Parametric Study on the Heating Values of Product gas via Steam Gasification of Palm Waste using CaO as Sorbent Material

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Abstract. The abundance of oil palm waste in Malaysia is a good candidate to be used as a feedstock for syngas and hydrogen production. Biomass steam gasification is one of the promising methods for syngas production. This work focuses on the steam gasification with in-situ CO_2 capture using CaO as absorbent materials for hydrogen production from palm oil empty fruit bunch (EFB). Three parameters (temperature, steam/biomass ratio and sorbent/biomass ratio) has been studied on the lower heating value (LHV) and higher heating value (HHV) of the gas produce. The results show that the current study gives higher value of LHV at lower temperature of 823 K. The higher value of LHV is obtained due to the lower concentration of CO_2 caused by using CaO as sorbent material. Furthermore, CaO materials enhanced the concentration of concentration of the CO, H_2 and CH_4 in the gas product.

Introduction

Due to the energy crisis and environmental issues mainly evoked by the use of fossil fuels as primary energy source, syngas and hydrogen (H_2) has the potential to become a significant form of energy in the future as it is relatively cleaner than fossil fuels. Several alternatives and renewable sources are under considerable interest to be used for production of syngas and H_2, including biomass. The usage of biomass for syngas production is an attractive approach to be explored in Malaysia due to its abundance. Being the world largest producer of palm oil [1], the availability of empty fruit bunch (EFB) provides excellent feedstock for syngas and H_2 production [1]. Syngas can be produced via a few methods: thermochemical processes (i.e. pyrolysis and gasification) or biological processes (i.e. biophotolysis and fermentation) [2]. Between the two thermochemical methods, Balat [3] reported that syngas and H_2 production via gasification process is more economical than pyrolysis due to lower production cost. For gasification, the conversion of biomass into gaseous product can be enhanced by processing at high temperature and using gasifying agent such as air, pure steam, air-steam or oxygen-steam mixtures. Reported literature studies showed that when pure steam is used as the gasification agent, higher H_2 content in the gas product can be obtained economically [4, 5]. Furthermore, the purity of H_2 in a steam gasification process can be increased when it is coupled with CO_2 adsorption material. Several performance indicators have been identified in the literature to study the gasification process for syngas and H_2 production (gasification efficiency, thermodynamic efficiency, lower heating value, higher heating value, carbon conversion efficiency etc). Many researchers have identified that lower heating value (LHV) and higher heating value (HHV) are very important performance indicators to investigate the effect of parameters on the gas product from biomass gasification using different biomass as feed stock [6-12].

The performance of biomass gasification process is affected by at least five factors, namely, temperature, steam/biomass ratio, pressure, space time and bed composition. In the gasification process coupled with CO_2 adsorption material, the sorbent/biomass ratio also has been identified as a factor affecting the gasification performance. In this work, a modeling approach is used to investigate the effects of these operation conditions on the performance indicators of the gasification process especially on the lower and higher heating values (LHV and HHV) of gas product.

Experimental Approach

In this study, the biomass considered for H_2 production via the steam gasification process is oil palm empty fruit bunch (EFB). The molecular formula for EFB is $C_{3.4}H_{4.1}O_{3.3}$ (based on 1 kg of biomass) with the molecular weight of 97.7 kg/kg mole [13]. Several assumption have been considered for the modeling approach: CaO is present in the system at a constant mass ratio with respect to EFB fed, the reactions proceed isothermally and occur at constant pressure, i.e. 1 atm, the tar and ash formations in this process are negligible and the operating temperature range taken below the 1043 K, at which beyond this temperature, the calcination reaction favored [14].

The flowsheet development, modelling and simulation have been presented by authors in the earlier work [15, 16]. The pervious study focuses on the mathematical modeling of the simplified process design for hydrogen production from palm waste using MATLAB. The flowsheet includes steam generation, gasification and gas cleaning units. The flowsheet model was incorporated with the mass and energy balances. The developed model is used as a platform to investigate the effects of process parameters: temperature, steam/biomass ratio and sorbent/biomass ratio on the hydrogen production and efficiency using MATLAB [15]. The effectiveness of the biomass gasification process is evaluated in terms of heating values of the gas product i.e. lower heating value (LHV) and higher heating value (HHV). LHV (MJ/Nm^3) and HHV (MJ/Nm^3) of the gas product are calculated using the Eq.1 and 2, respectively.

$$LHV = (30 \times CO + 25.7 \times H_2 + 85.4 \times CH_4) \times 0.0042 \quad (1)$$

$$HHV = (H_2 \times 30.52 + CO \times 30.18 + CH_4 \times 95) \times 4.1868 \quad (2)$$

where H_2, CO and CH_4 are the mole percentage of those components in the gas product.

Results and Discussion

The effect of temperature on the LHV and HHV is profiled in Fig. 1. It is observed that by increasing the temperature within the range of 823-1023 K, both LHV and HHV decrease. The heating values of the gas product are highly dependent on the CH_4, CO and H_2 contents [17-19]. With increasing temperature, the H_2 and CO_2 amounts increase whereas the amount of CH_4 and CO contents decrease leading to the decreasing of LHV and HHV of the gas product due to the water gas shift and methane reforming reactions.

