



Full Length Article

Experimental investigation of biomass devolatilization in steam gasification in a dual fluidised bed gasifier



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HIGHLIGHTS

- Woody biomass of radiata pine has been tested on a 100 kW DFB gasifier.
- Intermediate products from initial devolatilization were examined.
- Final products from biomass steam gasification were examined.
- Relationships between devolatilization and gasification were established.
- Effects of reaction temperature on gas yield and composition were determined.

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ABSTRACT

In this study, biomass devolatilization, which is the initial stage of steam gasification, was experimentally investigated in a 100 kW dual fluidised bed gasifier. In the experiments, pellets of radiata pine sawdust were used as the feedstock, and silica sand was used as the bed material. The operating temperature in the gasifier was varied from 700 to 800 °C and N₂ was used as the fluidisation agent. Once the devolatilization test was completed, corresponding gasification experiment was conducted at the same operation condition but N₂ was switched to steam as gasification and fluidisation agent.

From the experimental results, it is found that, in the devolatilization stage, gas yield was increased, and tar yield and concentration were decreased with increase in operation temperature. In this study, significant correlation was observed for gas yield and gas composition between the devolatilization stage and the gasification stage. Correlations on tar concentrations and yield were also clear for gases produced from the devolatilization and gases from the subsequent gasification. This study provides fundamental information for understanding and optimization of the biomass steam gasification.

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1. Introduction

Biomass as a sustainable source is expected to play an important role in future liquid fuel supply to substitute fossil fuels. Gasification is a promising process which converts carbonaceous feedstock to a combustible gas, termed as producer gas [1–4]. The producer gas, which consists of H₂, CO, CO₂, CH₄ and other hydrocarbons, can be used for production of heat and electricity or for synthesis of liquid fuel through Fischer-Tropsch process [5]. The yield and composition of producer gas from biomass gasification vary widely depending on the process conditions (temperature, residence time and gasification agent). When steam is introduced as a gasification agent in biomass gasification, hydro-

gen yield and content in the producer gas are promoted and biomass conversion efficiency is increased [6,7]. This is due to the fact that no nitrogen is present in the producer gas and homogeneous water-gas shift reaction is possible in early stage of the gasification process. In order to understand the mechanism of steam gasification and produce clean producer gas, a 100 kW_{th} dual fluidised bed (DFB) steam gasifier, as shown Fig. 1, has been constructed and extensive experiments have been conducted [8–12].

The DFB steam gasifier has two columns, a bubbling fluidised bed (BFB) column and a fast fluidised bed (FFB) column. Biomass gasification occurs in the BFB column where the feedstock is fed to the bed and the steam as gasification agent is injected from the column bottom. Based on a review of Xu et al. [13], this type of DFB gasification system has advantages of high gasification efficiency and low tar content in the producer gas in comparison with other DFB systems. At the base of BFB column, solid char generated from the gasification process and the bed material flow out, by

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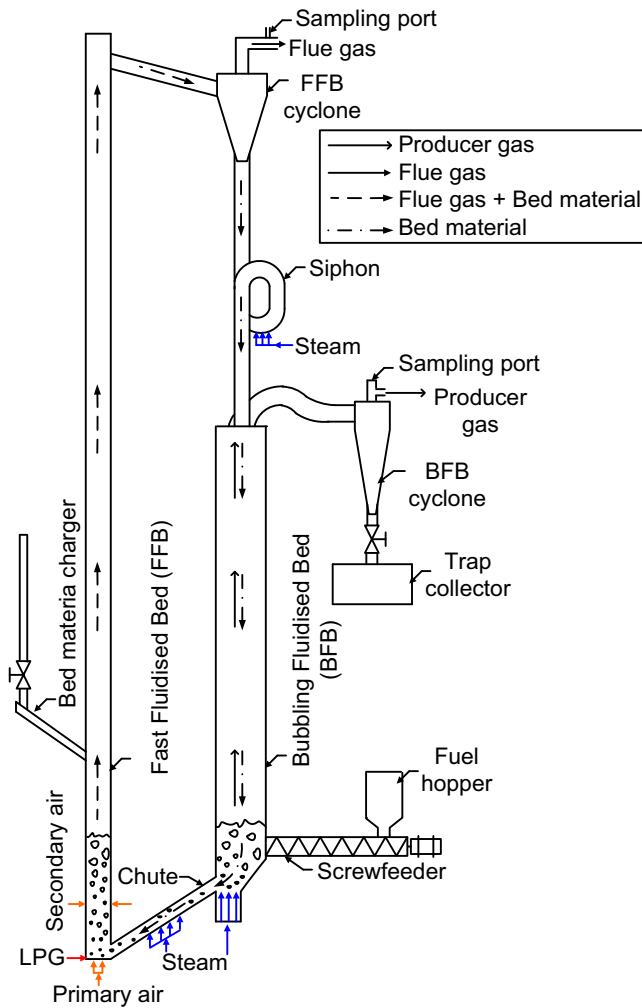
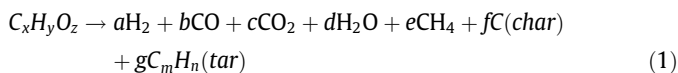


Fig. 1. Schematic diagram of dual fluidised bed steam gasifier [8,11].

