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Coating and melt induced agglomeration in a poultry litter fired fluidized bed combustor

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ABSTRACT

The combustion of poultry litter, which is rich in phosphorus, in a fluidized bed combustor (FBC) is associated with agglomeration problems, which can lead to bed defluidization and consequent shutdown of the installation. Whereas earlier research indicated coating induced agglomeration as the dominant mechanism for bed material agglomeration, it is shown experimentally in this paper that both coating and melt induced agglomeration occur. Coating induced agglomeration mainly takes place at the walls of the FBC, in the freeboard above the fluidized bed, where at the prevailing temperature the bed particles are partially molten and hence agglomerate. In the ash, P_2O_5 forms together with CaO thermodynamically stable $Ca_3(PO_4)_2$, thus reducing the amount of calcium silicates in the ash. This results in K/Ca silicate mixtures with lower melting points. On the other hand, in-bed agglomeration is caused by thermodynamically unstable, low melting HPO_4^{2-} and $H_2PO_4^-$ salts present in the fuel. In the hot FBC these salts may melt, may cause bed particles to stick together and may subsequently react with Ca salts from the bed ash, forming a solid bridge of the stable $Ca_3(PO_4)_2$ between multiple particles.

1. Introduction

Intensive livestock breeding is in many regions responsible for the imbalance between supply and demand for fertilizers in agriculture. The excessive supply of e.g. cattle manure, applied to agricultural land, may lead to nutrient saturation and eutrophication problems. This over-application of manure is counteracted by e.g. the EU Nitrates Directive [1] and other national or international legislation.

Legislation limiting the use of animal manure for land fertilization urges the development of alternative treatment options, such as recycling into animal feed, biogas production, composting and combustion [2,3]. As there is a growing demand for sustainable energy production, energetic valorization of manure is becoming more and more subject to research [4–6], and is already applied in full scale installations. The low moisture content in combination with the high organic carbon concentration of e.g. poultry litter results in relatively high heating values,

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which allows this biomass to be combusted in a fluidized bed combustor [7].

The fluidized bed combustor (FBC) of BMC Moerdijk in the Netherlands is one of the first power plants fired with poultry litter, a combination of poultry manure and bedding material of the sheds. The produced ash (bottom ash, boiler ash and air pollution control residue combined) is rich in P, K and Ca. It is exported to be processed into inorganic soil amendment.

The high concentration of P and K in the ash increases however the risk for bed particle agglomeration, which leads to defluidization resulting in unforeseen shutdown of the installation. Hence, the availability of the installation of BMC Moerdijk is somewhat limited (75%–93% for the period 2009–2012), compared to the availability of for instance a coal fired power plant. Given the temperature of the fluidized bed (750 °C–765 °C), agglomeration problems might be attributed to the melting of alkali silicates [4,8,9] and of alkali and alkaline earth phosphates [10–12].

In earlier research on agglomeration during combustion and gasification of biomass, Visser et al. [13] introduced the concepts of "coating induced agglomeration" (where a coating layer deposits on the bed particles that may partially melt and cause agglomeration) and "melt induced agglomeration" (i.e. agglomeration of bed particles caused by liquid bridges of molten ash particles), based on the composition of interparticle regions of agglomerated samples. However, to our knowledge, all subsequent research was based on the concept of coating induced agglomeration, as attempts were made to explain agglomeration by the equilibrium phase composition of the bed material (mostly sand particles coated with ash) and resulting melt phase [4,8,14,15]. Brus et al. [16] explicitly called coating induced agglomeration the dominant agglomeration mechanism.

