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Impact of parameters on gas ratios obtained from air gasification of date palm waste

MUHAMMAD Shahbaz[1,2,a*], MUDDASSER Inayat[2,3,c], TAREQ Al Ansari[1,b], GORDON Mckay[1,d]

[1]College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Education City, P.O. Box 5825, Doha, Qatar

[2]Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia

[3]Research Group of Energy Conversion, Department of Mechanical Engineering, School of Engineering, Aalto University, 02150 Espoo, Finland

[a]mshahbaz@hbku.edu.qa, [b]talansari@hbku.edu.qa, [c]muddasser.inayat@aalto.fi, [d]gmckay@hbku.edu.qa

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Abstract. Utilizing date palm waste as an energy source is a potential low-carbon energy source, especially in areas such as the Middle East. This study investigates date palm waste air gasification performed in a downdraft gasifier. The study aims to analyze the impact of various parameter ranges such as temperature of 600-900 ^{o}C, air flow rate of 1.0 to 4.0 l/min, and particle size of <2-6> mm on the gas ratios of producer gas. H_2/CO ratio is an important parameter which is an increase from 0.53 to 0.71 with a rise in temperature from 600 to 900 ^{o}C. A similar profiling of other gas ratios was noticed with the temperature increase. The H_2/CO ratio and H_2/CO_2 are found maximum at the air flow rate of 2.5 l/min and 3.0 l/min.H_2/CH_4 showed a very steady trend with an increase of air flow rate up to 2.5 l/min, but a sharp hike was noticed by increasing the air flow rate of 2.5 to 4.0 l/min. Larger particle size shows a lower value of H_2/CO, H_2/CH_4, and H_2/CO_2 due to the lower heat and mass transfer diffusion compared to smaller particle size.

Introduction

The extraction of energy from fossil fuels to satisfy energy demand is challenged by finite sources, oil price volatility, greenhouse gas emissions, and climate change [1]. As such, there are global efforts to identify alternative, renewable, sustainable, and carbon-neutral sources to satisfy the growing energy demand, which is expected to increase by 53% in 2030 [2]. Incidentally, biomass waste has emerged as a reliable, effective, and dependable source due to its extensive availability across the globe up to 70 EJ, no carbon footprint, and energy density have the potential to replace the crude-based fuel refinery with biorefinery [3]. The extraction of energy from biomass-based waste is based on the biological and thermochemical conversion process. Among all thermal treatment processes, Gasification is a well-known and progressive technology that converts organic biomass and wastes into gaseous fuel at higher temperatures using the oxidizing agent (steam, air, and oxygen) [4].

The Middle East, especially Gulf Cooperation Council (GCC), is known for its petroleum reserves and export of petroleum products. Date fruit is the main agricultural product and is well integrated with their culture, which contributes to 67% of global date exports and 75% of date production worldwide [5]. The date fruit industry including its cultivation and processing produces an ample quantity of waste including leaves, fronds, and date pits. According to an estimation, a date palm tree produces 20 kg of leaves and fronds waste per year [6]. The conversion of date palm waste can provide a valuable clean energy source, which has been significantly explored in recent years. The thermal kinetic study and pyrolysis of date palm wastes have been investigated to understand the thermal degradation as well as char and oil production [7, 8].

The production of syngas from the conversion of date palm waste is also investigated both in simulation and experimental studies, in which there are numerous simulation models that have been developed for the gasification of date palm wastes to predict the syngas by varying the temperature and steam flow rate [9, 10]. The quality and utilization of produced gas depend on the H_2/CO ratio and other gas ratios. These ratios have immense importance for converting into value-added products such as methanol, methane, dimethyl ether (DME), and F-T diesel. A few studies have been reported to investigate the impact of parameters on gas ratios. Shahbaz et al. [2] have reported the H_2/CO ratio optimization for the steam gasification of date palm wastes. Most of the reported literature is focused on the impact of temperature, steam flow rate, and catalysts on the H_2/CO ratio [11]. However, very few studies have focused on the other gas ratio such as H_2/CO, H_2/CH_4, H_2/CO_2, CO/CH_4, and CO/CO_2 and there is no study available for date palm waste gasification. This study aims to perform the air gasification of date palm waste in the downdraft gasifier. The impact of temperature (600-900 °C), air flow rate (1.0-4.0 l/min), and particle size of (<2-6> mm) on H_2/CO, CO/CO_2, H_2/CO_2, H_2/CH_4, and CO/CH_4 ratio. This study is very helpful to identify the ratios for the further utilization of producer gas into fuels and chemical conversion.

