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Steam gasification of oil palm trunk waste for clean syngas production

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ABSTRACT

Waste and agricultural residues offer significant potential for harvesting chemical energy with simultaneous reduction of environmental pollution, providing carbon neutral (or even carbon negative) sustained energy production, energy security and alleviating social concerns associated with the wastes. Steam gasification is now recognized as one of the most efficient approaches for waste to clean energy conversion. Syngas generated during the gasification process can be utilized for electric power generation, heat generation and for other industrial and domestic uses. In this paper results obtained from the steam assisted gasification of oil palm trunk waste are presented. A batch type gasifier has been used to examine the syngas characteristics from gasification of palm trunk waste using steam as the gasifying agent. Reactor temperature was fixed at 800 °C. Results show initial high values of syngas flow rate, which is attributed to rapid devolatilization of the sample. Approximately over 50% of the total syngas generated was obtained during the first five minutes of the process. An increase in steam flow rate accelerated the gasification reactions and resulted in reduced gasification time. The effect of steam flow rate on the apparent thermal efficiency has also been investigated. Variation in steam flow rate slightly affected the apparent thermal efficiency and was found to be very high. Properties of the syngas obtained from the gasification of oil palm trunk waste have been compared to other samples under similar operating conditions. Oil palm trunk waste yielded more syngas, energy and hydrogen than that from other types of biomass such as mangrove wood, paper and food waste.

1. Introduction

Oil palm (scientific name *Elaeis guineensis*) is an agro-industrial commodity that is used to produce edible oil [1]. Some oil palm is also used as fuel via direct combustion. In 2007, oil palm accounted for some 25% of edible oil in the world and this represents about 38.5 million tons of oil palm produced [2]. This large amount of palm oil produced has resulted in large amounts of biomass residues during the process. The residues consisted of 30.5% of empty fruit brunches (oil palm trunk), 17.23% of fibers, 10.62% of shells, 37.86% of fronds and trunks, and 3.79% of palm kernels [2]. A hectare of cultivated oil palm results in approximately 50–70 tons of biomass residues [3]. In order to seek benefits from such biomass residues, several researches have examined the potential of energy generation from these agricultural wastes. High temperature steam gasification has been considered as one of the most effective and efficient approaches waste to clean chemical energy conversion without any environmental degradation. The fuel thus produced can then be utilized for electric power generation, heat generation and in other industrial, transportation and domestic sectors.

The objective of this paper is to examine the thermo-chemical transformation of palm trunk waste to chemical energy using steam as the gasifying agent. Note that air gasification results in lower heating value of the syngas as compared to steam assisted gasification. The results are compared with the baseline case of pyrolysis under the same temperature condition. A batch type gasifier, maintained at a fixed temperature of 800 °C, was used for the results presented here. The effect of steam flow rate on the amounts of syngas produced and its characteristics from oil palm trunk are presented here. The experimental results are presented on the effect of steam flow rate on the evolutionary behavior of the resulting syngas flow rate, chemical composition of the syngas, hydrogen flow rate in the syngas as well as the overall syngas yield. Results of oil palm wastes under pyrolysis conditions are presented for evaluating the role of gasification on the syngas comparison. The emphasis in this investigation is on determining H_2 content, hydrogen/CO ratio and apparent thermal efficiency at different steam flow rates at a constant reactor temperature. These characteristics help identify the most suitable conditions of gasifying agent flow rate for efficient gasification of such biomass wastes.

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Table 1
Proximate and ultimate analysis of oil palm trunk.

Moisture (% as received)	8.34
Proximate analysis	
Ash (% at dry basis)	6.87
Volatile matter (% at dry basis)	79.82
Fixed carbon (% at dry basis)	13.31
Ultimate analysis	
Carbon (% at dry basis)	43.80
Hydrogen (% at dry basis)	6.20
Nitrogen (% at dry basis)	0.44
Oxygen (% at dry basis)	42.65
Sulfur (% at dry basis)	0.09
Higher heating value (MJ/kg)	19.257

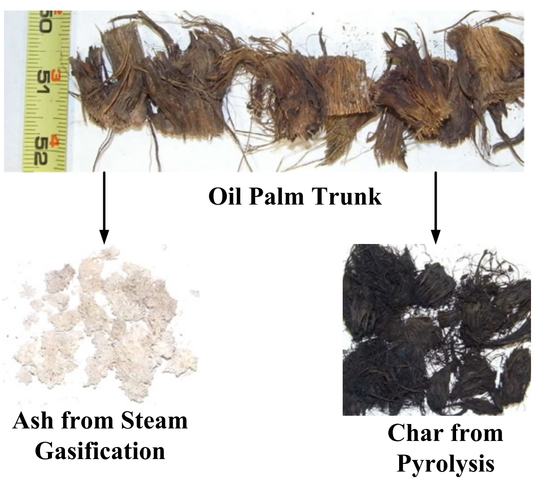

Fig. 1. Photograph of oil palm sample, ash and char.

