

Investigation of Co-Gasification of Rubber Seed Shell and High Density Polyethylene Mixtures

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In this study, the steam gasification of rubber seed shell and high density polyethylene mixtures were carried out in a thermogravimetric instrument coupled with mass spectrometer (TGA-MS) in argon atmosphere under non-isothermal condition to analyse the effect of the gas composition such as H₂, CO, CO₂, and CH₄ when using different percentage of high density polyethylene of 0-40 weight% in the mixtures and operating temperature of 700 -900 °C. The argon gas was supplied at a flowrate of 100 mL min⁻¹ and the steam was generated from superheater at 110 °C whilst injected at flowrate of 3,000 μL h⁻¹ into the TGA-MS system. The highest H₂ and CO concentrations can be achieved at 56 and 29 vol% in this system at a temperature of 900 °C.

1. Introduction

The efficient utilisation of biomass and plastic waste as a source of clean energy and chemicals has attracted much research attention in recent years amid fossil fuel energy as well as clean energy drive. Biomass is generally considered as the plant derived from the reaction between carbon dioxide (CO₂), in air, water and sunlight, via photosynthesis. Plastic is made from non-biodegradable polymers mainly consisting of carbon, hydrogen and few other elements such as chlorine, nitrogen and etc.

Gasification is said to be one of the most promising technologies that strategically enable biomass and plastic feedstock to supplement the diverse energy needs for wide applications such as power generation through gas turbines, production of liquid fuels using Fischer Tropsch synthesis, and production of hydrogen, ethanol, and methanol (Chin et al., 2011). Gasification is defined as the conversion of a solid into synthesis (syngas) with partial oxidation reaction at high temperatures of 800-900 °C using air/oxygen, steam, or combinations of these oxidizing agents (McKendry, 2002). The products from gasification process are mainly H₂, CO, with minimal amounts of CO₂, CH₄, and trace of other volatiles and contaminants.

The gasification of solid involved four steps which are (i) heating and drying, (ii) pyrolysis, (iii) gas-solid reaction, followed by (iv) gas reactions. The selection of the types of biomass and plastic as the gasification feedstock is essential as the properties of biomass and plastic can cause significant on the performance of the gasifier and also its downstream process.

The properties of biomass and plastic such as moisture content, calorific value, proportions of fixed carbon and volatiles, ash or residue content, alkali content and particle sizes of the feedstock can influence the effect during the gasification process.

Most studies are carried out using single component of biomass or plastic feedstock in the gasification feedstock. Yusup et al. (2013) investigated the in-situ catalytic adsorption (ICA) steam gasification process of palm kernel shell for hydrogen production. Wu et al. (2010) examined on the polypropylene, polystyrene, high density polyethylene, and their mixtures and mixed plastic waste using gasification in a two-stage

pyrolysis-gasification reactor system with and without the presence of Ni-Mg-Al catalyst. However, limited studies have been conducted on the co-gasification of biomass and plastic waste mixtures. Moghadam et al. (2013) studied on the hydrogen production from the binary mixtures of palm kernel shell and polyethylene waste using catalytic steam gasification in a pilot scale fluidized bed gasifier. Garcia-Bacaicoa et al. (2008) studied on the wood and high density polyethylene mixtures in a downdraft gasifier. The present work studied on co-gasification of rubber seed shell (RSS) and high density polyethylene (HDPE) mixtures in thermogravimetric analyzer coupled with mass spectrometer (TGA-MS). Rubber seed shell is selected as the lignocellulosic biomass for gasification feedstock since Malaysia is one of the major rubber growing countries with an acreage of 1,229,940 ha of rubber plantation in the year 2007 (Malaysian Rubber Board, 2008). HDPE is selected as the plastic source for gasification feedstock since it has the minimum degree of branching compared to other polyethylene (PE) types which allows the decomposition of the HDPE to be easily broken down.

Besides that, PE is reported to be the highest type of plastic consumption compared to other polyolefins which takes about 33 % of the world plastic consumption in year 2007 (Plastic Industry, n.d.). The outcome of high demand of PE will eventually lead to a generation of massive amount of plastic wastes which can contribute to secondary pollutions to the environment. Most studies carried out using TGA equipment studied on the thermal degradation and kinetic parameters of the biomass and plastic waste mixtures. However, limited studies are carried out on the output gaseous products produced from the gasification process. Hence, in this study the gas compositions such as H_2 , CO, CO_2 , and CH_4 are analyzed when varying the percentage of HDPE (0-40 weight%) in the mixtures and operating temperature (700-900 °C).