Methodology

For this study, the dried palm leaves from the Middle East were collected from one of the date fields. The received dried palm waste was characterized to determine the waste's heating values, and chemical compositions in terms of the proximate and ultimate analysis as presented in Table 1 was also reported in one of our previous studies[12]. In the next stage, the feedstock was sun-dried, crushed in the jaw crusher, and sieved using the sieve shaker into the desired particle sizes of <2, 4, and 6> mm, respectively. The prepared feedstock was stored in airtight jars to avoid moisture.

Table 1. Chemical composition of properties of date palm waste [12].

Feedstock	Analysis (weight% dry basis)								Higher heating value (MJ/kg)
	Ultimate					Proximate			
	C	H	N	S	O*	Volatile matter	Carbon	Ash	
DPF	37.12	5.78	3.12	0.20	53.78	80.60	12.69	6.71	16.61

*By difference method

The air gasification of date palm waste is instituted in the setup presented in Figure 1. The gasifier reactor is made of high-quality steel to perform the high-temperature process. The gasifier is insulated with high-quality ceramic material to obtain the isothermal condition. The mode of the gasification system was downdraft. The heating system consists of electric heaters that were externally mounted and jacketed to heat up the system. A system was mechanically cleaned and purged with N_2 to ensure the removal of dust and unburned material before each experiment. The gasifier was heated up to the targeted temperature by the electric heater. The temperature was measured and controlled through the thermocouple and microcontroller. The produced gas was passed through the pipes and gas analyzer system to measure the gas composition at intervals of 1.0 second. The 100 grams of feedstock was used for each batch. The air flow rate varied from 1.0-4.0 l/min and the temperature varied from 600-900 ^{o}C. The particle size of <2, 2, 2-6, and 6> mm was investigated. These experimental conditions ranges were identified with the series of test runs.

