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Study on the critical amount of liquid for bed material agglomeration in a bubbling fluidized bed

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A B S T R A C T

Agglomeration of bed materials at a high temperature is one of the most important and challenging problems for fluidized-bed biomass boilers for thermal/power generation. Inorganic alkali compounds derived from the biomass ash, mainly potassium (K) and sodium (Na) can be problematic as they form low-melting alkali compounds and may also react with the bed material (silica sand) forming low-melting alkali silicates. These low-melting alkali compounds, if surpassing a critical amount, could coat the sand particles to form agglomerates, eventually leading to partial or complete de-fluidization of the reactor. In the present study, the critical amount of liquid (molten ash in real biomass boiler operations) that would result in severe bed agglomeration and defluidization was studied a small pilot-scale cold bubbling fluidized bed (BFB) test rig filled with silica sand particles as bed materials equipped with non-invasive capacitance sensors and differential pressure transducers. In the cold BFB test rig, a solution of glycerol–water (30% *v*/*v*), employed to simulate molten ash in real biomass boiler operations, was injected to the bed at different quantities during the tests. It was found that in the present fluidization system the critical liquid amount causing bed agglomeration is likely 0.2 wt% (in relation to the weight of bed material loaded) and 0.7 wt% would cause severe channeling and de-fluidization conditions.

1. Introduction

The declining resources and soaring prices of fossil fuels have intensified the interest and efforts in searching for alternative energy resources (particularly the carbon-neutral energy sources) to substitute for fossil fuels [1]. As a carbon-neutral energy source, biomass has received a great deal of attention [2]. Among the technologies that can be used to burn biomass for thermal/power generation, fluidized beds are emerging as the most commonly used due to their fuel flexibility and high efficiency [3]. Conversion of carbonaceous solid material such as coal and biomass in fluidized bed (FB) has proved to be promising for generating steam, electricity and hydrogen [4].

High pressure steam and electric power are needed in pulp and paper mills, for many processes including drying pulp and paper products, heating water and process liquors, and concentrating spent cooking liquor (e.g., black liquor). Burning concentrated black liquor in recovery boilers contributes about 60 to 70% of the energy requirement in a modern pulp/paper mill, while the remaining 30 to 40% is generated by biomass combustion in biomass boilers. There are about 300 large biomass boilers in pulp and paper mills in North America; along with a large number smaller units operated in lumber mills, tissue mills, and plywood mills, etc.

Despite its broad application, biomass combustion/gasification in fluidized bed processes still has some technical difficulties. Bed material agglomeration is a major operational problem. Usually, a fluidized bed biomass boiler involves silica sand as bed material in the presence of ash. Inorganic alkali components from the fuel, mainly potassium (K) and sodium (Na), can be problematic as they form low-melting alkali compounds and may also react with the bed material forming low-melting alkali silicates [5]. The alkali content can vary much between fuels; it is especially high in the case of agricultural crop residues. When both alkalis and silica are present in the bed, they can form compounds with low melting temperatures, forming a “viscous” layer to coat the sand particles and form agglomerates. The sand particle agglomerates with a sticky layer would grow larger with time upon collisions. This eventually leads to partial or complete defluidization of the reactor, which in turn results in a lengthy and expensive unscheduled shutdown [4]. Pjontek et al. [6] demonstrated that gas–liquid–liquid–solid fluidized beds are subject to particle agglomeration, depending on particle size and shape of the bed materials.

In terms of agglomeration mechanisms, when two particles adhere to agglomerate, material at the point of contact migrates forming a neck with adhesion forces that are stronger than the disruptive forces in the fluidized bed [7]. Thy et al. [8] reported that in fluidized combustor fueled by wood and rice straw blends thin discontinuous films of adhesive cement, formed preferentially on surfaces and contact areas between bed particles, ultimately led to bed agglomeration. The cement

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films originated by filling of irregularities on individual and partially agglomerated bed particle surfaces by accumulation of liquid droplets preferentially in areas sheltered from turbulence and mechanical interaction. Two types of adhesion have been proposed in literature: 1) visco-plastic sintering of glassy material, and 2) liquid phase (leading to capillary force) produced by melting or by chemical reactions [9,10]. It is obvious that there exist a minimum or critical amount of visco-plastic or liquid phase to form the bed material agglomerates. However, to the best of the authors' knowledge, such minimum or critical amount of visco-plastic or liquid phase for bed material agglomeration is yet to be reported.

There is a common agreement between many researchers that the bed material agglomeration process in a bubbling fluidized bed (BFB) boiler is the result of stickiness or adhesiveness of bed material caused by alkali compounds. "Stickiness" of bed particles can result mainly from the presence of a liquid (melt) phase or glassy phase by visco-plastic sintering.

Bed material agglomeration dramatically changes the fluidization behavior of a BFB, thus the fluidization characteristics of the bed such as minimum fluidization velocity, bubble size and bubble frequency, among others are highly affected [11]. Therefore changes in bubble properties can be used as a method for agglomeration detection in BFBs.

