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Research paper

Effect of ash circulation on the performance of a dual fluidized bed gasification system

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ABSTRACT

During gasification of biomass, ash forming elements are released from the fuel and some of these elements can have a positive impact on the quality of the gas produced. In a dual fluidized bed (DFB) gasifier, a significant amount of these components are found in the fly ash from the gasification and combustion reactors. In order to increase carbon conversion and bed material recovery, these streams are generally circulated back to the combustor for the raw gas fly ash and in some cases to the gasifier for the flue gas fly ash. The impact on the gasification performance has, however, not been investigated. Circulation of flue gas coarse ash was carried out in the Chalmers gasifier, with the aim of assessing the impact on gas quality, in particular in term of tar yields, and how it relates to the flow and properties of ash streams. The coarse ash was first enhanced by an injection of untreated olivine in a fine particle size and was then recirculated, yielding a direct decrease in tar concentration. This effect persisted after the recirculation and the bed activity was seen to increase with time, at a higher rate than a reference aging experiment. Both the internal bed material cycle and the external fly ash loop were found to get enriched in ash components, which was linked to the activity gains observed. These results show the potential of continuous fly ash recirculation as an activity enhancer in industrial dual fluidized bed gasification systems.

1. Introduction

Gasification of biomass is an attractive route towards a reduction of fossil fuel utilization for energy production [1]. As a potentially carbon dioxide neutral energy source, it contributes to a more sustainable society. The raw gas produced by the gasification process can be used for power production or as a precursor to synthetic fuel such as synthetic natural gas (BioSNG) or Fischer-Tropsch diesel [2]. This gas is mainly composed of H_2, CO, CO_2, CH_4, light hydrocarbons and heavy hydrocarbons commonly referred to as “tar”.

Indirect gasification is a technology whereby fuel combustion and gasification occur in two separated reactors. The enthalpy needed by the gasification reaction can be provided by a circulating bed material. This bed receives heat from the combustion of the unconverted char from the gasifier and product gases if the process conditions require it.

The main issue facing gasification is the presence of tar in the product gas. The definition of “tar” describes in general a range of organic compounds, which are produced under partial thermochemical conversion of carbonaceous material and are considered to be mainly aromatics compounds. Tar is known to condense already at 350 °C and can cause fouling of equipment downstream of the gasifier. Tar content can be decreased at high gasification temperature. However, this temperature is limited by the melting behavior of ash components from the fuel and the bed material, as well as the products of their interactions.

In order to alter the raw gas composition and decrease the tar content, a catalytic bed can be used. Such catalysts, used directly with the biomass in the gasifier-boiler system are called primary catalysts [3], as opposed to secondary catalysts used in a reactor downstream of the gasifier [4]. The choice of a catalyst will depend on a number of parameters, among which its market price, the type of catalytic activity, its mechanical properties, and the means and cost of its disposal.

Olivine, a magnesium iron silicate of general formula $(Mg, Fe)_2SiO_4$, is an attractive natural ore for use as an active bed material for biomass gasification and is actively used in existing pilot and demonstration plants, such as GoBiGas in Göteborg, Sweden and Senden, Germany both originating from the design of the Güssing gasification plant in Austria. The catalytic activity of olivine has been extensively investigated [5–8]. Beyond the consideration of olivine as a primary catalyst, it is suitable as a bed material due to its availability, low cost and mechanical properties. The interaction of olivine with fuel ash has been seen to impact gas quality [5,9] and can be considered as an activation process of the olivine particles with respect to catalytic activity [5].

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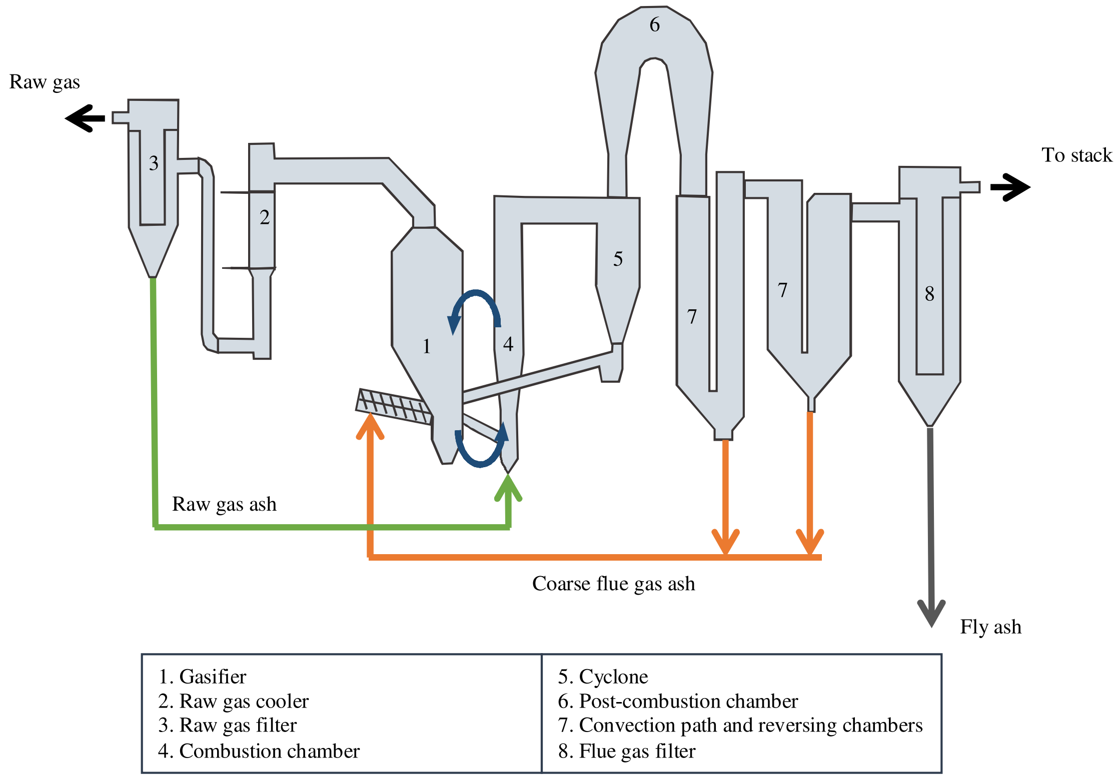

