Powder Technology 189 (2009) 57–63

Contents lists available at ScienceDirect

Powder Technology

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

Inhibition and promotion: The effect of earth alkali metals and operating temperature on particle agglomeration/defluidization during incineration in fluidized bed

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ARTICLE INFO

Article history:
Received 28 November 2007
Received in revised form 13 April 2008
Accepted 5 June 2008
Available online 15 June 2008

Keywords:
Agglomeration
Defluidization
Incineration
Fluidized bed

ABSTRACT

Some studies have demonstrated that earth alkali metals promote agglomeration; however, others have shown that they inhibit the generation of agglomeration. The earth alkali metals (Mg and Ca) may cause both inhibition and promotion of agglomeration/defluidization. Therefore, this study focuses on the effect of Mg, Ca and the operating temperature on the agglomeration/defluidization of sodium during incineration in a fluidized bed reactor. The results indicate that the added Mg and Ca inhibit agglomeration and increase the defluidization time. At low Na/Mg and Na/Ca mole ratios, Mg and Ca inhibit defluidization significantly. However, the inhibition reduces as the concentration of Na increases. When the mole ratio (Na/Mg and Na/Ca) exceeds two, the inhibition of Mg and Ca is not apparent. Under these conditions, the operation temperature is the main factor with regard to agglomeration/defluidization. When Mg and Ca are added to reduce the agglomeration/defluidization, both the concentration of Na and operating temperature must be considered.

1. Introduction

During fluidization, the accumulation of agglomerates changes the fluidization characteristics such as bubble size, bubble frequency, pollutant emission and minimum fluidization velocity [1]. This phenomenon influences the operation of fluidization even to the extent of shutting down the fluidized bed. Nonetheless, agglomeration requires many factors for it to take place. According to Langston and Stephens [2], Moseley and O'Brien [3] and Wank et al. [4], the agglomeration of particles is associated with particle size, surface, density, reaction mechanism, gas velocity, temperature, physical and chemical characteristics, area of contact and momentum of the particles. Therefore, it is clear that the agglomeration mechanism is fairly complex.

Fluidized bed reactors provide various advantages such as good solid mixing, large contact surface area and strong heat transfer [5], which have been exploited in incineration. However, most waste contains many materials such as plastics [6], heavy metals, alkalis and earth alkali metals [7]. Skrifvars et al. [8,9] have reported that visco-materials cause the sintering of glassy materials, where liquid phase materials are produced by melting and chemical reactions which lead to agglomeration/defluidization. During incineration, the generation of agglomeration in a sand bed changes the fluidized behaviours and results in the production of secondary pollutants. Lin et al. [10] have pointed out that the concentration of emitted polycyclic aromatic hydrocarbons (PAHs) increases with agglomeration. Furthermore, defluidization significantly increases the emitted concentration of heavy metals (Pb, Cr and Cd). These results show that agglomeration/defluidization influences the emission of pollutants during incineration.

Some literatures reported that various elements markedly affect the agglomeration/defluidization during fluidization [7,11,12]; these elements include vanadium, nickel, ferrum, sulphur, chlorine, alkali metals and alkali earth metals. When alkali metals (Na and K) are present in coal or waste, they increase the risk of agglomeration during combustion [12–14]. However, the alkali earth metals (Mg and Ca) may also cause inhibition and promotion of agglomeration/defluidization. Atakül et al. [15] have reported that Mg and Ca accelerate agglomeration to form CaO and MgO in the sand bed. Fernández et al. [16] further stated that the amount of Ca in the agglomerates exceeds that in the non-agglomerated particles. This result reveals that Ca promotes the generation of agglomerates. Additionally, Mg and Ca may react with other elements to form the compounds magnesium sulphate and calcium carbonate, which agglomerate in the sand bed and ash [7,15,16]. On the other hand, Lin et al. [13] have reported that the addition of Mg and Ca to the waste has two effects (inhibition and promotion) on agglomeration.

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0032-5910/$ – see front matter.
doi:10.1016/j.powtec.2008.06.003

