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Fluidized bed gasification of biomass– In bed investigation of gas and tar formation

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HIGHLIGHTS

- Axial tar and gas profiles are measured in fluidized bed and freeboard.
- Most tar compounds are released at the beginning of the freeboard.
- Inside the fluidized bed heterocyclic tar compounds are hardly measured.

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ABSTRACT

Allothermal steam gasification in fluidized bed reactors is a promising way to convert biomass into a high quality product gas. Due to its low nitrogen content the gas can be used in a variety of processes. Besides the direct production of heat and power in, e.g. internal combustion engines (ICE), the product gas can be converted to clean synthesis gas and second generation biofuels. A major problem in all downstream applications is the high tar content in the product gas. The tar, a mixture of mostly aromatic hydrocarbons, has to be removed prior to downstream processes to avoid blocking of equipment by condensed material. Besides the operational parameters, the gas quality depends on the reactor design.

This study investigates the axial formation of tar and main gas components in an allothermal steam-blown bubbling fluidized bed gasifier. Therefore an axial movable sampling probe is used to withdraw gas samples at different heights directly from within the fluidized bed as well as from the freeboard.

The gasification agent H_2O decreases rapidly over the bed height. The reason is the release of volatile compounds from the injected biomass and formation of dry gas components inside the bed. The main dry gas components CH_4, CO, CO_2 and H_2 increase continuously over the bed height and reach a maximum at the bed surface.

The tar concentration of product gas withdrawn from inside the bed is comparably low. No oxygen containing species but only light aromatic and light polyaromatic compounds are measurable in this region. The main fraction of tar is released in the transition zone between fluidized bed and freeboard due to partially degassed fuel particles that float on the surface.

1. Introduction

Environmental problems and the growing shortage of fossil fuels make it necessary to use alternative energy sources. Wind and solar power currently have the highest growth rate in Europe but have the disadvantage of being intermittent [1]. In contrast to these fluctuating sources, biomass can deliver power on demand. Furthermore, the production of hydrogen, synthetic natural gas (SNG), liquid biofuels or basic chemicals like dimethyl ether is possible using biomass [2,3]. For the latter utilization paths, the gasification of biomass is the first process step and the production of a nitrogen free product gas is beneficial. To produce such a high quality product gas, allothermal steam gasification in fluidized beds seems to be a promising way [4,5].

One of the major problems in product gas utilization is the production of condensable hydrocarbons, known as tar, during gasification. A detailed description of tar formation during gasification has been made by Milne and Evans and can be found in [6]. Milne and Evans describe the following evolution of tar: When biomass is heated up to pyrolysis conditions, primary tar compounds like levoglucosan, glycolaldehyde and furfural are formed as fragments of the biomass compounds cellulose hemicellulose and lignin. These compounds break up at further temperature increase and form the secondary compounds phenolics and olefins. Both,

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primary and secondary tar compounds contain oxygen and are therefore reactive and relatively easy to destroy. A further increase in temperature leads to the formation of tertiary tar compounds, aromatic ring systems that are formed out of the fragments of primary and secondary tar compounds. These tertiary products are very stable and can have a very high dew point.

Tar is a problem whenever the gas temperature cools below the tar dew point, since fouling and blocking of equipment will occur [7]. Therefore prior to further gas use (e.g. in an internal combustion engine ICE), the tar content has to be reduced drastically by primary or secondary measures [8]. At this time no fluidized bed gasifier can directly reach the limits for use in an ICE. Secondary gas cleaning and conditioning steps are indispensable and can be facilitated by a low initial tar content.

A first step in improving fluidized bed systems is to understand what happens in the reactors. Most investigations on fluidized bed gasification report about experimental data measured downstream of the gasification reactor and conclusions on the events inside the reactor are difficult. Nevertheless, some experimental facilities are equipped with several sampling points distributed along the axis of the gasification reactor. The main studies on this topic were carried out by the following researchers.

Padban and Bramer [9] use an air-blown bubbling fluidized bed reactor with a fuel input of 1 kg/h. They measure the tar composition at two heights in the freeboard after a residence time of 0.5 s and 1.3 s. The tar measurement is performed using the solid phase adsorption (SPA) method [10] and the tar species are sorted into the five class system proposed by the Energy research center of the Netherlands (ECN) [9]. The authors monitor a decreasing content of class 2 components with increasing residence time in the freeboard and an increasing content of class 3 components. Since the fuel is introduced on one side of the bed in their facility, the gas profile is not axisymmetric and different effects interfere. The results for class 4 and class 5 components cannot be interpreted.