2. Experimental

2.1 Materials and Sample Preparation

The raw materials used in this work are RSS from Vegpro Trading, Malaysia and HDPE plastic from Shen Foong Plastic Industries Sdn Bhd, Malaysia. These materials are grounded and sieved to a particle size of $\leq 710 \mu m$ fractions. Homogenized HDPE/RSS blends in respective weight ratio are prepared. The characteristics of the materials used in this study are presented in Table 1. The ultimate and proximate analysis of the HDPE and RSS are conducted in LECO CHNS-932 elemental analyser and thermogravimetry analyser EXSTAR TG/DTA 6300 (Seiko Instrument Inc.) respectively.

Table 1: Characteristics of RSS and HDPE waste

Sample	Ultimate analysis (weight%, dry ash basis)					Ultimate analysis (weight%, dry basis)			
	C	H	N	S	O	Moisture Content	Volatile Matter	Fixed Carbon	Ash
RSS	44.31	4.38	0.51	0.13	50.67	8.59	80.98	6.62	3.81
HDPE	81.45	12.06	0.34	0.79	5.36	0.00	99.46	0.00	0.34

2.2 Experimental Apparatus and Procedure

The experiments are performed using the thermogravimetric analyser EXSTAR TG/DTA 6300 (Seiko Instrument Inc.) as illustrated in Figure 1. The TGA instrument is used to study the kinetic parameters and also the thermal degradation behaviour of the binary mixture meanwhile the MS instrument is used to study the gaseous products from the gasification process. Approximately 5 mg of sample was placed on a ceramic crucible in TGA under an inert atmosphere of argon. A flow rate of 100 mL min^{-1} of argon gas is fed into the system for 20 minutes at a temperature of 50 °C. Subsequently, all samples are heated from 50 to 900 °C at respective heating rates and temperatures were kept constant at 10 min.

During heating, the TGA was used to measure mass variation of the materials and furnace temperature. Steam is generated by a superheater at 110 °C and is injected into the TGA at a flowrate of $3,000 \mu\text{L h}^{-1}$ when the temperature inside the TGA equipment reached to 110 °C to avoid any occurrence of condensation within the system. The equivalence ratio for the gasification process is 0.25. All experiments are repeated three times.

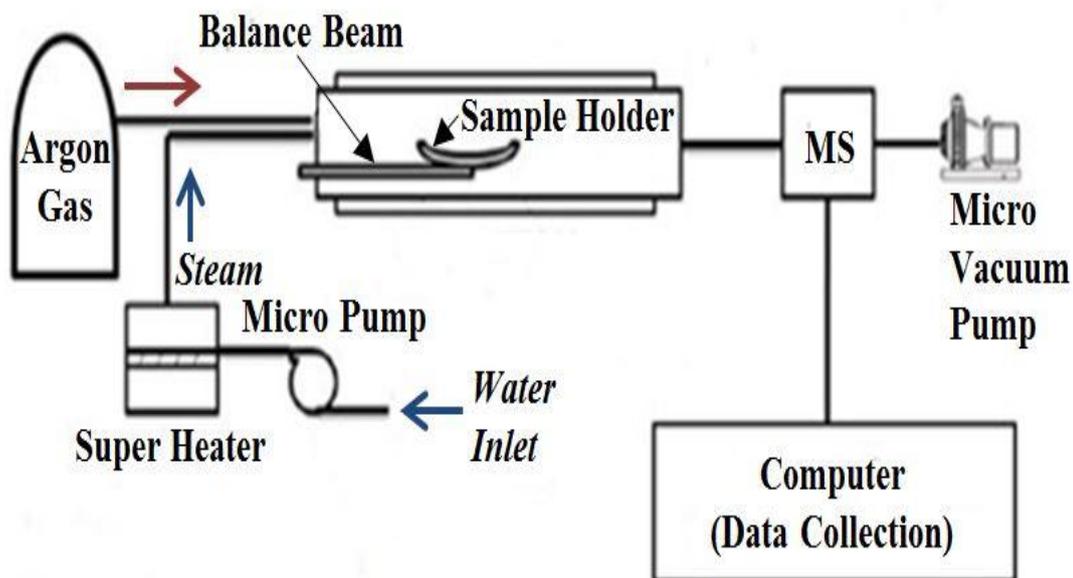


Figure 1: Experimental setup of TGA-MS

3. Results and Discussion

3.1 On the Effect of Different Percentage of HDPE in the Mixtures

Figure 2 illustrates the effect of different percentage of HDPE in the mixtures at temperature of 900 °C. It is observed that significant increased in the H₂ concentration when the percentage of HDPE in the mixture is increased. The H₂ concentration increased from 38 to 56 vol% as the HDPE content increased from 10 to 40 weight% in the mixture at temperature of 900 °C. Ahmed et al. (2009) and Moghadam et al. (2013) reported similar behaviour in the H₂ concentration when the percentage of plastic is increased in the mixture.