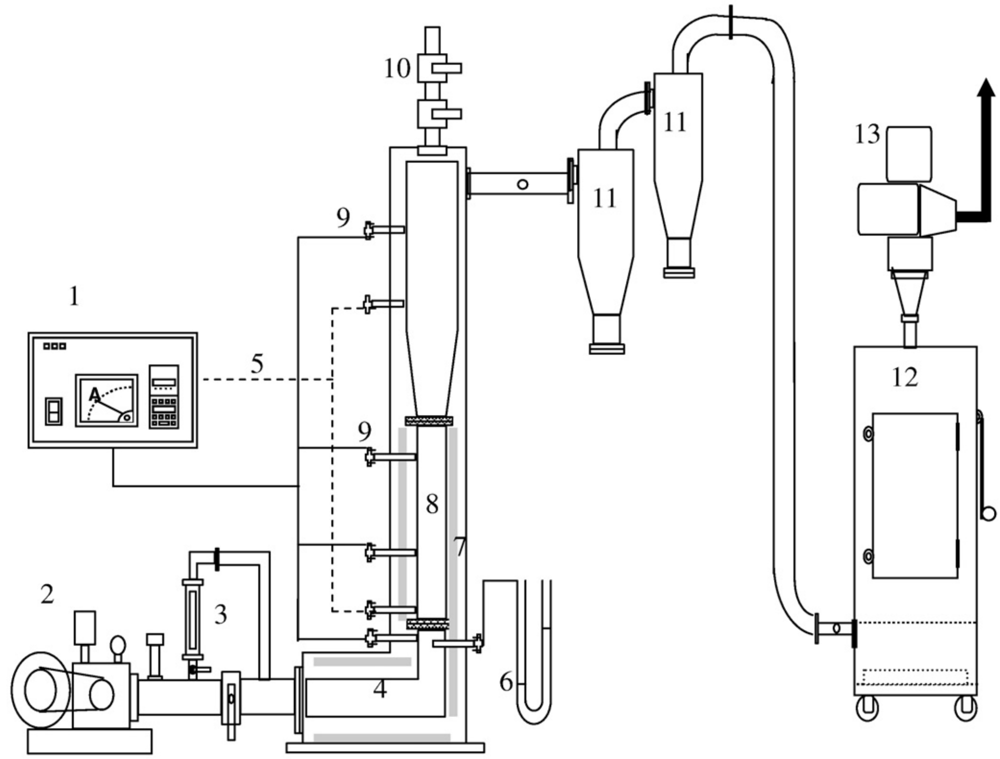

Fig. 1. The bubble fluidized bed incinerator. (1) PID controller, (2) blower, (3) flow meter, (4) preheater chamber, (5) pressure transducer, (6) U manometer, (7) electric resistance, (8) sand bed, (9) thermocouple, (10) feeder, (11) cyclone, (12) bag filter, (13) induced fan.

However, the results are inconclusive. Most researches have focused on analyzing the relationship between the components in coal and agglomerates during the combustion of coal. The components of coal are complex and contain various metal elements. Therefore, the relationships between various metal constituents and agglomeration have not been clarified.

However, municipal waste generally contains some alkali and alkali earth metals. Marco et al. [17] have pointed out that these metals may melt to form agglomerates at temperatures between 700 °C to 800 °C. The generation of agglomerates must be prevented during municipal incineration in order to reduce the secondary pollutants. However, few studies have addressed this issue. The effect of Mg and Ca on agglomeration/defluidization must be considered distinctly. Accordingly, this study considers the effects of alkali earth metals (Mg and Ca) and operating temperature on the agglomeration/defluidization of Na during incineration. Different ratios of alkali metal (Na) to alkali earth metals (Mg and Ca) were added to artificial waste. The signal addition and mixture addition of different metals were used to simulate the effects of Mg and Ca on agglomeration during incineration.

2. Experimental

The experimental apparatus was a bubbling fluidized bed incinerator as shown in Fig. 1. The reactor contains a preheated chamber (50 cm long), a main chamber (110 cm high) with an internal diameter of 10 cm, and a secondary combustion chamber (100 cm high) with an inner diameter of 25 cm. The chamber was composed of 3 mm thick stainless steel (AISI 310). The apparatus was surrounded by an electrically resistant material and packed with ceramic fibres for thermal insulation. The reactor was equipped with a stainless steel porous plate with a 15% open area for distributing gas. Three thermocouples were employed to measure the temperatures of the freeboard chamber, sand bed and preheated chamber. The temperature was controlled using a program logical control (PID) controller. The elutriation particles from the combustion chamber were collected using two cyclones that were connected to a bag filter.

In this experiment, Na was utilized to simulate agglomeration during incineration. The Mg and Ca were also added to test the inhibition or promotion for defluidization.

During experiment, the alkali and alkali earth metals were added as nitrates by single alkali and mixture addition of alkali and alkali earth metals. The added metal nitrates were $NaNO_3$, $Ca(NO_3)_2$ and $Mg(NO_3)_2$. The various mole ratios of Na/Mg and Na/Ca were prepared. In order to change the mole ratios of Na to Mg and Ca, Na samples of mass between 0.4% and 3.0% were added into artificial waste, but the mass of Mg and Ca was maintained 0.84% and 1.39%. Therefore, the ratios of Na/Mg and Na/Ca were changed from 0.5 to 3.75. Table 1 shows the operating conditions of Na/Mg and Na/Ca ratios were used

Table 1
Operating conditions for the experiments

Run	T (°C)	Na (%)	Mole ratio of Na/Mg, Mg (0.84%)	Mole ratio of Na/Ca, Ca (1.39%)
1–9	900	0.4, 0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	–	–
10–18	900	0.4, 0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	0.5, 1.0, 1.5, 1.75, 2.0, 2.25, 2.75, 3.25, 3.75	–
19–26	900	0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	–	1.0, 1.5, 1.75, 2.0, 2.25, 2.75, 3.25, 3.75
27–35	800	0.4, 0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	–	–
36–44	800	0.4, 0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	0.5, 1.0, 1.5, 1.75, 2.0, 2.25, 2.75, 3.25, 3.75	–
45–52	800	0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	–	1.0, 1.5, 1.75, 2.0, 2.25, 2.75, 3.25, 3.75
53–61	700	0.4, 0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	–	–
62–69	700	0.8, 1.2, 1.4, 1.6, 1.8, 2.2, 2.6, 3.0	1.0, 1.5, 1.75, 2.0, 2.25, 2.75, 3.25, 3.75	–

Gas velocity = 0.14 m/s, Material size = 770 μm, Static bed height = 20 cm.