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Characterization of mineral matter particles in gasification and combustion processes

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HIGHLIGHTS

- Method to collect particle samples from combustion and gasification processes.
- Characterization of mineral matter particles depending on process conditions.
- Information on the deposition probability of mineral matter particles.
- Information on the precipitation of volatile mineral matter species.

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ABSTRACT

Slagging and fouling mechanisms in high temperature solid fuel conversion processes are usually related to the presence of mineral components in the fuel. These mineral components can be extraneous particles or organically bound to the fuel. Both types will be released during the combustion or gasification process. The released mineral particles are diverse and can undergo certain transformation mechanisms along the flue gas path. Common fuel investigation methods rely on bulk ash analysis and other methods that do not take into account the process parameters. It is difficult to predict the deposition and also corrosion behavior of a certain fuel with these laboratory methods alone. An approach with more information about the actual particle situation and where the actual process parameters can be reproduced would be preferable.

One way to make the released mineral particles visible, depending on temperature and concentration, is the so called Particle-Wire-Mesh method. Flue gas is extracted from the process through a wire-mesh formed by twilled Dutch weave. The twilled Dutch weave serves as a filter, i.e. particles that are contained in the flue gas will deposit in the pockets or on the wires of the weave.

This weave also serves as the sample holder for SEM and EDS analyses. With these analyses the particles can be made visible in the same form as they are extracted from the process. The particles can then be characterized in terms of size, shape, and elemental composition. Size and shape give information about whether the particle has possibly been fused during the combustion process (spherical particles) or not (regularly shaped particles with sharp edges). The location where a particle is found on the wire-mesh can typically be either the wire itself or the pocket. It indicates whether the particle has a probability to stick on furnace walls and heat exchanger surfaces and form a deposit. In order to be found on the wires a particle has to have a sticky surface or impact at a surface that is sticky itself. Particles that are found in the pockets are not sticky.

The Particle-Wire-Mesh method of collecting particle samples gives the opportunity to characterize a certain fuel toward the behavior of its mineral content. The metal weave makes it possible to differentiate between single particles. Together with extracting particle samples at different locations in the process, to get the influence of different temperatures, this results in a detailed image of the different species contained in the mineral matter of the fuel.

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1. Introduction

In spite of the continuing rise of renewable energy sources, such as wind and solar power, the world still relies on solid fuels as one

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main energy source. Regardless of the fuels origin, fossil or biogenic, all solid fuels contain mineral matter that does not contribute to the energy output but is responsible for fouling and slagging phenomena. The amount of minerals contained in the fuel as well as their composition can vary widely from fuel to fuel. A higher content of minerals in the fuel potentially leads to a higher risk of slagging and fouling in the combustion or gasification facility. But the content of mineral matter in the fuel is not the only criterion contributing to slagging and fouling. Among others, fuel characteristics (e.g. fuel composition, mineral chemistry), process parameters and the design of the reactor[2] play a significant role.

Mineral matter particles[3] in a gasification or combustion process can be very diverse. Each particle can be characterized in regard to origin of the particle (fuel, oxidant, additive or previously deposited and rereleased particle), how the mineral was originally bond in the fuel, its size and shape, the state of matter, chemical composition, and how the particle was released from the fuel or formed out of the gas phase. As the mineral matter particles undergo certain transformation processes (heating and cooling, vapor release, gas phase reactions, fragmentation, heterogeneous or homogeneous condensation, crystallization, etc.) on their way through the reactor, these characteristics may change. The transformation processes can be divided into [1,2]

- *Thermal processes:* heating and cooling.
- *Phase change:* vapor release and formation of aerosols, fusion and liquefaction, homogeneous or heterogeneous condensation, solidification.
- *Chemical transformations:* oxidation, sulfation or other chemical reactions.
- *Mechanical transformations:* fragmentation, agglomeration.

The characterization of particles at different process locations with different flue gas temperatures creates an image of the process and gives information about these transformations.