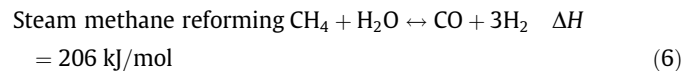
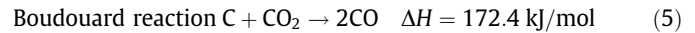
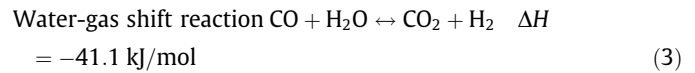
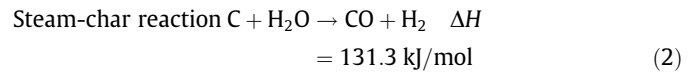
gravity, to the FFB column where the char is combusted and the bed material is heated [8,12]. Then the hot bed material flows up carried by the flue gas into a cyclone where the bed material is separated and flows into the BFB column through a siphon to provide heat for the endothermic gasification process. The producer gas flows out from the BFB top.

The steam gasification process can be divided into two stages after a short period of biomass drying: (1) biomass devolatilization; (2) gasification process [14]. Before the biomass devolatilization, biomass is dried and moisture is removed when the temperature reaches 200–300 °C [15]. However, the biomass for gasification is commonly pre-dried to a moisture content of 15–20% [16], therefore, the drying in the gasification process is very short. With further increase in the temperature to 300–500 °C, biomass devolatilization occurs, and the biomass is decomposed into gases, char and tar [17] as shown in Eq. (1).



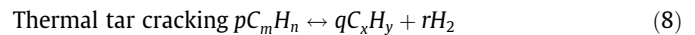
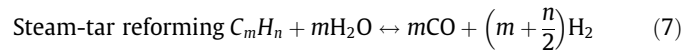
Previous studies have examined characteristics and changes of biomass structure in stand-alone fast pyrolysis in which decomposition behaviour of each biomass component (cellulose, hemicellulose and lignin) were investigated under various operation conditions [18–20]. It has been reported that in the gasification

process, homogeneous reaction (among gases and steam) and heterogeneous reactions (among char and gases as well as steam) occur simultaneously which can be described in Eqs. (2–8) [21].



By examining the above reactions, it is found that in Eqs. (2), (3) and (6), steam is involved as a reactant; therefore, steam supply as a gasification agent is important. It is also observed that the gasous products from the initial devolatilization act as the reactants in reactions described by Eqs. (2–6) whereas char is a reactant in reactions (2), (4) and (5). Therefore, the product yields and gas composition from the initial devolatilization have significant impacts on the yield and composition of the final producer gas from the gasification process although the steam-char reaction (Eq. (2)) is believed to be dominant in the subsequent gasification process [22–27].

The steam input and gasification operation conditions also have impacts on tar formation and cracking as described in the following reactions [28,29].



where C_mH_n represents tar which can be a mixture of several high molecular weight compounds in the tars and C_xH_y represents hydrocarbons with less carbon number than C_mH_n .

By knowing the correlation between yield and composition of the product gas from the initial devolatilization and those of the final producer gas from the gasification process, the gasification operations (such as temperature, bed material and steam/biomass ratio) can be optimised. Therefore, results from this study can be used in process design and operation optimisation for biomass steam gasification.

In past two decades, extensive research has been reported on biomass gasification with a focus on producer gas properties and operation optimization. A number of studies investigated the influence of operating conditions on the final producer gas yield and composition [30–40]. However, the mechanism of devolatilization during the gasification process is still not fully understood. No report has been found in the literature on the relationships between initial devolatilization and subsequent gasification during biomass steam gasification in a dual fluidized bed gasifier.

Meanwhile, mathematical models on steam gasification of biomass in the DFB gasifier have been developed to predict the final producer gas composition [41–44]. However, the resulting intermediate products from the initial devolatilization in a pilot-scale reactor were not available in the literature. The modelling studies [37,39,44–46] used experiment results from stand-alone, bench scale fast pyrolysis reactors which are different from the BFB reactor in terms of operation temperature and the way of char separation.

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