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Behaviour of tars on the filter in high temperature filtration of biomass-based gasification gas

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HIGHLIGHTS

- The amount of tars is reduced in high temperature filtration at 800 °C.
- This is due to thermal and catalytic tar reactions on the filter.
- Tar reduction on the filter could improve the operability of downstream units.

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ABSTRACT

Behaviour of tars in high temperature filtration was studied at atmospheric pressure in steam and air/steam gasification conditions. Wood pellets and bark pellets were used as feedstock and silica sand and dolomite (Myanit B) as bed materials. Experiments were carried out in a bench-scale bubbling fluidised-bed gasifier coupled with a hot gas filter unit. Interestingly, it was found that filter could act, in a sense, as a prereformer when it was operated at 800 °C. The total amount of tars in the gas was reduced on the filter in all tests regardless of the used feedstock, bed material or gasifying agent. Highest reduction, in the order of 50 wt% of total tars, was obtained in steam gasification tests when dolomite was used as bed material. It was concluded that the changes in tars are derived from thermal tar reactions due to long residence time at high temperature on the filter but also from catalytic reactions induced by the presence of unreacted biomass char and carry-over dolomite on the filter surface. Tar reduction on the high temperature filter could be beneficial for downstream units and improve their operability, especially the reformer where the lower tar level could reduce coking tendency on the catalyst.

1. Introduction

Biomass gasification converts biomass into combustible gas that can be used for power and heat production but also upgraded to other valuable products, such as FT liquids, SNG, hydrogen or chemicals. Hot gas filtration is one of the key unit operations in gasification-based concepts. Hot gas filters are used for removing solid particulates from the gas but also for capturing alkali and heavy metals. Alkali metal concentrations can be reduced close to acceptable limits e.g. for gas turbine applications (to around 0.1 ppm-wt) if the gas is cooled down and filtered below 500 °C – the exact temperature of course depending on the gasification conditions and the used feedstock [1]. Hot gas filtration of biomass-based gasification gas is typically performed in the temperature range of 350–500 °C while recent research and development in this field has been focused on increasing the filtration temperature closer to the temperature in the gasifier outlet, in the range of 800–850 °C. This would increase the overall efficiency of the gasification plant and reduce the cost of the final product as the extra cooling and heating steps upstream and downstream the filter, as illustrated in Fig. 1, could be avoided. The potential improvement for a 300 MW (fuel input) pressurised steam/O_2-blown gasification-based BTL plant producing FT liquids from forest residue has been estimated at around 5%-points increase in the overall efficiency and 5% reduction in the production cost of FT liquid if filtration temperature is increased from 550 to 850 °C [2].

Ceramic and fabric filters have been successfully operated in biomass-based demonstration-scale and commercial gasification

Abbreviations: BTL, biomass-to-liquid; CHP, combined heat and power; FID, flame ionization detector; FT, Fischer–Tropsch; GC, gas chromatograph; IGCC, integrated gasification combined cycle; PAH, polyaromatic hydrocarbon; SNG, synthetic natural gas; SPA, solid phase absorption; STP, standard temperature and pressure (273.15 K and 1 bar); TC, thermal conductivity.

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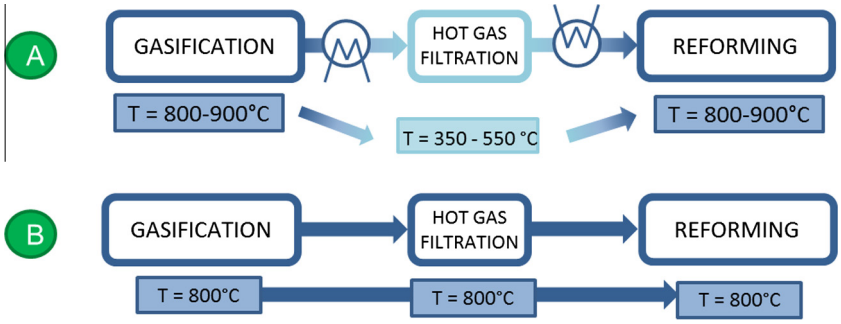

Fig. 1. Block diagram of a typical gasification process with hot gas filter operating at 550 °C (above) and at 800 °C (below).