Similar trends of LHV and HHV changes with increasing temperature have been reported by other researchers in their work on catalytic steam gasification [10, 20] and steam gasification with CO_2 capture [9, 11, 21]. The effect of steam/biomass ratio on LHV and HHV is shown in the Fig. 1. It is observed that both LHV and HHV slightly decreased when increasing the steam/biomass ratio. The value of LHV and HHV changes due to the variation in the gas composition of the gas product. By increasing the steam/biomass ratio H_2 increases while CH_4 and CO amounts decreases as reported in the previous work [15, 16]. Excess of steam not only makes the water gas shift reaction faster but also moves forward to char gasification and methane reforming reaction, which produced more gases along with H_2. Therefore, LHV and HHV decrease when increasing steam/biomass ratio but the effect is less significant compared to when increasing the temperature (Fig. 1). Similar trends of LHV and HHV have been reported by other researchers in their work investigating the effect of increasing steam/biomass ratio for catalytic steam gasification of biomass [9, 10, 20] and steam gasification [4, 5, 22]. In addition, the effect of sorbent/biomass ratio on LHV and HHV is plotted in Fig. 2. It is observed that when increasing sorbent/biomass ratio, both LHV and HHV increase. LHV and HHV depend on the composition of H_2, CO and CH_4 in the gas product as mentioned before, LHV and HHV increase when increasing the sorbent/biomass ratio due to increase of H_2, CO and CH_4 amounts in the gas product. Similar trends for increase of HHV and LHV by using CaO material is observed by Xu *at el*. [23] and Mahishi *et al*. [24], respectively. Table 1 shows the comparison of LHV between the current study and those reported by other works on biomass gasification for hydrogen production.

It is observed that the current study gives higher value of LHV at lower temperature (823 K) compared to others due to the CaO using as sorbent material.

Conclusion

Current study presented the steam gasification with in-situ CO_2 capture using CaO as absorbent materials for hydrogen production from palm oil empty fruit bunch (EFB). Three parameters (temperature, steam/biomass ratio and sorbent/biomass ratio) has been investigated on the lower heating value (LHV) and higher heating value (HHV) of gas product. The results showed that the current study gives higher value of LHV at lower temperature of 823 K. The higher value of LHV is obtained due to the lower concentration of CO_2 caused by using CaO as sorbent material. Furthermore, CaO materials enhanced the concentration of concentration of the CO, H_2 and CH_4 in the gas product.

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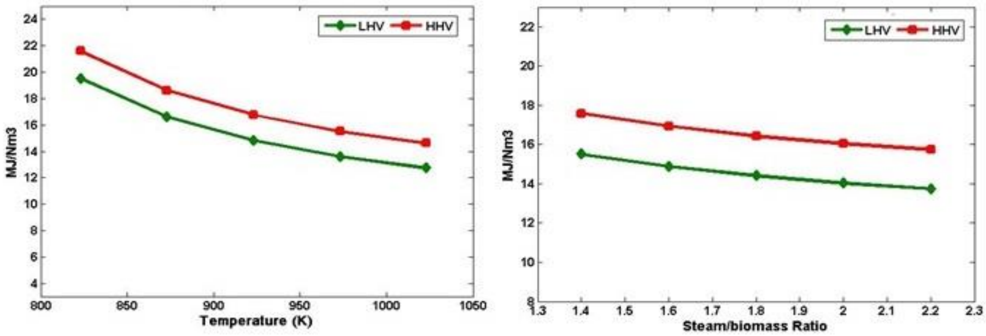

(a) (b)

Fig. 1: (a) Effect of temperature on lower heating value and higher heating value of gas product. (Steam/biomass ratio=1.8, Sorbent/biomass ratio=0.9); (b) Effect of steam/biomass ratio on lower heating value and higher heating value of gas product. (T=973 K, Sorbent/biomass ratio=1.0).

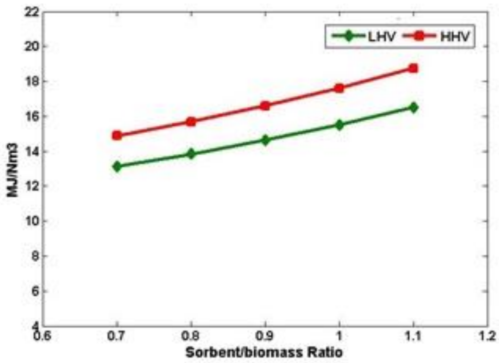

Fig. 2: Effect of sorbent/biomass ratio on lower heating value and higher heating value of gas product. (T=973 K, Steam/biomass ratio=1.4).

Table 1: Comparison of for LHV based on biomass gasification.

Gasification Process	Biomass	T (K)	LHV MJ/Nm^3	Reference
Air	EFB	1123	12.84	[25]
Steam-Catalyst	Municipal Solid Waste	973	14.44	[7]
Steam-Catalyst	Pine Sawdust	1123	12.67	[8]
Steam-Catalyst	Oil Palm Waste	1023	11.26	[10]
Steam-CaO	Larch	1023	15.48	[12]
Steam-CaO-Catalyst	EFB	823	20.20	Current Study