Fuel 111 (2013) 696–708

Contents lists available at SciVerse ScienceDirect

Fuel

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

Composition of agglomerates in fluidized bed reactors for thermochemical conversion of biomass and waste fuels Experimental data in comparison with predictions by a thermodynamic equilibrium model

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HIGHLIGHTS

- Well controlled full-scale tests in a fluidized bed boiler.
- The use of line-scans by the EDX spectrometer of the SEM on bed samples.
- Thermodynamic equilibrium modelling as a powerful tool in understanding the phenomena of bed agglomeration using quartz sand.

ARTICLE INFO

Article history:
Received 18 December 2012
Received in revised form 6 March 2013
Accepted 13 March 2013
Available online 10 April 2013

Keywords:
Fluidized bed boiler
Quartz sand
Alkali chlorides
Bed material
Agglomeration

ABSTRACT

Controlled combustion tests of biomass were performed in the 12 MWth circulating fluidized bed (CFB) boiler located on the campus of Chalmers University of Technology. The aim was twofold: to investigate the composition of agglomerated material and also to highlight the reasons for sintering and agglomeration during thermochemical conversion of biomass and wastes in fluidized bed reactors using quartz sand as bed material. Bed ash from three different tests regarding fuel or fuel mixtures (wood with straw, bark, and bark with refused derived fuel) was analysed to determine the ash elements using: (a) inductive coupled plasma (ICP) equipped with optical emission spectroscopy (OES) and (b) scanning electron microscopy equipped with an electron dispersive X-ray spectrometer (SEM–EDX). Chemical equilibrium calculations were also performed to support the interpretation of the experimental findings. It was found that the combination of (i) well controlled full-scale tests in a fluidized bed boiler, (ii) the use of line-scans by the EDX spectrometer of the SEM on bed samples and (iii) thermodynamic equilibrium modelling is a powerful tool in understanding the phenomena of bed agglomeration using quartz sand.

1. Introduction

Thermochemical conversion of biomass and waste-derived fuels for the production of heat, power and fuels used in the transportation sector are instrumental in the development of a sustainable society [1]. Biomass fuels are renewable and have the potential to be carbon dioxide neutral. The use of waste-derived material as fuel, as well as the disposal of waste by means of incineration, is expected to increase due to enforced legislation and the fact that the rate of waste generation is growing with population expansion. There are several environmental and socio economic benefits related to the above-mentioned energy carriers, but also technical challenges due to texture, chemical content and heterogeneity of the waste.

Fluidized bed reactors are well suited for thermochemical conversion of a wide range of biomass and waste fuels provided that the fuel can be given a suitable particle size. This technology is characterised by the bed which, in terms of combustion, is operated at relatively low temperatures, has a substantial heat capacity and is capable of tapping hazardous elements [2–5]. The capacity of the bed material to capture trace elements can be improved by adding clay minerals and/or limestone [6–9]. Further, fluidized bed reactors can handle mixes of fuels to evoke positive synergy effects with regard to the conversion process, reactor operation and emissions [10–12]. Biomass and waste derived fuels contain quite high concentrations of alkali metals, i.e. potassium and sodium. During heating, alkali metals are partly captured in the ash and partly released to the flue gas [13]. The main gaseous products pre-

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0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.03.018

dicted by thermodynamic models are hydroxides (MOHs), sulphates (M_2SO_4), and chlorides (MCls) where M represents either K or Na, [14]. The formation depends on the access of chlorine and sulphur [13]. Alkali metal sulphates and, in particular, alkali metal chlorides have low melting temperatures and high vapour pressures [15]. Alkali metal compounds may deposit on the superheaters located in the exit- and/or convection section of the boiler. This can cause severe deposits and blockage of the flue gas pass in addition to corrosion of the superheater tube material. Ash may also deposit on surfaces exposed to predominantly radiant heat, e.g. furnace walls, subsequently causing so-called slagging [16].

A major problem in fluidised bed reactors for the conversion of biomass is sintering and agglomeration of bed particles, which prevent a proper fluidization and eventually result in the total collapse of the fluidised bed [19–29]. Both the terms agglomeration and sintering are used to describe the same phenomena. Sintering can be defined as the formation of bonds between particles at high temperatures [30] and is utilised in powder metallurgy in the production of items sustaining high temperature environments such as engine parts or turbine blades in steam- and gas turbines. An illustration of the high temperature sintering of a ceramic powder is shown in Fig. 1A. Agglomeration is defined as the formation of clusters of particles, i.e. agglomerates. In a fluidized bed reactor system, agglomeration and sintering of the bed material are associated with the formation of sticky coatings on bed particles. The coatings consist of multiple layers of ash or ash compounds. The

