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Influence of pressure, temperature and steam on tar and gas in allothermal fluidized bed gasification

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ABSTRACT

Gasification is considered to be a promising way to use biomass with high efficiency in combined heat and power production, for the production of second generation biofuels and in the chemical industry. Especially allothermal fluidized bed steam gasification produces a medium calorific, nitrogen free gas suitable for a variety of downstream processes. In general the raw product gas has to be cleaned from condensable hydrocarbons (tar) and conditioned (e.g. adjustment of the H_2/CO-ratio) before downstream use. The operating conditions of the gasification reactor have a large impact on the quality of the product gas. Hence first steps to a product gas low in tar content can be undertaken directly in the reactor. In this study the capability of influencing the tar content and gas composition by changing temperature (750–840 °C), steam to biomass (S/B) ratio (0.8–1.2) and pressure (0.1–0.25 MPa) in an allothermal bubbling fluidized bed steam gasifier is investigated. It is found that rising temperature reduces the total tar content and affects especially heterocyclic and light aromatic compounds. At atmospheric pressure the naphthalene content increases slightly with increasing temperature in contrary to pressurized gasification where naphthalene decreases significantly with increasing temperature. An increase in the S/B ratio leads to a decreasing total tar content, this tar reduction according to a higher steam content is higher at higher temperatures. Increasing pressure leads to increasing total tar content mainly due to naphthalene, the effect is most distinct for low S/B ratios.

1. Introduction

The growing shortage of fossil fuels as well as increasing environmental problems make it necessary to use alternative, renewable energy sources. The renewable sources currently used in Europe are hydro-, wind-, solar-, geothermal power, and biomass [1]. Hydro power has the greatest share followed by wind and solid biomass. The growth rate is the highest in solar and wind power, hence in the future a major part of renewable energy will be produced from these non-predictable sources. Compared to wind- and solar power, biomass has the advantage to be storable and power can be produced on demand. Furthermore, through gasification biomass can be transformed into a secondary energy carrier which creates various possibilities for further use. The product gas can be utilized for power production in combined heat and power (CHP) plants, for the production of biofuels through Fischer Tropsch synthesis, for synthetic natural gas (SNG) production or the production of basic chemicals like dimethyl ether [2]. To produce a medium calorific product gas, allothermal steam gasification in fluidized beds seems to be a promising way [3,4]. A serious problem that has to be faced in all these processes is the formation of condensable hydrocarbons (tar) in the gasification reactor. When the temperature is falling below the tar dew point, i.e. the partial pressure of tar compounds exceed the saturation pressure, these tar compounds can condense and lead to blocking or fouling of pipes or other equipment downstream the gasifier. Removal of the tar using scrubbers has the disadvantage that the heating value of the tar is lost in the product gas, leading to a lower cold gas efficiency. Thermochemical conversion (such as reforming or cracking of tar components) can be enhanced by application of catalysts either directly in the fluidized bed (e.g. iron containing minerals like olivine [5]) or downstream of the gasification reactor (e.g. nickel based catalysts) [6]. Also the operational parameters of the gasifier itself have a great influence on the tar content and composition.

The motivation of this study is to investigate the extent to which the gas quality (tar and gas) can be influenced by comparably small changes in the operating conditions, to facilitate further

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gas cleaning and conditioning steps. The study was carried out in the frame of the EU FP7 project GreenSyngas. Results of measurements within the GreenSyngas project carried out in a circulating fluidized bed gasifier at TU Delft are reported in [7]. Preliminary results of this study have been presented at the 19th European Biomass Conference and Exhibition [8].

2. Materials and methods

2.1. Experimental facility

Experimental study was performed in a bubbling fluidized bed (BFB) gasifier, Fig. 1 shows the flow sheet of the experimental facility.

The reactor vessel is made of high temperature resistant steel (german material number 1.4841, AISI SS 310), has an internal diameter of 154 mm and a length of 1500 mm. The reactor can be operated up to 850 °C and pressurized up to 0.5 MPa. The biomass is fed through a pressurized screw-conveyor into a drop shaft directly to the bottom of the BFB. A small amount of nitrogen is used to flush the biomass feeding system to avoid product gas or steam entering the screw-conveyor. This has to be prevented by all means since steam swells up the wood pellets in the drop shaft which leads quickly to blocking of the feeding system. The bed has a height of approximately 700 mm and is fluidized with steam, which is used as gasification medium. The heat required for the endothermic gasification reactions is provided by electrical heating and transferred into the bed via four high temperature heat pipes which use sodium as a working fluid. The heat pipes have a diameter of 20 mm and a length of 660 mm inside the fluidized bed.