Fig. 1. Schematic of the DFBG of GoBiGas. The orange arrows represent the recirculation of coarse flue gas ash and the green arrow the recirculation of raw gas ash. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

The ash components aforementioned originate from the fuel and include mainly Ca, Si, Al, Ti, Fe, Mg, Na, K, S and P [10]. These inorganic species are released during the conversion of the fuel and are found in the fly ash exiting the combustor and the gasifier. Attrition and entrainment of the bed material also occurs and, although the coarser fraction of these entrained particles is recirculated to the gasifier *via* a cyclone, the finer fraction is carried through the convection path, where the gas is cooled. The flue gas fly ash is then collected by a number of separation devices such as a cyclone.

Gasification fly ash is relatively rich in unconverted carbon and, as such, is less attractive than combustion fly ash for agricultural use. So far, there are almost no possibilities to use it in building products [10–12]. In the GoBiGas dual fluidized bed gasification (DFBG) plant, the carbon content issue is addressed by reintroducing raw gas fly ash into the combustor, with the aim of improving carbon conversion and thereby efficiency. Flue gas fly ash is similarly reintroduced to the gasifier to recover bed material, thus decreasing the need for make-up feeding.

The layout of the GoBiGas DFB gasifier is shown in Fig. 1 and the material flows are described in the following paragraph:

The main material cycle is the continuous circulation of bed material between the gasifier (1) and the combustion chamber (4), represented here by the blue arrows. The raw gas ash is mixed with a precoat, in this case limestone, before reaching the product gas filter (3) where it is separated from the gas and introduced to the combustor (green arrow). The flue gas ash is collected from the bottom of the flow reversal spaces in the convection path (7) and from the flue gas filter (8). Only the coarse flue gas ash from the flow reversal spaces is reintroduced to the gasifier, thanks to a pneumatic sender working intermittently, and through the bed material screw feeder. This corresponds to the orange arrows in the figure. The two cycles are henceforth referred to as internal and external loop (or circulation), for the bed material circulation and the raw gas and flue gas ash circulation respectively.

Kirnbauer et al. [13] investigated the impact of the continuous reintroduction of ash components, in particular alkali, on undesired operational issues such as slagging, fouling and bed agglomeration. However, positive aspects beyond recovery of carbon and bed material has yet to be extensively investigated.

Kuba et al. [14] recently carried out an optimization of the inorganic flows in the DFB gasifier of HGA Senden. In this facility, logging residues are used as fuel, and contain significant amounts of foreign mineral matter, mainly quartz, which has a negative influence on the operation of the power plant. The optimization consisted in collecting the bottom ash from the combustor, separating the large foreign particles from the layered, active olivine particles *via* sieving, and collecting the latter fraction in a silo. These layered particles were then returned to the DFB loop, replacing part of the make-up fresh olivine, while the coarse flue gas ash was discharged instead of being fed back to the DFB (as is normally the case), due to its high content of foreign mineral matter. The authors reported a decrease in tar concentration, mainly affecting naphthalene and acenaphtylene, a decrease in methane concentration and an increase in hydrogen.

In order to further explore the impact of inorganic loops in a DFB system, a recirculation of flue gas coarse ash has been carried out in the Chalmers DFBG system. It should be noted that the Chalmers gasifier is a research facility, which is not equipped with raw gas cleaning and upgrading equipment. Instead, the raw gas is burnt in the combustor. As a result, the raw gas ash loop is permanently integrated in the design of the Chalmers gasifier. Despite this difference, previous research on ash chemistry and bed material activation has shown to transfer accurately to full scale DFB gasification [15]. Consequently, this work served as a simulation of the external loop of an industrial DFBG plant. To assess the impact on the process performances; the gas composition, tar content and mineral composition of the bed and flue gas coarse ash were monitored. The present work expands on preliminary results presented in Ref. [16], and offers an insight on the relation between the observed gas quality variation and the particles flow and their properties. The