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Experimental simulation of particle agglomeration in an internally circulating fluidized bed

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ABSTRACT

The internally circulating fluidized bed (ICFB) plays an important role in waste incineration. To investigate the agglomeration phenomenon in the ICFB, polyethylene particles were used to simulate the process of particle agglomeration in a two-dimensional internally circulating fluidized-bed. Along a “long” agglomeration process, the evolution of the particle size distribution was followed by taking samples at different times. The study was aimed at understanding the agglomeration process, examining its influence factors, and ultimately controlling the agglomeration. Experimental results indicated that the whole process could be divided into two stages: the formation and acceleration stages. The temperature, the percentage of cohesive particles and the fluidizing air distribution apparently affect particle agglomeration. A reasonable fluidizing air distribution was beneficial for restraining agglomeration. Combined with air-winnowed discharging, the uneven fluidizing air distribution reduced the possibility of defluidization in ICFBs.

1. Introduction

Different from traditional fluidized beds, the internally circulating fluidized bed (ICFB) is a new type of gas-fluidized technology, where the circulation of the bed materials is achieved by distributing air unevenly. It has several promising advantages such as a reduced bed height, a high heat/mass transfer coefficient, and a good operation performance, and has been widely applied in coal combustion/gasification, biomass pyrolysis/gasification, and solid waste incineration, among other applications [1,2]. Despite the good progress that has been made in the study and application of ICFB, many aspects of ICFB characteristics are still far from being fully understood [3,4]. One aspect worthy of further consideration is the coking/slagging process. An understanding of the underlying physics of the process is not only important from an academic point of view but also of industrial relevance. Coking/slagging and the resulting defluidization can seriously endanger ICFB safety, especially for biomass and solid waste fuels with high alkali content.

The coking/slagging process is not a new phenomenon in fluidized beds (FBs), and the earliest investigations can be dated back to 1975, when Yerushalmi et al. published an article on ash coking/slagging phenomenon in fluidized beds on Science [5]. Since then, various researchers have conducted a great deal of valuable work [6–9]. Skrifvars et al. found that the slagging mechanism was associated with the melt, the reaction liquid and the sintering of the glassy material [6]. Operation parameters, including the particle properties, the reaction mechanism, the temperature, the pressure and gas velocity all affected the slagging process [6–9]. Siegell argued that the coking/slagging process in FBs was basically proportional to the contact area and the viscous force between the particles and was inversely proportional to the particle momentum [9]. These investigations have important significance for understanding the coking/slagging process, but the ash coking/slagging phenomenon occurs at high temperatures and in a very short time, resulting in difficulty in observing the complete process.

The coking/slagging problem is essentially an agglomeration phenomenon of cohesive particles, which is caused by thermally induced surface-melted particles. To reveal the agglomeration mechanism, adoption of low-melting-temperature simulation materials such as paraffin and polyethylene is one useful experimental method, which allows investigating the complete agglomeration process at low temperatures and over a relatively longer time period. Compared with high-temperature agglomeration, low-temperature agglomeration is relatively easy to observe. In the food and pharmaceutical fields, Turchiuli et al. [10] studied skim milk powder agglomeration by sampling in a conical fluidized bed, and Mehr et al. investigated the agglomeration process that occurs while producing instant sugar [11]. Avilés-Avilés et al. observed the fluidized bed agglomeration of particles with different glass transition temperatures [12]. These reports

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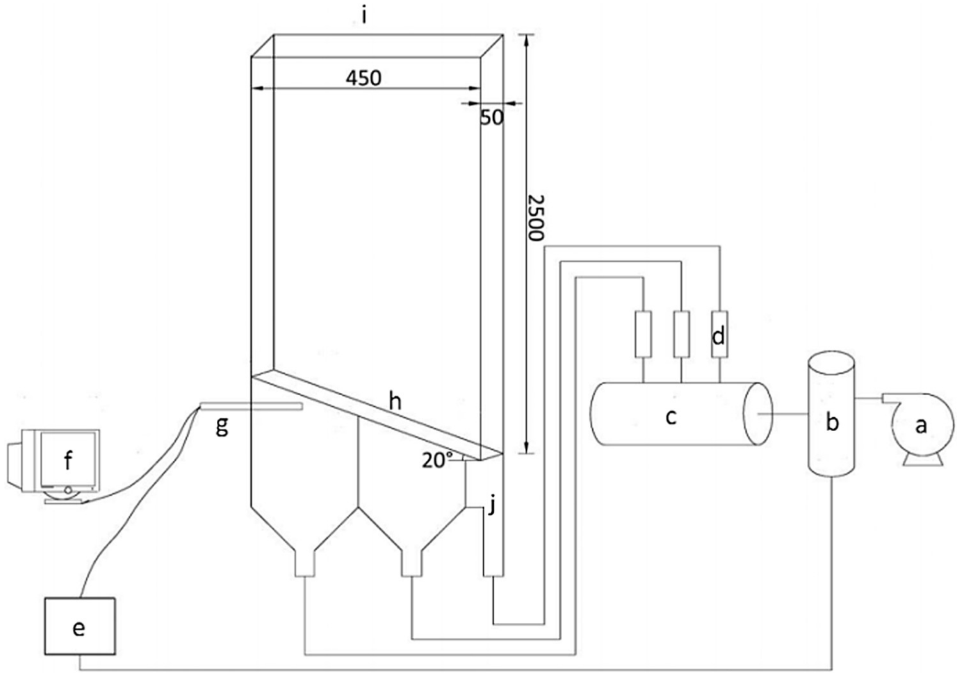

