduction of central jet gas to improve the mixing effect.

1. Introduction

During the processing procedure of tobacco, around 20% of the raw materials are turned into burnable solid wastes such as tobacco powders and broken stems (Piotrowska-Cyplik et al., 2009; Li et al., 2011). Currently, these wastes are dumped in landfills, but it should be feasible to utilize this waste for energy production. One way of achieving this goal is through the co-combustion with coal (Khan et al., 2009; Saidur et al., 2011). Among various combustion technologies, fluidized bed is one of the best choices in modern heat and power plants due to its advantages such as simple construction, excellent solid–gas contact, uniform temperature distribution, and high heat and mass transfer rates (Cui and Grace, 2007; Mehran et al., 2011). While coal combustion in bubbling fluidized or circulating fluidized beds has been well-established from small to large scale, co-combustion of coal and biomass-based feedstock is still underdeveloped. Some unique hydrodynamic and chemical characteristics such as distinct mixing behaviors and different gaseous emissions have been identified for the co-combustion of coal and biomass (McIlveen-Wright et al., 2007; Akpulat et al., 2010; Silvennoinen and Hedman, accepted for publication; Yu et al., accepted for publication). Most studies have used thermogravimetric analysis to investigate the reactivity of biomass and biomass-coal mixtures (Cao et al., 2008; Darvell et al., 2010; Gil et al., 2010; Munir et al., 2010; Damartzis et al., 2011; Li et al., 2011; Yang et al., 2012), while studies on the physics and mechanics are limited (Cui and Grace, 2007).

In contrast to coal particles, tobacco stems exhibit low density and long and thin shapes. Such properties generally lead to a 'dead' fluidized bed or cause bubble coalescence, resulting in a poor fluidization quality (Sun et al., 2005; Cui and Grace, 2007; Pei et al., 2011). Generally for biomass-based thermo-conversion process in fluidized beds, different bed materials, i.e. silica sand, dolomite, olivine, or artificial catalysts, are needed to facilitate the fluidization and to intensify transfer processes and chemical reactions. The scenario becomes even more complicated for the co-combustion with coal, where a particle mixture consisting of biomass,

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http://dx.doi.org/10.1016/j.biortech.2012.05.132