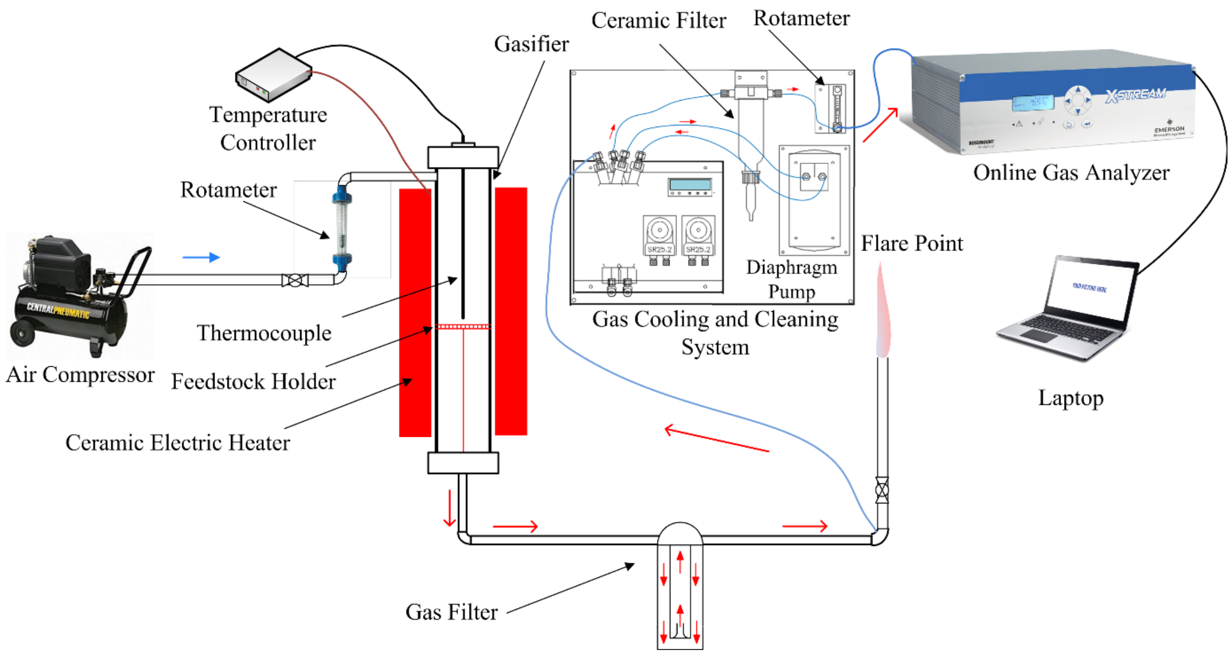

Figure 1. Air gasification system for date palm waste.

Results and Discussion

Impact of Gasification Temperature

The temperature has ample impact on the gas composition and the gas ratio is very important for the conversion of syngas into value-added products. H_2/CO is increased from 0.53 to 0.71 with the increase of temperature, as shown in Figure 2. This is due to the activation of the water shift reaction which enhanced the H_2 content [12]. Similarly, the H_2/CH_4 ratio increase from 0.77 to 2.05 shows the activation of methane reforming reaction at higher temperature [13]. The increasing trend of CO/CO_2 and H_2/CO_2 ratio shows that the CO_2 is decreased with the activation of endothermic reactions such as bourdourd reaction. This trend was also reported in the literature with the temperature increase [2]. The CO/CH_4 ratio also follows a similar profile due to the reduction of methane and the activation of methane reforming reaction at a higher temperature [13].

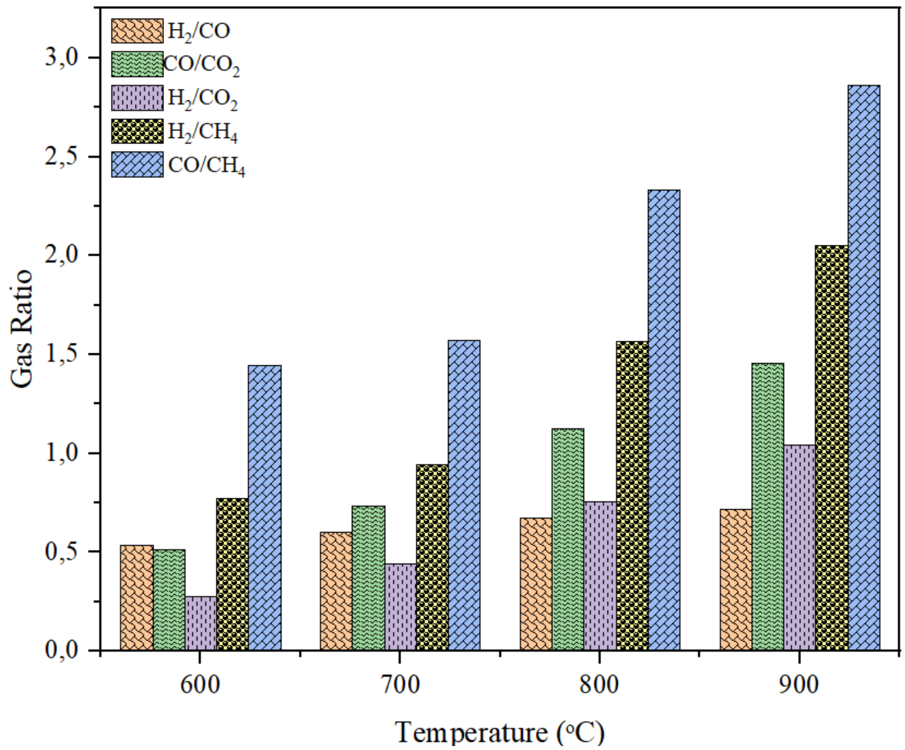

Figure 2. Impact of gasification temperature on gas ratio of H_2/CO, CO/CO_2, H_2/CO_2, H_2/CH_4, and CO/CH_4 at 3.0 l/min and 2-6 mm particle size.

