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Research article

Evaluation of sintering behavior of ash particles from coal and rice straw using optical heating stage microscope at high temperature fouling conditions

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ABSTRACT

Ash adhesion and elimination in the gasification process is one of the main challenges in maintaining a continuous operation of the plant. The properties of ash adhesion and elimination are mainly related to particle sintering behavior. Different sintering behaviors of Shenhua coal ash (SCA) and rice straw ash (RSA) below the inherent initial deformation temperature (IDT) were observed by using optical heating stage microscope (OHSM) under CO_2 and Ar environments. The particle interaction of the RSA, the IDT of which was lower than that of SCA, was higher than that of SCA at the same temperature. Adding RSA to the SCA was an effective means of increasing particle sintering of SCA. The sintering reaction rate of ash particles highly increased at beginning of sintering stage. The effects of inorganic chemicals in the sintering process were evaluated by using scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) and typical fouling indices. The Ca and K were predominant contributors to the increase in sintering. The degree of sintering through the experiments was compared to a modified Frenkel sintering model, which accurately simulated the sintering tendency under isothermal conditions.

1. Introduction

Coal gasification is a promising clean coal technology (CCT) that can produce versatile energies such as electricity, fuel gases/liquids, and chemicals for the satisfaction of energy demands [1,2]. In particular, entrained-flow gasification process has many advantages for treating the large coal capacity, high energy conversion, and emission control [3]. Biomass has recently become more attractive to industry owing to its potential as a significant resource in the renewable energy sector [4]. Many gasification plants attempt to use biomass resources such as input fuels to produce the energy, because the biomass is recognized as a carbon-neutral resource [5]. However, co-gasification of biomass and coal might be a way due to biomass defects (e.g. high moisture, low heating value, and low density) [6,7].

Ash deposition, which is the main challenge to continuous plant operation, always occurs in the gasification process using solid fuel containing the ash [8–12]. Ash deposition critically reduces the thermal efficiency of the plant [13]. To solve this problem, a soot-blower is normally adopted in gasification plant to eliminate the deposited ash; however, it does not effectively remove all deposited ash. Elimination efficiency is related to the chemical components of ash and their physical characteristics on the deposition surface. If the ash is formed as a powdery layer on the deposit, it can be easily removed without great force. In the case of a sintered layer, however, elimination efficiency is very low, as the particles are partially melted and adhere strongly to the deposition surface. Sintering can occur at temperatures lower than the inherent melting temperature of the ash if the ash chemicals form a eutectic compound, which lowers the melting temperature [14,15]. The sintering behavior of the particles reduces the volume of deposited ash and increases the strength of particle interaction.

Research regarding sintering behavior is crucial to handling the deposition growth and elimination of the ash particles, such as that investigated by pioneer researcher Frenkel [16]. The sintering mechanism differs according to the type of solid, because it is influenced by various characteristics of the materials. In particular, many researchers in material science field have investigated the particle sintering behavior. Unfortunately, the sintering behavior of ash particles through optical heating stage microscope (OHSM) has not yet been studied in depth.

Our research group [8,17–20] investigated coal and ash particle interaction in the high temperature range by using OHSM, which is substantially useful for figuring out the interaction and reaction of micro-sized particles at high temperature gasification conditions. However, the investigation of the sintering behavior of coal and biomass ash was insufficient, and the research for their compound effects in the