Melt induced agglomeration therefore rather appeared a concept, than experimentally evidenced. In our research on agglomeration at the FBC installation of BMC Moerdijk, we observed experimentally that two mechanisms can clearly be distinguished when poultry litter is combusted. In both mechanisms melt formation is responsible for agglomeration, though coating induced agglomeration results from the melting of thermodynamically stable compounds in the bed ash, i.e. the bed material (silica sand) coated with fuel ash, after thermodynamic equilibrium was reached. On the other hand, melt induced agglomeration is caused by low melting salts present in the fuel that melt, form a liquid bridge between bed ash particles, and only then react with the ash particles to achieve thermodynamic equilibrium. In that case, the agglomeration occurs before thermodynamic equilibrium is reached.

In this paper, both coating and melt induced agglomeration in the poultry litter fired FBC of BMC Moerdijk are discussed. Thermodynamic calculations were performed to estimate the speciation of the four main ash forming elements, Ca, K, P and Si. Phase diagrams were then used to detect species that may cause coating induced agglomeration. Melt induced agglomeration is observed based on the composition of the poultry litter, containing low melting salts, forming a liquid bridge between bed ash particles, and only then reacting to reach the thermodynamic equilibrium composition of the bed ash.

2. Materials and methods

2.1. Installation

The installation of BMC Moerdijk (the Netherlands), with a capacity of 37 MW of electricity, includes a bubbling fluidized bed combustor (BFBC), followed by an energy recovery section and a flue gas cleaning section. The installation processes 1200 t d^{-1} of wet poultry litter, transported from approximately 600 poultry farmers all over the Netherlands [17], producing approximately 165 t d^{-1} of ash, of which 66.3 t d^{-1} is bed ash. The ash, rich in K and P, is used as a resource for the production of inorganic fertilizer. 23.3 t d^{-1} of silica sand (approx. 80% between 550 μm and 900 μm) is continuously injected into the FBC as fresh bed material. The bed ash (i.e. silica sand coated with poultry litter ash) is not recirculated, but continuously extracted at a low rate at the bottom of the bed via extraction hoppers and a conveyor screw.

The BFBC operates at a bed temperature of 750 °C–765 °C, with an average pressure drop over the bed of 13 kPa. Above the bed, in the freeboard, secondary air is injected and the temperature may exceed 1000 °C. In the installation, both in-bed agglomeration, and severe agglomeration to the wall in the freeboard occur occasionally. When the wall agglomerates have grown significantly, they may fall into the fluidized bed, disturbing the fluidization and potentially causing complete defluidization.

2.2. Elemental analysis

105 bed ash samples (i.e. sand particles coated with ash, sampled at the conveyor screw below the extraction hoppers at regular times over a period of approximately 24 months) and 53 agglomerates (sampled after a shutdown) from the FBC of BMC Moerdijk were analyzed. The samples were each dissolved in aqua regia. K, Na and Mg were analyzed using atomic absorption spectrometry, according to NEN 7436 (Manure and derivatives – determination of the potassium content in digests. Delft, the Netherlands, Nederlands Normalisatie-instituut; 1998); the P concentration was determined according to NEN 7435 (Manure and derivatives – determination of the phosphorus content in digests. Delft, the Netherlands, Nederlands Normalisatie-instituut; 1998); Ca was analyzed with ICP-MS. The chloride and sulfate content of the samples were determined spectrophotometrically according to NEN-EN-ISO 15682 (Water quality – Determination of chloride by flow analysis (CFA and FIA and photometric or potentiometric detection). Delft, the Netherlands, Nederlands Normalisatie-instituut; 2001) and NEN-ISO 22743 (Water quality – Determination of sulfates – Method by continuous flow analysis (CFA), Delft, the Netherlands, Nederlands Normalisatie-instituut; 2006), respectively. Because the analyses were mainly performed for process control reasons, chloride, sulfate and Na were not analyzed in all of the samples.

Si was not analyzed, but it can be estimated from literature and operational data. Most of the Si in the bed ash comes from the added silica sand. From the 66.3 t d^{-1} of bottom ash that is produced in the FBC of BMC, 23.3 t d^{-1} was added as silica sand bed material. As discussed by Billen et al. [8], it is not