Impact of Air Flow Rate

The air flow rate is very important because it works as an oxidizing agent to instigate the gasification reaction and defines the concentration of gases in the product gas. H_2/CO ratio is increased and reached 1.03 at the air flow rate of 2.5 l/min but has dropped to 0.5 at a higher air flow rate of 4.0 l/min as presented in Figure 3. A similar pattern was also noticed for H_2/CO_2 ratio air flow rate. This trend shows that 2.5 l/min provides enough oxygen to activate the water gas shift reaction and methane reforming reactions [14]. Furthermore, it was noticed that H_2/CH_4 and CO/CO_2, and CO/CH_4 also increased with the increase of air flow rate up to 3.5 l/min and higher values 1.52, 1.27, and 2.4 1respeitevly. These also follow the decreased trend at a higher flow rate. The increasing trend shows that a higher flow rate enables the higher content of CO and CO_2 gases due to the higher oxygen availability that enhances the combustion reaction and forms the CO and CO_2 [15].

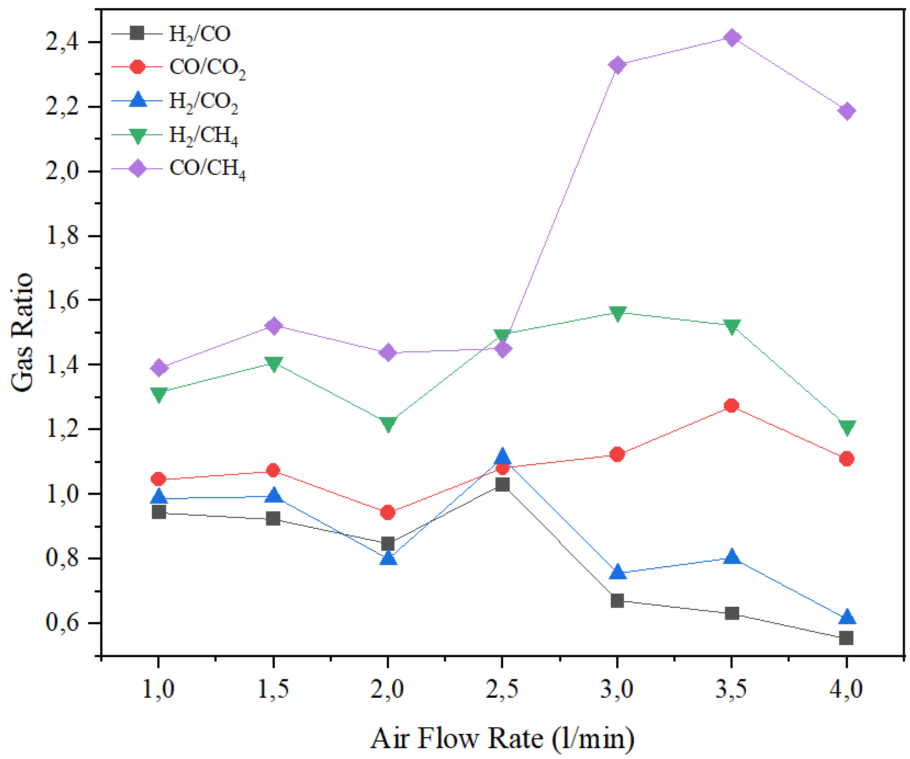

Figure 3. Impact of air flow rate on gas ratio of H_2/CO, CO/CO_2, H_2/CO_2, H_2/CH_4, and CO/CH_4 at 800 ℃ and 2-6 mm particle size.