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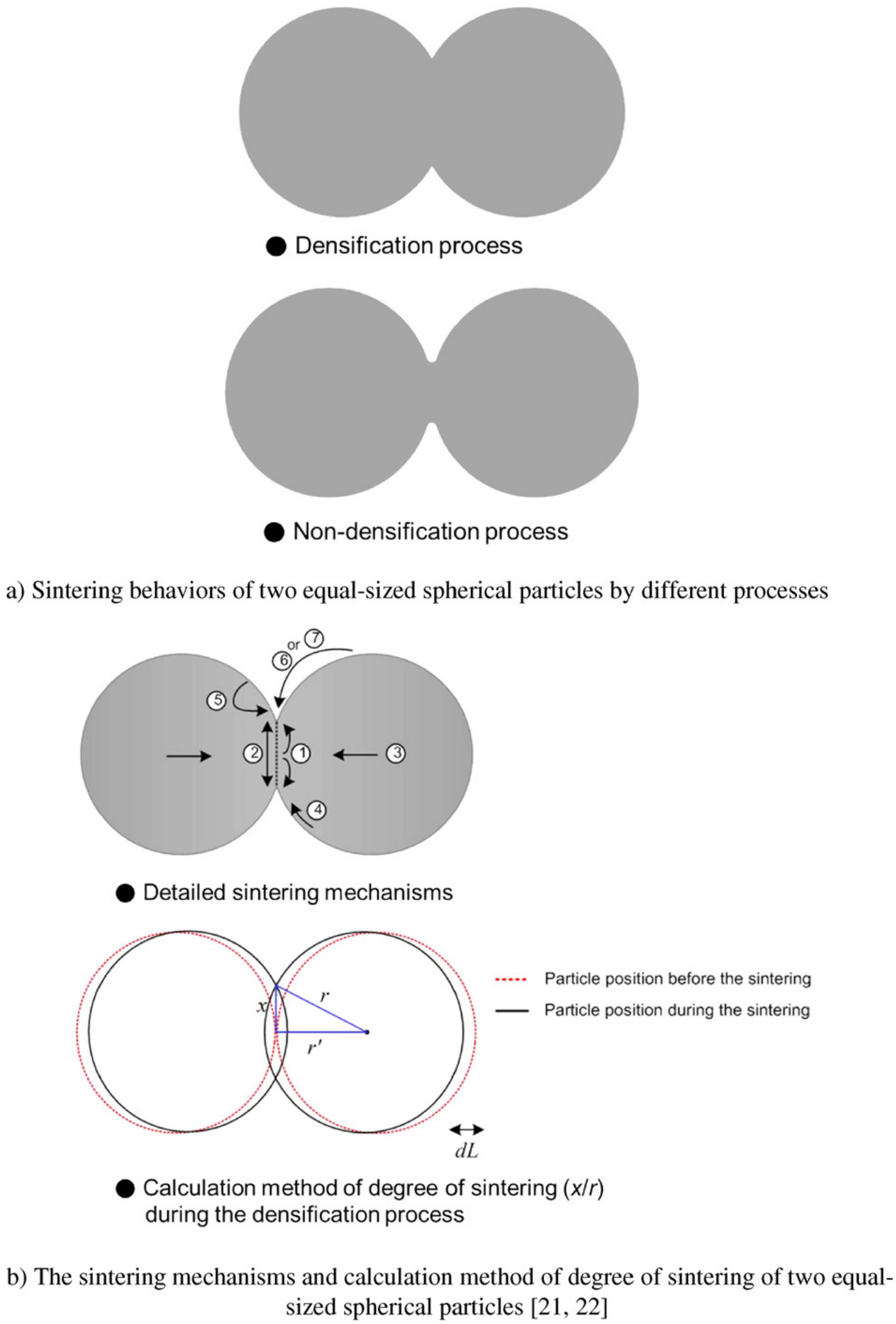

Fig. 1. Theoretical example for the particle sintering.

sintering process was not evaluated under isothermal conditions lower than the melting temperatures. The mainly considered ash chemicals of coal and biomass might differ in ash deposition phenomenon because of their different forming mineral groups. In the case of coal, excluded minerals are mainly contained within the coal. On the other hand, in the case of biomass, a minor amount of excluded minerals is contained

Table 1
Summary of sintering mechanisms [21].

Material transport mechanism	Type of solid	Source of material	Sink of material	Related parameters	Densification or non-densification
1. Lattice diffusion	Polycrystalline	Grain boundary	Neck	Lattice diffusivity, ①	Densification
2. Grain boundary diffusion	Polycrystalline	Grain boundary	Neck	Grain boundary diffusivity, ②	Densification
3. Viscous flow	Amorphous	Bulk grain	Neck	Viscosity, ③	Densification
4. Surface diffusion	Polycrystalline	Grain surface	Neck	Surface diffusivity, ④	Non-densification
5. Lattice diffusion	Polycrystalline	Grain surface	Neck	Lattice diffusivity, ⑤	Non-densification
6. Gas phase transport	Polycrystalline				
6.1 Evaporation condensation		Grain surface	Neck	Vapor pressure difference, ⑥	Non-densification
6.2 Gas diffusion		Grain surface	Neck	Gas diffusivity, ⑦	Non-densification