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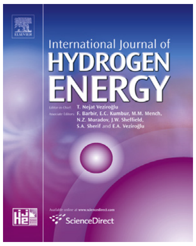

Impact of using calcium oxide as a bed material on hydrogen production in two-stage fluidized bed gasification

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ABSTRACT

This paper describes the effect of equivalence ratio and steam/biomass ratio on the gas production of a two-stage fluidized bed gasifier. The calcium oxide was employed as bed material in the second stage to evaluate the influence of gasification efficiency. The result shows the H_2 molar percentage increased by approximately 2–3 mol% at the end of the second stage fluidized bed reactor without adding CaO. The second stage fluidized bed gasifier plays an important role of cracking and reforming of tar which generated from the first stage one. On the other hand, when the calcium oxide was used as the bed material in the second stage, it enhanced the generation of H_2 under most parameters. Highest H_2 molar percentage in syngas was observed as 37 mol% at ER and S/B ratio is 0.3 and 2, respectively. Generally, more H_2 generation through second stage gasifier was found than that in first stage by 6.1–12.8%.

Introduction

Gasification is a process where a partial oxidation reaction occurs in the degradation of biomass converted into reusable gases with medium and low heating values, such as carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) [1], which can be used after purification. Recently, many studies regarding to gasification focused on the fluidized bed gasifier [2–4], because it has the advantages of good gas-fuel mixing and heat transfer efficiency, uniform temperature, ease of continuous operation, and many types of feed materials that can be processed [5,6]. However, several operating parameters may impact the gasification efficiency of a fluidized bed gasifier such as bed material, operating temperature, different types of biomass, particle size of biomass, feed velocity, equivalence ratio (ER), and steam/biomass ratio (S/B). Those key factors mainly influence the gas yield, gas composition, carbon conversion efficiency and energy efficiency of a fluidized bed gasifier [7–11].

For several gasification researches, the ER and S/B ratios are important parameters. ER refers to the actual air fuel ratio divided by the stoichiometric air fuel ratio. Lv et al. [12] investigated the impact of adjusting ERs during the

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gasification process on the composition of generated gases. When ER was raised from 0.19 to 0.27, proportion of CO_2 showed an increasing trend in the gas production, but slightly decreased in CO and H_2. Ran and Li [13] also pointed that ER value affected the syngas composition and total gas yield. When he tested the ER from 0.2 to 0.35 during gasification, the ER was 0.2 that had highest proportion of H_2 in the syngas. Research of fluidized bed gasification conducted by Li et al. [14] adjusted ER between 0.31 and 0.47, and they found that the contents of H_2 and CO decreased when the ER was increased. This was because more oxygen entered the gasifier when the ER was raised, improving the carbon conversion efficiency and hence the yield of CO_2, but the yields of CO and H_2 decreased. Aznar et al. [15] illustrated that the gas heating value, total gas yield, amount of char and tar decreased with ER increased, when the ER value was controlled between 0.3 and 0.46. Additionally, Chiang et al. [16] also reported that an increase in ER would reduce the total gas yield, and the proportions of CO and H_2 in the gas production decreased as CO_2 increased. Accordingly, the suitable range of ER value was suggested in the range from 0.2 to 0.4 during gasification [7].

On the other hand, an important parameter to gasification is S/B ratio which defined as the ratio of steam to biomass in the gasifier. Kumar et al. [8] conducted the gasification experiment with S/B = 0, 7.3 and 14.29 as the experimental conditions, and the result indicated that the yield of H_2 increased when the S/B increased. He et al. [17] also noted that, after increasing S/B from 0.39 to 1.04, the proportion of H_2 in the synthesis gas (syngas) increased from 27.5% to 53.22%. Loha et al. [18] reported that production of H_2, CO_2 and CH_4 increased with S/B ratio increasing when the gasification temperature was constant at 750 °C, but the amount of CO decreased with S/B ratio increasing. Song et al. [19] illustrated that the tar content in the gas reduced as increasing S/B ratio from 0.8 to 1.4 and Mayerhofer et al. [20] also had the same results when the S/B ratio was increased from 0.83 to 1.2. An increase in S/B could increase H_2 yield because raising S/B could increase hydrogen in the gasification reactions, and more H_2 was produced. However, the S/B must be controlled within a range to avoid too much moisture absorbs heat energy in the gasifier, that decreases the temperature and suppresses the gasification reactions [21].