Fig. 1. System diagram of the two-dimensional fluidized bed (a: blower; b: heater; c: air box; d: flow meter; e: temperature controller; f: displayer; g: temperature sensor; h: air distributor; i: two-dimensional ICFB; j: air-winnowed slag-charging orifice).

help further our understanding of the fluidized bed agglomeration process, but the agglomeration process, which sprays a liquid in conical fluidized beds, is different from the thermally induced agglomeration in an ICFB either in the agglomeration mechanism or in the study aim.

In this study, low-melting-temperature materials, namely, polyethylene particles, were used to simulate cohesive particle agglomeration. We carefully investigated the agglomeration process in an ICFB and the effect of the operation parameters. Finally, to reduce agglomeration in the bed, we designed an air-winnowed slag-charging orifice to charge the agglomerates. The objectives of this study were to reveal the agglomeration process of cohesive particles in ICFBs and to find methods to reduce agglomeration.

2. Experimental section

The experimental setup of an ICFB is shown in Fig. 1. The whole system included a two-dimensional ICFB (450 × 50 × 2500 mm, with a front/back side made by organic glass), a heating system (maximum air temperature 200 °C), an air supply system, and a measuring and control system (flow meter, temperature sensor and controller, etc.). In the ICFB, an inclined distributor was adopted, and the angle of the inclined distributor is equal to 20°. Two gas inlets and two independent air chambers at the bottom of the air distributor were designed in the bed where the right side is high-velocity fluidizing air, and the left is low-velocity fluidizing air. Two types of particles were used in the fluidizing experiment: polyethylene particles (diameter 1.5 mm) as the thermal-induced cohesive particle, and resin particles (diameter 0.8 mm) as the non-cohesive particle. The deformation and flowing temperatures are 105 and 149 °C for the polyethylene material. The minimum fluidization velocity (u_{mf}) of polyethylene particles was measured to be 0.59 m/s at average bed temperature of 100 °C.

The agglomeration experiments were conducted in the ICFB. The particles (total mass: 3.750 kg) were put into the two-dimensional ICFB and were fluidized by the preheated air with a total flow rate of 108 m^3/h. The particles were all taken out after certain time and were sieved and weighed, respectively. The agglomeration degree was characterized by the mass percentage of agglomerates and their size distributions. To obtain the agglomeration degrees at different times, in every run we used new particles, and repeated the above procedure separately. During the fluidizing experiments, we examined the effects of operation parameters such as the fluidizing air temperature (T_b), the fluidizing air distribution (the flow ratio of high-velocity fluidizing air to low-velocity fluidizing air, R_a), and the mass ratio of the cohesive particles to the non-cohesive particles (R_p). The range of these variables is listed in Table 1.

To reduce agglomeration in the bed, we designed an air-winnowed slag-charging orifice (Fig. 1) to charge the agglomerates. The principle was based on the density and weight discrepancies between bed particle and agglomerate. The orifice with an upward airstream was set at the bottom of the bed. The upward airstream prevented small particle discharge from the bed and allowed for the discharge of large agglomerates. Compared with traditional slag-charging orifice, the new slag-charging orifice added the winnowing air.

3. Results and discussion

3.1. The agglomeration process

Particle agglomeration occurs only if their surfaces become viscous with the increasing temperature. At average bed temperatures below 110 °C, the particles were well fluidized for a long time in the ICFB, and almost no sign of agglomeration appeared. At temperatures between 110 and 120 °C, agglomeration occurred. Fig. 2 shows a particle agglomeration process for a typical case (average bed temperature T_b = 110 °C, high fluidization air velocity U_h = 3 u_{mf}, low fluidization air velocity U_l = 1.5 u_{mf}, flow ratio of high-velocity air/low-velocity air R_a = 2:1, mass ratio of cohesive particle/non-cohesive particle R_p = 1:2). The mass percentage of the agglomerates increased over time, and the whole process could be divided into two stages: the first stage was from the beginning to the 20 min mark, where the agglomeration rate was slow, and single particles bonded together to form and

Table 1
Test variables.

Bed temperature, T_b	110 °C, 120 °C, 130 °C
Flow ratio of high-velocity fluidizing air to low-velocity fluidizing air, R_a	1:1, 1.5:1, 2:1, 2.5:1, 3:1
Mass ratio of the cohesive particles to the non-cohesive particles, R_p	4:1, 1:2, 1:6