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Effect of bed agglomeration by mineral component with different coal types

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ABSTRACT

Bed agglomeration is a major operating problem in fluidized bed systems because the bed agglomeration phenomenon reduces the solid–gas interaction that increases the system efficiency. The bed deposit from a 3 ton/day transport reactor integrated gasifier (TRIG) system was analyzed with electron probe micro analyzer (EPMA) mapping to detect the chemical components in the bed deposit. The bed agglomeration tendency was assessed through a muffle furnace under different experimental conditions such as particle size, temperature, coal/sand mixing ratio, and fuel type. To prevent the bed agglomeration, some additives, such as kaolin and alumina, were used at different mixing ratios. Major mineral components for the formation of bed agglomeration are Fe, Ca, and Mg from EPMA. The bed agglomeration tendency increases with decreasing particle size and increasing temperature and coal/sand mixing ratio. The prevention effect of bed deposit increases with increasing input ratio of additives.

1. Introduction

The fluidized bed reactor has been used widely for thermo-chemical reactions because of its good adaptation such as fuel size, temperature control, and the usage possibility of wide range of fuel types [1]. The fluidization regime is categorized as bubbling, slugging, turbulent, circulating, and pneumatic transport forms. The transport reactor is an advanced circulating fluidization type for converting coal into the syngas because the reactor is operated at considerably higher solids circulation rates, velocities, and riser densities than a conventional circulating fluidized bed and has better mixing rates and higher mass/heat transfer rates than existing fluidization reactors [2].

Ash deposit is a major problem in the continuous operation of thermo-chemical conversion reactor such as a gasification and combustion system [3–6]. The ash deposition problem occurs on heat transfer surfaces in entrained-bed gasification systems due to fly ash. However, when ash is deposited with sand particles in a fluidized bed gasification system, it is called the bed agglomeration phenomenon. If the reaction of ash and sand particle makes the agglomerated deposit clinker, then operation of the gasification system should be shut down due to de-fluidization (suspension of heat and mass transport in the gasifier).

There are several major factors in the bed agglomeration phenomenon such as particle size, feeding mode, reaction environment (oxidation/reduction), temperature, fluidization velocity, and contents of alkaline earth and alkali mineral [7]. Geldart [8] classified the particle groups into four types, A, B, C, and D, based on their fluidization behavior and mapped the particle types by size and density. The four clearly recognizable kinds of particle behavior are explained briefly.

- Group A: aeratable, or materials having a small mean particle size and low particle density ($<\sim 1.4$ g/cm^3)
- Group B: sand-like, or most particles of size 40 μm $< d_p <$ 500 μm and density $1.4 < \rho_s < 4$ g/cm^3 (where d_p = mean particle diameter, ρ_s = density of particles)

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- •Group C: cohesive or very fine powders
- •Group D: spoutable, or large and/or dense particles

Molerus [9] provided a theoretical interpretation of Geldart's classification of particle types by taking inter-particle adhesion forces into account. The particle classification may change with bed agglomeration. Sticky particles tend to adhere to each another in a gas–solid particle interaction because of the partial melting characteristics of the particle surface. As the amount of the melted part of particle increases, the behavior of group B particles defined by Geldart's classification can shift to group C behavior (it is hard to fluidize with initial fluidization velocity). This difficulty arises due to high inter-particle forces, which are greater than the fluid can exert on the particle [8]. Finally, fluidization of bed particles disappears.

Bed agglomeration problems in fluidized beds are related mainly to a high content of alkali and alkaline earth metals in the fuel because they lower the inherent melting temperature of the fuel. Studies of the evolution of ash during gasification have generally categorized two major mechanisms in ash particle formation. 1) The small fractions of ash (less than 1%) vaporize due to the reaction temperature. 2) Many residue ash particles in the fuel are exposed to burning into char particles. Exposed ash, including the majority of the mineral matter, becomes coagulated and sintered. Sometimes they form a eutectic compound (eutectic compounds lower the inherent mineral melting temperature), composed of alkali and acid metals. The particle size in a fluidization bed increases while the ratio of partially melted particles, which have sticky forces, increases with burning char particles. However, gas–solid fluidization is complex at high temperatures, where chemical reactions and transport phenomenon occur. Inter-particle interactions should be verified to understand the mechanism.

First, deposited clinker from a 3 ton/day TRIG pilot unit was analyzed to assess important chemical components in bed agglomeration. The main chemicals in particle adhesion were determined with EPMA and SEM-EDX analysis. In this study, fixed-bed tests with an alumina crucible were carried out to compare bed agglomeration effects under different experimental conditions, such as with different particle sizes, temperatures, coal/sand mixing ratios, and amounts of additives. According to experimental results, it is assessed which experimental parameters critically affected the increase in agglomeration tendency as well as prevention effect of additives.

2. Experimental section

2.1. Samples preparation

Two different coal samples were chosen for the experiments, representing a wide range of mineral contents of sub-bituminous and lignite coal. The basic properties of the coal samples are illustrated in Table 1 as the results of proximate and ultimate analysis. The chemical compositions and fusion temperature of the coal ash are given in Table 2, in with the chemical compounds, SiO_2, Al_2O_3, Fe_2O_3, CaO, and MgO are assigned as major components of the ashes. The original coal samples and sand were dried and crushed, and then separated with different sizes such as 250–200 μm, 200–150 μm, 150–100 μm and <100 μm. All particle samples were dried in an electric oven at 60 °C for 24 h before the experiments.

2.2. Experimental facility and method

To determine important parameters in particle agglomeration and growth, agglomeration tests through a coal/sand or coal/(sand + additive) mixture were conducted in a fixed bed using an electric muffle furnace. Samples with different particle sizes and coal/sand

Table 1
Basic analysis of coal samples in the experiment.

		Sub-bituminous Russia Sakhalin	Lignite Neimenggu Hulunbuir
Proximate Analysis (air dry basis, wt %)	M	11.73	11.20
	V	42.57	33.66
	F.C	38.03	35.42
	Ash	7.67	19.72
Ultimate Analysis (dry basis, wt %)	C	70.45	56.91
	H	6.82	5.12
	O	12.15	14.56
	N	1.57	0.65
	S	0.32	0.55
	Ash	8.69	22.21
Heating Value (HHV)	kcal/kg	5750	4370

Table 2
Chemical components and fusion temperature of ash in coal samples.

		Sub-bituminous Russia Sakhalin	Lignite Neimenggu Hulunbuir
Inorganic Analysis (wt %)	SiO_2	51.62	58.91
	Al_2O_3	24.40	29.76
	Fe_2O_3	4.93	4.74
	CaO	11.53	2.37
	MgO	2.71	1.17
	Na_2O	2.74	0.60
	K_2O	1.06	1.14
	TiO_2	0.99	1.31
Ash Fusion Temp. (°C)	FT	1310	1290

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