The main objective of this work is to investigate and determine the critical amount of liquid phase required to form agglomeration in BFB boilers. The results of this research would help develop new strategies to prevent bed agglomeration in biomass BFB boilers. In this study, a small pilot-scale cold BFB test rig was used, and a solution of glycerol–water (30% *v*/*v*) was employed to simulate molten ash in real biomass boiler operations and was injected to the bed at different quantities during the tests. Two techniques used for agglomeration detection were planar capacitance sensors and differential pressure drop signals.

It shall be noted that in this cold-bed study, we employed the glycerol–water (30% *v*/*v*) solution to simulate molten ash only due to their similarity in viscosity. This study concerned the liquid–solid agglomeration formed by the liquid phase of low-melting alkali compounds by the "melt induced" mechanism. Nevertheless, in a real fluidized-bed biomass boiler, the molten ash can react with bed materials, which can contribute to bed material agglomeration too. However, such phenomenon cannot be simulated in the cold-bed tests, so the hypothesis employed in this study (using glycerol–water as the model system to simulate molten ash in a cold BFB test rig) can only be an approximate. In fact, the following continued studies have been performed and the results will be submitted for publication soon: (1) In a hot BFB (electrically heated to ~400–800 °C) using model compounds of salts to simulate molten ash; (2) In a hot BFB (heated to ~800 °C by wood pellet combustion) with addition of different amounts of agricultural residues (e.g., corn stalk) with high KCl content.

2. Experimental apparatus and methods

2.1. Facility description

The research was completed at room temperature in a small pilot-scale cold BFB test rig at ICFAR in Western University. A schematic of the cold BFB test rig is shown in Fig. 1. The rig is 1.97 m total high, has stainless steel walls with a trapezoidal cross sectional area, and is equipped with planar capacitance sensors located on the outside of the bed wall over a rectangular wood window embedded in the reactor wall. The rig is also equipped with a differential pressure transducer to monitor the total bed pressure drop. A porous steel plate distributor is located at the bottom of the bed.

Cold BFB tests were chosen and a mixture of glycerol–water solution was used to simulate the molten ash in real biomass boiler operations, because at room temperature the simulated molten ash can be injected into the reactor in a well-controlled way.

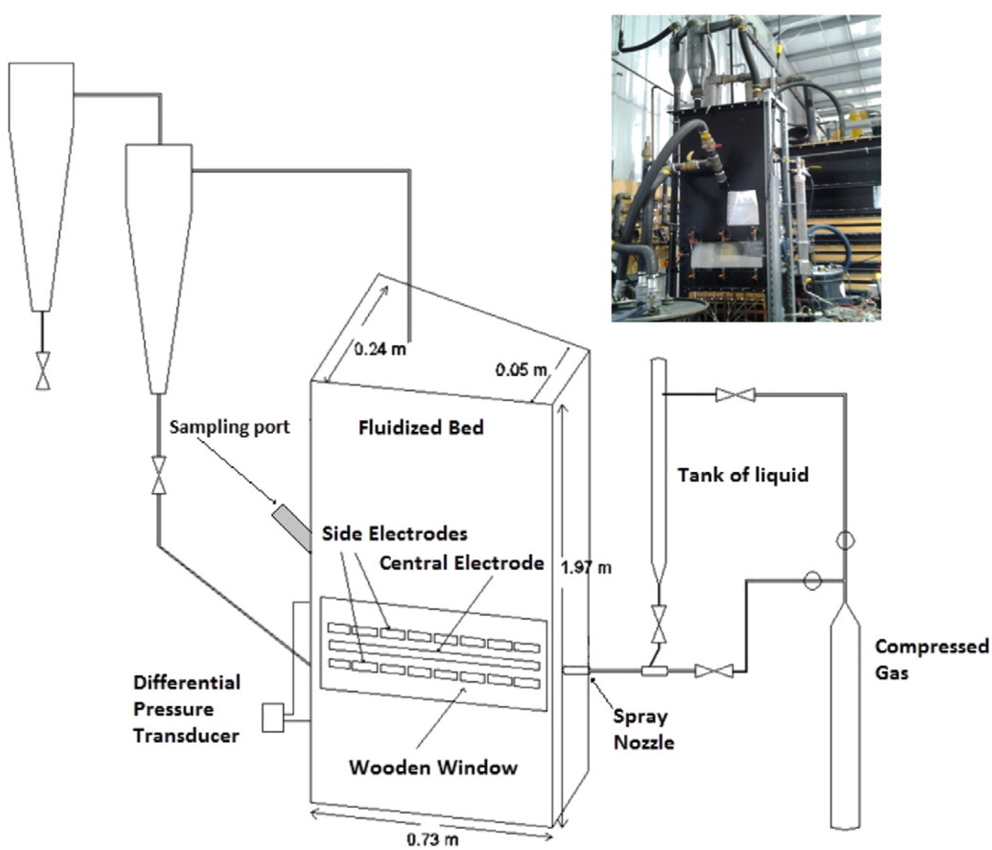

Fig. 1. Schematic diagram of the small pilot-scale cold BFB test rig used.