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Study of the effects of operating factors on the resulting producer gas of oil palm fronds gasification with a single throat downdraft gasifier

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ABSTRACT

Malaysia has abundant but underutilized oil palm fronds. Although the gasification of biomass using preheated inlet air as a gasifying medium is considered an efficient and environmentally friendly method, previous studies were limited to certain types of biomass wastes and gasifier designs. Hence, the effects of preheating the gasifying air on oil palm fronds gasification in a single throat downdraft gasifier are presented in this paper. In addition, the effects of varying the flow rate of the gasifying air and the moisture content of the feedstock on the outputs of oil palm fronds gasification were studied. A response surface methodology was used for the design of the experiment and the analysis of the results. The results showed that preheating the gasifying air to 500 °C increased the concentrations of CO from 22.49 to 24.98%, that of CH_4 from 1.98 to 2.87%, and that of H_2 from 9.67 to 13.58% on dry basis in the producer gas at a 10% feedstock moisture content. Conversely, the dry basis concentrations of CO, CH_4, and H_2 decreased from 22.49, 1.98 and 9.67% to 12.01, 1.44 and 5.45%, respectively, as the moisture content increased from 10 to 20%. The airflow rate was also proven to significantly affect the quality of the resulting producer gas.

1. Introduction

Malaysia is the world's second largest producer and exporter of palm oil. The palm oil sector generates a very large amount of waste from its plantations and milling activities compared to other types of biomass. In the year 2009, the total amount generated from plantation and milling activities was estimated to be 195.8 million tons on a wet basis [1,2]. The oil palm waste generated constituted 82.21% of the total energy that could be obtained from biomass waste in the country. The oil palm fronds (OPF) are generated from pruning and re-plantation activities at the plantation. The OPF generated from pruning and re-plantation contributed to 46.71% of the total palm oil waste, which was equivalent to 97 million tons per year, or an energy content of 9.68×10^6 toe [3].

In the 1999 revised fuel diversification policy of the Malaysian Government, renewable energy was considered one of the five alternative energy sources (oil, coal, natural gas, hydro, and renewable energy) with 5% target share of the total energy supply by 2010, although the achieved target did not exceed 1% in the same year [4]. Increasing the renewable energy share (biomass, solar, biogas, solid waste, and mini-hydro) to 5.5% by 2015 has been a continual target of the government [5,6]. In the diversification plan, oil palm wastes are considered one of the major options to achieve this goal [4]. Although efforts have been made to use fronds to produce pulp and animal roughage, most fronds are abandoned at plantations without significant applications [1,3]. Thus, the unutilized OPF present a great opportunity for power generation through appropriate technologies which will consequently help to achieve the national plan for energy diversification.

Recently, the gasification of biomass waste using preheated air has received significant attention because of the improvement gained in the quality of producer gas and the reduction of tar as compared to a conventional gasification process. Studies showed that the amount of H_2 increased when a high gasifying air temperature was maintained, although the CO and CH_4 concentration exhibited different trends depending on the feedstock used. Endothermic reactions which were responsible for the production of hydrogen were favored when the gasifying air temperature increased. In addition, as a result of heavy hydrocarbons breakdown into lighter gases, lesser amount of tar was obtained in the producer gas when the gasifying air temperature increased [7–11]. On the other hand, a high moisture content in the biomass has

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adverse impacts on the quality of the producer gas by draining the part of the deliverable energy that vaporizes the moisture. In addition, a high moisture content reduces the reaction temperature, which in turn hinders the efficiency and stability of the process and the quality of the producer gas [12]. The feedstock consumption rate also decreases as the moisture content increases due to the decreased rate of the reactions [13]. A high moisture content in the biomass causes a high CO_2 output due to enhancement of the water–shift reaction by consuming CO and liberating H_2. The amount of air required for the process of gasification is usually expressed as an equivalence ratio, which is the ratio of the air flow rate in the gasification process to that of stoichiometric air. The optimal equivalence ratio depends on the type of gasifier and feedstock used for the process [13,14].