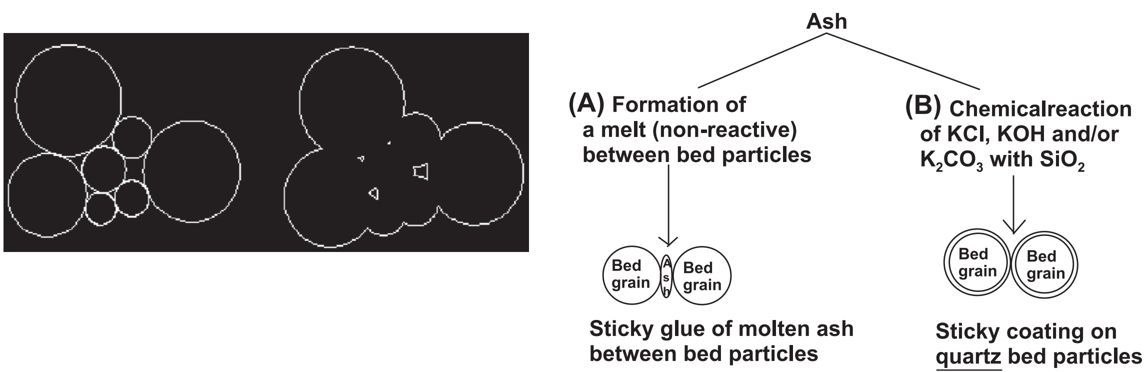

Fig. 1. (A and B) Theory of agglomeration/bed sintering of the bed material in fluidized bed systems using biomass.

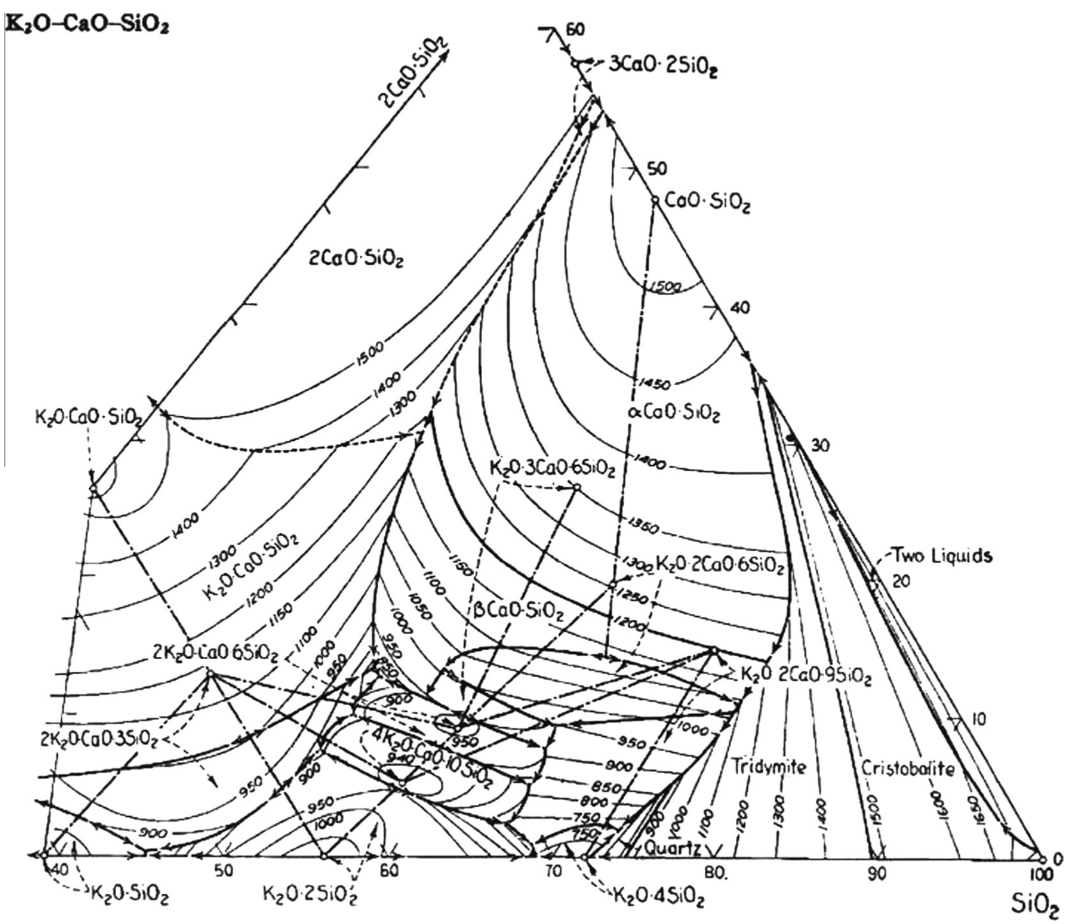

Fig. 2. The high SiO_2 corner of the phase diagram of the ternary system K_2O–CaO–SiO_2 [47,52].