Kiel and Van Paasen [9,11] use an air-blown bubbling fluidized bed gasifier with a fuel input of 1 kg/h. They measure the tar composition by SPA after different residence times in the freeboard (1.2–5.4 s). With increasing residence time in the freeboard, the class 2 components are reduced significantly and the class 3 components decrease moderately. The polyaromatic compounds of class 4 and class 5 tar components are increasing with increasing residence time. The number of unknown tar species is reduced significantly with increasing residence time in the freeboard.

Ross et al. [12] use a steam/air-blown bubbling fluidized bed gasifier with a fuel input of 20 kg/h. Their facility allows product gas to be sampled from the freeboard and also directly from the fluidized bed. The authors do not measure tar directly but use the concentration of gaseous C_2 and C_3 components as a tar indicator. These components increase inside the fluidized bed and have a maximum in the freeboard.

The motivation of this study is to investigate the processes inside the fluidized bed of an allothermal steam blown gasifier. The focus is on the axial tar- and gas profile and the location of the release of the tar species.

2. Materials and methods

2.1. Experimental facility and measurement equipment

The experimental facility used in this work is described elsewhere in detail [13]. Fig. 1 shows a simplified flow sheet. The gasifier is an allothermal bubbling fluidized bed reactor that uses steam as a gasification medium. The steam flow is controlled by a control valve and a coriolis mass flow meter type Rheonik (RMH 04 GET 2). The gasifier is heated electrically and the heat

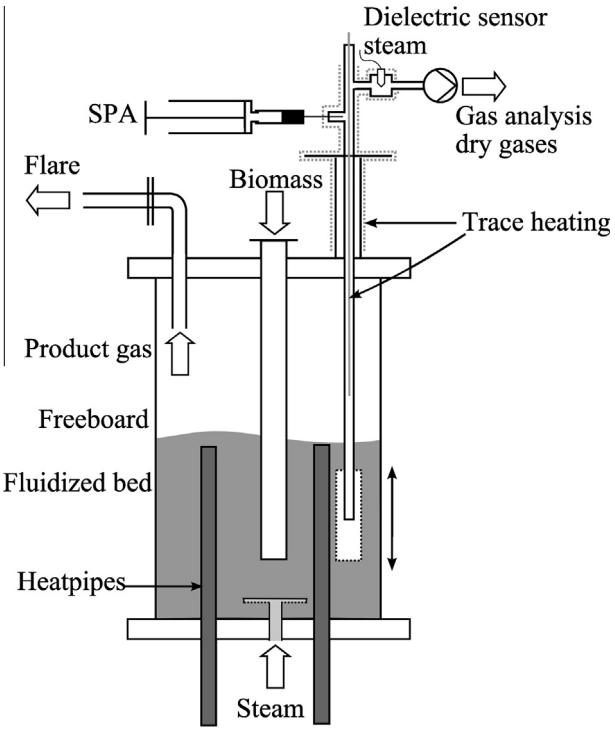

Fig. 1. Simplified flow sheet of reactor with sampling probe.

is transported via four high temperature heat pipes, which use sodium as a working fluid, into the fluidized bed. The axial temperature profile is measured with 15 thermocouples equally spaced along the axis inside the reactor vessel. The dimensions of the reactor are 154 mm of internal diameter and a length of 1500 mm. The heat pipes have a diameter of 20 mm and a length of 660 mm inside the fluidized bed. The biomass particles enter the reactor via a drop tube that ends 200 mm above the bottom. A screw conveyor is used to transport the biomass particles into the drop tube. The drop tube is flushed with a small amount of nitrogen (120 Nl/h) to prevent product gas from entering the fuel feeding system.

The flow dynamics are influenced by the heat pipes and the drop tube to some extent and lead to the formation of a slug flow (see [14]). Under slug flow conditions the rising velocity of a bubble is influenced by the walls. Slug flows occur often in non-industrial-scale bubbling fluidized bed facilities due to the relatively small diameters and this fact has to be taken into account for scale up.

The product gas exits the reactor and is cleaned in a cyclone and a ceramic candle filter. The main fraction of the product gas is burnt in a flare. A sampling probe is used to withdraw product gas directly from the gasifier for analysis of main gas components and the tar composition. This sampling probe consists of a sinter metal filter and a high temperature resistant stainless steel tube with an internal diameter of 4 mm. The sampling probe is connected to the gas measurement equipment and the product gas is removed using a diaphragm pump. Any axial position can be reached within the gasification reactor to remove gas, while the sampling probe is sealed and hold in position by a gland seal.

The main dry gas components CH_4, CO, CO_2 and H_2 are analyzed with an IR gas analyzer (type S700, Sick Maihak). The total H_2O content is measured in the slip stream of the sampling probe using a dielectric sensor (type EE31-D, E+E Elektronik). A psychrometer for steam measurement (type Hygrophil-H, Bartec) is installed in the main gas line after the gasifier. The comparison between the steam value at the highest location in the freeboard and the steam