Conventional fuel investigations rely on laboratory methods. Chemical fractionation, computer controlled scanning electron microscopy (CCSEM) and X-ray fluorescence spectrometry (XRF) are common methods to determine the mineral matter composition in a fuel [3,4]. However, with these methods only the elemental composition can be determined. They give no information about mineral phases. Particularly in regard to corrosion, it is important to know, in which phases and compositions (e.g. salts or silicates) certain elements (e.g. alkaline and alkaline earth metals, sulfur, halogens, lead and zinc) are existent in a gasification or combustion process and how these phases and compositions change along the reaction path. Especially salts are critical for corrosion processes.

Ash fusion temperatures can to a certain degree be used to predict the deposition behavior of a specific fuel. However, the method of determining the ash fusion temperatures is not applicable for pulverized fuel fired processes, since the heating rate of the ash samples in this method is only 10 K per minute, significantly lower than in a pulverized fuel fired reactor [5]. All of these fuel analysis methods rely on bulk ash analysis and do not take into account any process specific parameters. Therefore it is difficult to predict the deposition and also corrosion behavior of a certain fuel with these laboratory methods alone. An approach with more information about the actual particle situation and where the actual process parameters can be reproduced would be preferable.

The authors, together with CheMin GmbH from Augsburg, Germany, developed a method to collect and characterize particles from gasification and combustion processes [6,7]. This so-called Particle-Wire-Mesh method extracts particles from the flue gas, which then deposit on a metal wire mesh. Characteristics like size and shape can be determined by scanning electron microscopy (SEM) and the elemental composition can be analyzed with energy dispersive X-ray spectroscopy (EDS). The extraction and analysis of particles at different locations and flue gas temperatures creates a detailed image of the particle behavior of that specific fuel. This is a strong basis to understand the combustion or gasification behavior and to predict the deposition behavior in a certain combustion or gasification facility. Problems that are currently being investigated with the Particle-Wire-Mesh method include the impact of changes in fuel or fuel quality on existing furnaces and steam generators, the design of new steam generators for a specific fuel and the impact of combustion optimization, especially NO_x reduction mechanisms, on the behavior of mineral matter.

2. The Particle-Wire-Mesh method

The Particle-Wire-Mesh method is a method to collect and characterize particle samples at specific locations in the reactor or flue gas duct of a combustion or gasification process. The setup consists of a cylindrical, un-cooled probe and a pressurized air ejector to provide the depression for the extraction flow. The probe has a radial opening which is covered by a metal wire mesh. Flue gas is extracted through the probe, while particles that are contained in the flue gas deposit on the wire mesh. In order to get a single particle layer deposit on the wire mesh, the extraction time is set to 1–5 s, depending on the amount of particles in the flue gas. The short extraction time is necessary to be able to differentiate between single particles in order to characterize them properly. A long extraction time would result in many particles depositing on top of one another, which would make the differentiation between single particles very difficult.

The wire mesh used to collect the particle samples is a metal filter (austenitic steel 1.4301) constructed as a twilled Dutch weave with a wire diameter of 20 μm. Four wires form a pocket, as can be seen in Fig. 1. The ideal understanding is that the particles would follow the flue gas flow and accumulate in the pockets. Experiments show however, that the particles not only accumulate in the pockets but also deposit on top of the wires. To be able to adhere to the wire a particle has to impact at a location where the wire has a sticky surface or have a sticky surface itself. A sticky particle surface can be the result of melting or fusion processes, a sticky wire surface can be the result of condensation of mineral vapors out of the gas phase. Also particles can impact at a location on the wire where particles with sticky surfaces have previously impacted.

Transport of mineral matter to, and deposition of mineral matter particles at a surface mainly result from impaction and interception, thermophoreses or diffusion mechanisms [3,5,8]. The wire mesh is preheated to flue gas temperature prior to extracting the flue gas. Therefore thermophoreses as a deposition mechanism can be neglected.

Fig. 2 shows a basic model of the different ways a particle can deposit on the wire mesh, divided in deposition in the pocket and deposition on the wire.

Deposition in the pocket:

(a) Particles that can follow the flue gas flow at a change of direction (i.e. fine and very fine particles).
(b) Particles that do not need to change direction on their way into the pocket.

[2] Reactor refers to either the furnace (in a combustion process) or the gasifier (in a gasification process).

[3] Mineral matter particle in the context of the method presented in this paper refers to solid and liquid particles.

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