plants, such as in the biomass IGCC demonstration plant in Värnamo [3] and the 8 MW_{fuel} CHP plant in Güssing [4] where the filtration temperatures were 340–370 °C and 160–180 °C, respectively. Reaching filtration temperatures above 500–550 °C has, however, shown to be challenging. Blinding of filter elements has been reported at temperatures above 600 °C. Kurkela et al. [5,6] observed rapid blinding of the ceramic filter elements during pressurised air-blown fluidised-bed gasification of sawdust with sand as bed material when the filter was operated at 690–715 °C. Stable filter operation was obtained by lowering the filter temperature to 400–550 °C. Based on their experiments, Kurkela et al. [5,6] suggested that filter blinding was caused by the formation of soot and high-molecular-weight polyaromatic tars on the filter resulting in a sticky cake that was difficult to be fully removed by traditional pulse cleaning. On the other hand, Simeone et al. [7] found that stable filter operation can be achieved even at 800 °C if the bed material and feedstock combination is carefully selected. Simeone et al. [7] investigated the performance of rigid ceramic filter candles at 600–800 °C with different bed material (sand, olivine and magnesite) and feedstock (clean wood, recycled demolition wood, straw and miscanthus) combinations during atmospheric pressure, steam/oxygen-blown fluidised-bed gasification. For instance, when magnesite was used as bed material and the filter temperature was around 800 °C, filter operation was stable with clean wood as feedstock but with miscanthus the filter was blinded.

As already proposed by Kurkela et al. [5,6], tars influence filter performance at elevated temperature but the mechanism is not yet well-known. Over the years, much research effort has been put to investigating tar formation in the gasifier and the effect of different gasification conditions on tar content in the gas since tars are typically the core issue in biomass gasification processes causing clogging in downstream units and end-use applications. However, tar behaviour in filtration conditions at high temperature is a less studied area. Based on literature survey, only Simeone et al. [7] have reported results on the effect of high temperature filter on tars while other studies related to this subject have been carried out with catalytically activated filters [8–13] and are therefore not relevant for this work. Simeone et al. [7] discovered during their experiments at filtration temperature of 800 °C that tars were affected by the long residence time and high temperature on the filter. In steam/oxygen-blown gasification tests with magnesite as bed material, the concentration of PAH compounds heavier than pyrene decreased while the concentration of naphthalene and PAH compounds up to pyrene increased. In tests with olivine as bed material, naphthalene was also formed on the filter but the results concerning PAH compounds were not all in agreement. Tars were measured using the SPA method.

Deeper understanding of the behaviour of tars in high temperature filtration is required to explain filter performance at elevated temperatures. The objective of this work was to study the behaviour of tars in filtration temperature of 800 °C during steam and air/steam gasification of woody biomass at atmospheric pressure. Bench-scale tests were carried out with crushed wood pellets and bark pellets as feedstock and sand or dolomite (Myanit B) as bed material. Changes in tar concentration and composition across the filter were examined by comparing tar samples measured in parallel before and after the filter unit. Based on the results, different factors contributing to the observed changes are discussed. The relation between tar behaviour and filter blinding will not be addressed as this subject will be covered in a separate paper.

2. Experimental

2.1. Test rig

Gasification experiments were carried out in a bench-scale, atmospheric pressure bubbling fluidised-bed gasifier (AFB60) coupled with a hot gas filter unit and a gas residence time tube/reformer (Fig. 2). The test rig is designed for air, air/steam and steam-blown gasification testing and it has a maximum fuel feeding capacity of around 1.5 kg/h. The bubbling fluidised-bed gasifier (bed i.d. 63 mm, freeboard i.d. 102 mm) is equipped with electrically heated ovens which compensate thermal losses and supply the heat for the endothermic gasification reactions in steam-blown gasification mode. Gasifying/fluidising agents (steam, air and/or nitrogen) are introduced from the bottom of the reactor through a multiorifice plate distributor. All gas and water feeds are mass flow controlled and the feed gases are preheated before entering the reactor. In steam-blown gasification experiments, superheated steam is produced in a two-stage steam generator. Stability of the steam flow is monitored by measuring the pressure difference across the orifice plate installed in the steam line. In air/steam-blown gasification experiments where the amount of steam is markedly smaller (20 vol-% of fluidising gases in this study), steam is generated by injecting the water directly to the preheated air stream where it vaporizes and the air/steam mixture is passed through a second heat exchanger for superheating the steam. There is also an option for secondary and tertiary air injection to the freeboard located 650 and 950 mm from the plate distributor, respectively. Gasifier temperature is continuously measured from three heights in the bed (50, 145 and 270 mm from the plate distributor) and from two heights in the freeboard (800 and 1100 from the plate distributor). Gasifier pressure is measured from the freeboard and pressure differences, respectively, across the plate distributor, the freeboard and the whole reactor. A small purge nitrogen flow (appr. 7 vol-% of the total feed gas flow) is used to flush the temperature/pressure difference measurement lines in the gasifier bed to prevent the transport of bed material in the lines. Bed material is introduced as a batch through the top of the reactor at the beginning of each experiment.