This research aimed to investigate the producer gas results obtained from the gasification process of oil palm fronds in a throated downdraft gasifier using preheated air as a gasifying medium. Because biomass feedstocks have a wide range of properties, the study of the performance of a particular biomass as a feedstock material in the gasification process is essential to the evaluation of the technical and economical viabilities of the biomass [15]. The gasification of biomass using preheated inlet air as a gasifying medium is considered an efficient and environmentally friendly method. However, previous studies that used preheated air as a gasifying medium were limited to few types of biomass wastes and gasifier designs. Hence, the complete spectrum of benefits that can be obtained from the gasification process of different feedstocks and gasifier designs is not well understood. In particular, as oil palm fronds are abundantly available in Malaysia, the gasification of oil palm fronds using preheated air as a gasifying medium has only been examined in a preliminary work by the authors of this study [16]. The few studies that had been previously conducted on oil palm fronds gasification focused only on conventional methods in which unheated ambient air was used as a gasifying medium [17–19]. In this paper, the effects of varying the air flow rate and moisture content of the feedstock on the quality of the producer gas are presented in addition to the study of the effects of the gasifying air inlet temperature.

2. Methodology

2.1. Feedstock preparation

OPF was used as a feedstock for the gasification experiment. After collecting the fronds in the plantation, the leaves were shredded using a machete, and the petioles were chopped using a chopper to a maximum length of 25 mm as shown in Fig. 1. Open air and oven-dried feedstock were used for the experiments. An oven at 105 °C was used to dry the feedstock in order to meet the moisture content requirement (below 15%, wet basis). The results of proximate and ultimate analyses and higher heating value (HHV) of OPF are shown in Table 1.

Table 1
Proximate and ultimate analyses of OPF.

Proximate analysis (% db)	
Volatile matter	83.5
Fixed carbon	15.2
Ash	1.3
Ultimate analysis (% db)	
Carbon	44.58
Hydrogen	4.53
Oxygen	48.80
Nitrogen	0.71
Sulfur	0.07
Higher heating value (HHV)	17 MJ/kg

db: dry basis.

2.2. Design of experiments

In the current study, a response surface methodology (RSM) with a Box–Behnken design (BBD) was used for the design of experiment. Three input factors, namely, the flow rate of gasifying air, the temperature of the gasifying air, and the feedstock moisture content were identified for the study. The biomass type, gasifier type, gasification medium, etc., were determined during the gasifier design stage. The upper and lower limits of the input factors were determined based on the information obtained from the preliminary experimental results and from the technical limiting conditions of the experiment.

The range of the gasifying air flow rate was determined from the preliminary experimental study of its effect on the nature of the flare observed at the flare point. When using unheated gasifying air, a flare was observed when the volume flow rate exceeded 200 L/min. The flare strength and stability showed increasing trends as the airflow rate increased to 400 L/min. The flare became unstable when the air flow rate exceeded 500 L/min. Therefore, the maximum and minimum air flow rates were determined to be 500 L/min and 300 L/min, respectively. The maximum and minimum gasifying air temperatures were set at 500 °C and 30 °C, respectively based on the heating capacity of the electric air heater and the average ambient air temperature. Slight increments in hydrogen concentration are reported by few literature as the temperature increased above 500 °C [8,9]. However, the increment in the desirable gases may not be significant as compared to the cost incurred by increasing the air temperature to above 500 °C.

The maximum and minimum moisture contents were determined to be 20% and 10% on a wet basis, respectively. In downdraft

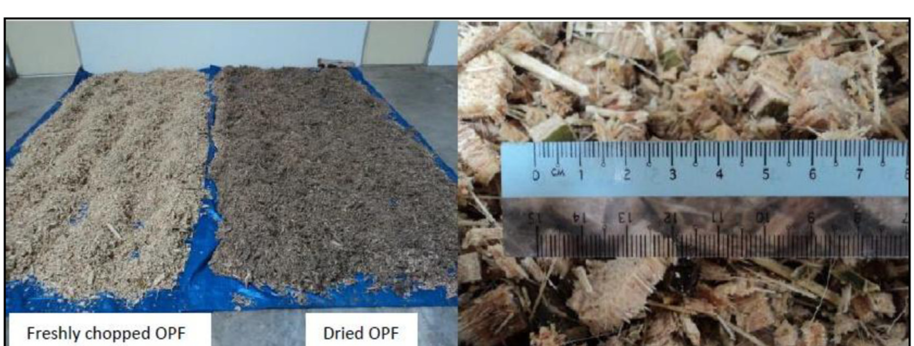

Fig. 1. Chopped OPF feedstock.