In addition to the above-mentioned operating parameters, the use of additives may also impact the gasification efficiency. For example, Chiang et al. [22] added 10% CaO in the biomass, and the result indicated that the proportion of CO_2 in the gas yield was 7.5% less than that without adding CaO. The reason was that CaO could absorb CO_2 in the gasification process. Kobayashi et al. [23] also noted that the use of CaO in the gasification process could absorb CO_2 in the gasification process. According to the research results of Acharya et al. [24], with the addition of CaO (CaO/biomass = 2) during gasification, the proportion of H_2 in the gas yield increased by 54.43% and the proportion of CO_2 decreased by 93%. The primary reason was the same as that proposed by Udomsirichakorn et al. [25] in their research on the circulating fluidized bed gasifier: CaO absorbed CO_2, which decreased the proportion of CO_2 in the gas yield and further stimulated the generation of more H_2 from the water gas shift reaction. The reaction formulae were given as follows:

$$CaO + CO_2 \rightarrow CaCO_3 \tag{1}$$

The gasification studies in recent years attached importance to the improvement of gasification efficiency. Soni et al. [26] compared two fixed-bed gasifiers with one-stage gasification to discuss the gasification efficiency after gasification. The results showed that two-stage gasification could more effectively raise the hydrogen yield (from 7.3% to 22.3%) and the total gas yield (from 30.8% to 54.6%), and it decreased tar production from 18.6% to 14.2%. Park et al. [27] also conducted the two-stage gasification experiment by using two fixed-bed reactors, and they revealed that the tars generated in the first stage gasifier could undergo the cracking reaction in the second stage gasifier. Tar cracking would produce H_2, CO and other gases. The tar yield of the fixed bed gasifier was more, but the gas yield was less than that from the fluidized bed. In recent years, related work reported that, when a fluidized bed was used for the first stage and a gasifier operation was used for the second stage gasification, and after adding dolomite and activated carbon as additives in the second stage gasifier, the total gas yield was between 66.6 and 75.1% and the tar production was less than 1% [28].

It was found that the two-stage gasification could effectively enhance the gasification efficiency and decrease the generation of tar, but the current second-stage gasification studies mostly used the fixed bed gasifier as the second stage gasifier [26,29]. If the fluidized bed gasifier was utilized as the second stage gasifier for the second-stage gasification experiment, the gasification efficiency may be improved, the tar yield in the gasification process may be decreased, and the gas production may increase. However, few studies are available at present that have investigated this process. Thus, this research will discuss the impacts of different operating conditions (ER and S/B) on the gasification efficiency of the two-stage fluidized bed gasifier, and it compares the impact on the gasification efficiency when the calcium oxide is used as an additive in the second stage gasifier.

Experimental

This research utilized the laboratory-scale two stage fluidized bed gasifier, whose structure is detailed in Fig. 1. The gasifier is made of the stainless steel (AISI-310), with the thickness of 0.49 cm, the height of 50 cm, the outer diameter of 4.27 cm and the inner diameter of 3.29 cm. The first stage uses the same gasifier as the second stage. The connecting tube of two gasifiers is made of stainless steel with the thickness of 0.42 cm. A stainless steel distributor plate is installed at the bottom of each gasifier and its opening area is 15.2%. The electric heating system is used for heating the gasifier. The outer layer of the gasifier is enclosed by thermal insulation fiber to prevent heat loss. Three thermocouples are mounted to monitor and record the temperature changes in the gasifier. The feed inlet is made by the double valve design, so as to prevent gas escape or entering of external air from affecting the experimental results while the materials are feed into the gasifier.

The artificial simulated wastes were used in the experiments, mainly composed of polypropylene (PP) plastic particles, wood chips and plant capsules. The basic element