Impact of Particle Size

Particle size also plays a very important role in the gasification process. It is directly related to the heat and mass transfer with the particle and from the oxidizing agent as well as the heating medium which directs the reactions placed in the gasification process [16]. Particle size is directly related to heat and mass transfer diffusion. H_2/CO is found to be higher 0.85 at smaller particle size due to better heat and mass transfer at higher temperature [12, 17]. A similar profile was noticed for H_2/CO_2 ratio and CO/CO_2 ratio, showing that smaller particle size helps the water gas shift reactions. But in the case of CO/CH_4 and H_2/CH_4, it shows an increasing or no effect trend with the smaller particle size. The reason for this is related to the CH_4 content. The gasification is performed at a higher temperature of 800 °C such that the particle size has less influence on methane formation or reforming [18].

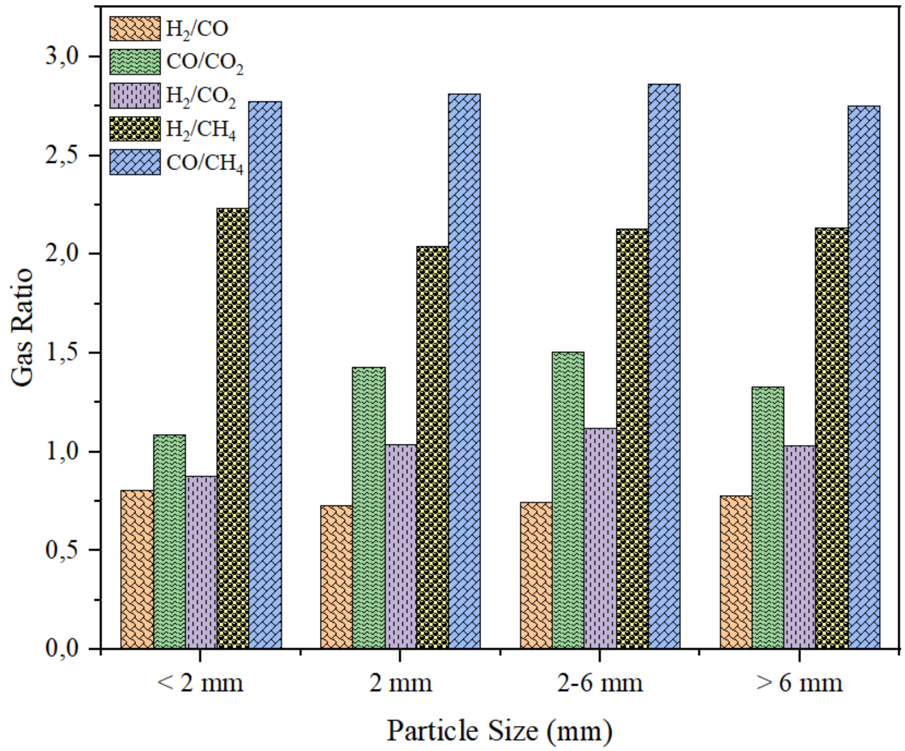

Figure 3. Impact of particle size on gas ratio of H_2/CO, CO/CO_2, H_2/CO_2, H_2/CH_4, and CO/CH_4 at 800 °C and 3.0 l/min air flow rate.

Conclusion

This study investigated the conversion of date palm wastes into gas using a downdraft gasifier. In the investigation, the impact of parameters temperature (600-900 °C), particle size <2, 2, 2-6, and 6> mm), and air flow rate (1.0-4.0 l/min) on the gas ratio produced from date palm waste. Generally, the gas ratio has an increasing trend with the increase in temperature. It was noticed that H_2/CO and H_2/CH_4 increased from 0.53 to 0.71 and 0.77 and 2.05 by increasing the temperature due to the activation of endothermic reactions. The air flow rate of 2.5 l/min was the best in which H_2/CO ratio and H_2/CO_2 were maximum. However, H_2/CH_4 was 1.5 at air flow rate of 3.0 l/min. The CO/CH_4 shows a very sharp increase at a higher air flow rate, which may be ineffective for methane reforming reactions. The smaller particle size is more effective in obtaining the higher H_2/CO and H_2/CH_4 ratio. This study supports the understanding of the gas ratios, which is important for the conversion of producer gas into valuable products such as methanol, DME, CH_4, etc.

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