The heat pipes influence the flow dynamics to some extent and lead to the formation of a slug flow (see e.g. [9] chapter 2) throughout the whole height of the fluidized bed. In comparison, a reactor without the heat pipes (but the same geometry) would form a slug flow after ≈120 mm from the bottom of the bed. Under slug flow conditions the rising velocity of a bubble is influenced by the walls. Slug flows occur often in non-industrial scale BFB facilities due to the relatively small diameters and this fact has to taken into account for scale up.

The product gas exits the reactor and is cleaned in a cyclone and a ceramic candle filter. After the filter, the gas is expanded in the pressure control valve to atmospheric pressure. At this point, tar samples can be taken while a slip stream of the gas is analyzed online for its main components (H_2, CO, CO_2, CH_4) using an IR gas analyzer (type S700, Sick Maihak). To prevent tar condensation before the sample point all piping, the cyclone and the filter are heated up to approximately 330 °C. From the top of the reactor vessel 15 thermocouples are placed equidistantly along the axis to monitor the temperature profile. The thermocouples are therefore bundled in a closed small steel tube that is introduced through the top flange of the reactor and sealed with a compression fitting.

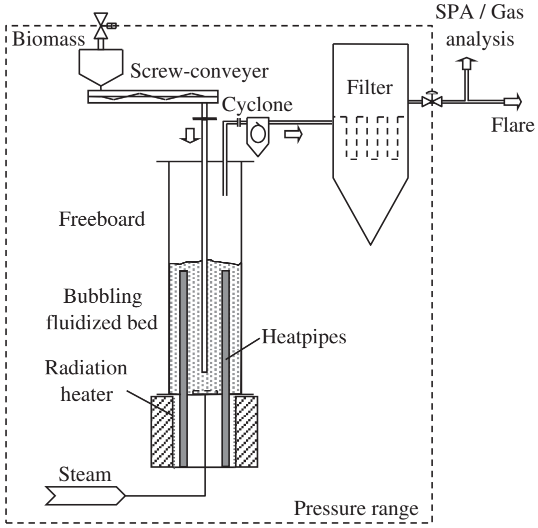

Fig. 1. Flow sheet of the BFB gasifier.

2.2. Measurement procedure

The bed was heated up to the requested temperature and fluidized with steam while the biomass feeding rate was set to achieve the requested S/B ratio (definition see Section 3.2). After reaching a stable gas composition (after 20–30 min) two tar samples, using the solid phase adsorption (SPA) method, were taken. Therefore 100 ml of product gas was drawn with a syringe over an amino phase column. The samples were sent to KTH, Sweden, Dept. of Chemical Engineering and Technology for tar content analysis by means of gas chromatography (GC). The term total tar, used in this work, refers therefore to GC-detectable tar compounds. A detailed description of the SPA sampling and analysis method can be found in [10]. The results of the analysis are given by KTH as μg_{tar}/sample. With the assumption that the steam in the gas is condensed in the amino phase and does not enter the syringe in vapor form, this value was converted into g/m^3 at standard conditions (atmospheric pressure and 0 °C).

Thirteen different operating points of the gasifier have been tested and the influence on the tar and gas composition has been observed. The operating conditions are summarized in Table 3. For atmospheric pressure three temperatures and in each case three S/B ratios have been tested. For a pressure of 0.25 MPa two temperatures and in each case two S/B ratios have been tested. The SPA method is a commonly applied method to analyze the tar content of compounds larger than benzene [11] up to coronene [10]. Due to the time during shipment to KTH, toluene was lost from the samples which has to be taken into account when evaluating the results.

2.3. Biomass and bed material

Wood pellets with 8 mm diameter were used as biomass feedstock (provided by the company Lantmannen (Sweden). Proximate and ultimate analysis (Vario Macro CHNS analyzer) are given in Table 1. The pellets are commercially available under the trading name Agrol and are a blend of 80% spruce and 20% pine.

As bed material olivine was used, the analysis was performed with wavelength dispersive X-ray fluorescence (WDXRF) analysis (Panalytic) and is given in Table 2. The average particle size is 0.25 mm with a range from 0.1 mm to 0.3 mm. With the approach presented in [9] chapter 2 the minimum fluidization velocity is $v_{mf} = 0.034$ m/s. In the experiments around 15 kg of olivine where contained in the reactor. Besides olivine around 1.2 kg to 1.4 kg of char were present in the reactor.

Table 1
Main characteristics of feedstock.

Water content	4.84	wt.%
Ash	0.12	wt.% db
Volatiles	85.58	wt.% db
Fixed C	14.30	wt.% db
Low heating value	20.6	MJ/kg db
C	49.84	wt.% db
H	6.74	wt.% db
N	0.10	wt.% db
S	0.08	wt.% db
O	43.12	wt.% (100 − $\sum$)

db = dry base.