2. Experimental facility and conditions

2.1. Experimental facility

Fig. 2 shows a schematic diagram of the laboratory-scale experimental facility used for the gasification and pyrolysis experiments. Steam was generated from the stoichiometric combustion of hydrogen and oxygen in a specially designed burner. The steam generated was then introduced into a gasifying agent conditioner. The temperature of the gasifying agent conditioner was kept at same temperature as that desired in the main reactor where gasification of the sample material occurs. Steam is then introduced into the main reaction chamber containing the biomass feedstock hydrocarbon sample (oil palm trunk). The syngas flowing out from the reactor is allowed to flow into two sections; one passes to the gas sampling line for gas analysis while the remaining syngas is vented to the environment via the exhaust system. The bypass line incorporated a no-return valve and a flow meter to monitor the flow rate and to ensure the desired unidirectional flow out from the gasification reactor. The syngas sample is then introduced into a condenser followed by a filter and a moisture absorber (anhydrous calcium sulfate) so that the sample is moisture free prior to its introduction into the GC or other gas analyzers. The flow of syngas is then directed to a three way valve. This three way valve allows sampling by two means. First is from collection of the syngas sample in the sampling bottles. The second means involved introducing the syngas directly into the micro gas chromatograph (GC). Sampling bottles were used only when short sampling intervals were required (in the range of 0.5–11 min) in between the sampling. This procedure allowed determination of evolutionary behavior of syngas from the sample. However, direct sampling and analysis were carried out by the GC when longer sampling time intervals were desired. A constant flow rate of an inert gas (nitrogen) was introduced with the oxygen flow to the reactor. The nitrogen is detected by the GC and is then used to

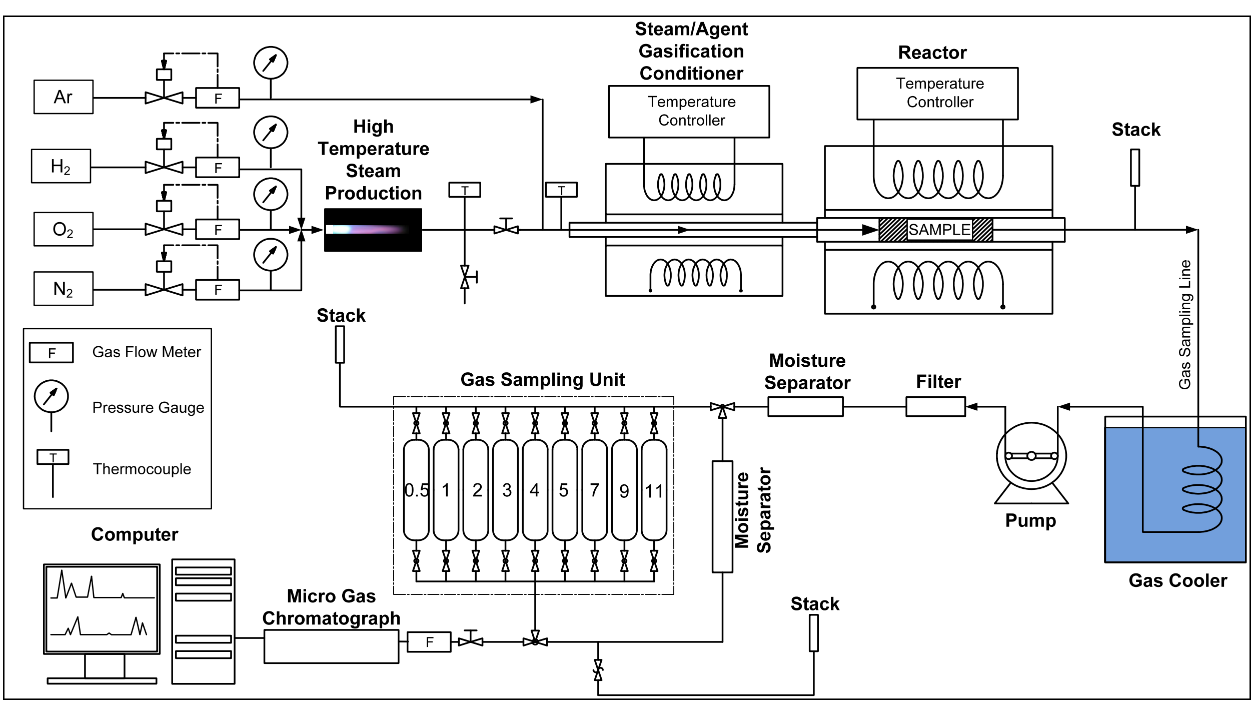

Fig. 2. Schematic diagram of the experimental setup.