A slight reduction in the CO and CO₂ concentration with HDPE content in the mixture is seen. The CO and CO₂ concentration reduced from 29 to 22 vol% and from 20 to 12 vol% as HDPE content in the mixture increased from 10 to 40 weight%. Similarly, Pinto et al. (2002) also reported the CO₂ and CO concentration reduced when the HDPE content in the mixture is increased in their gasification system. However, there is not much change in the CH₄ concentration with presence of HDPE content in the mixture.

The CH₄ concentration is reported to be in the range of ~7-15 vol%. Similarly, Pinto et al. (2002) observed not much change in the CH₄ concentration when polyethylene (PE) content is increased in the PE/wood pine mixtures and it is reported that the concentration is within the range of ~10-15 vol/vol%. It is believed that the increased of the H₂ concentration and the small changes in the hydrocarbon concentration is due to the cracking reactions occurring with presence of the HDPE (Pinto et al., 2002).

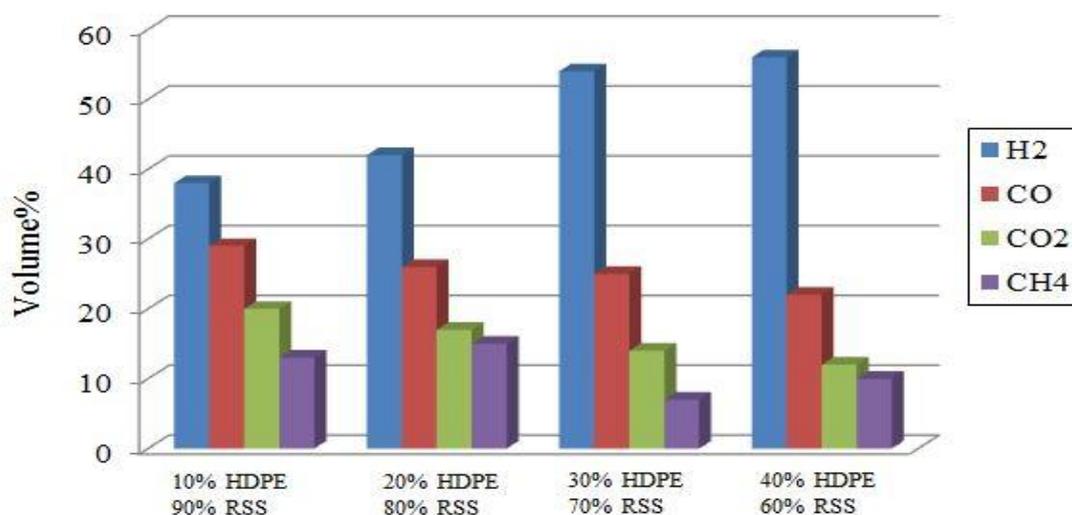


Figure 2: Effect of different percentage of HDPE in the mixtures at temperature 900 °C

3.2 On the Effect of Temperature

Figure 3 depicts the effect of different operating temperature when using 0.4/0.6 of HDPE/RSS mixtures. Temperature is said to be one of the most influential process parameters that determines the yield of the gas liquid, and char and also the quality of the gas (Peng et al., 2012). The quality of the gas is determined based on the individual components of the product gas such as H₂, CO, CO₂, and CH₄ (Zhang, 2011). This can be further explained that the increase of the gasification temperature influence the rate of reactions of the gasification, oxidation, steam, and dry reforming, and hydrocarbons cracking, hence leading to the different concentration of the individual components in the producer gas (Pinto et al., 2003).

It is observed that a significant increased on the H₂ concentration from 46 to 56 vol% with an increase in temperature from 700 to 900 °C when using 0.4/0.6 of RSS/HDPE mixtures. The highest H₂ concentration of 56 vol% can be achieved at temperature of 900 °C. Moghadam et al. (2013) observed similar increasing trend for H₂ with temperature in a catalytic co-gasification of palm kernel shell with PE waste. This further explained that higher temperature enhances the secondary cracking and endothermic reaction such as water gas shift reaction that leads to higher attainable H₂ concentration. This satisfied the Le Chatelier's principle that states temperature favours the products in an endothermic reaction.

A slight increased in CO concentration with temperature is also observed. The CO concentration increased from 24 to 30 vol% as the temperature increased from 700 to 900 °C. Conversely, Moghadam et al. (2013) and Pinto et al. (2002) show a decreasing trend and no significant change respectively on the CO concentration with temperature. Furthermore, it is seen that there is no significant change on the concentration for CO₂. It is reported that the concentration for CO₂ is in the range of ~10-13 vol%. The concentration of CH₄ shows a decreasing trend when temperature is increased from 700 to 900 °C. It is reported that the concentration for CO₂ decreased from 20 vol% to 2 vol% when temperature increased from 700 to 900 °C.

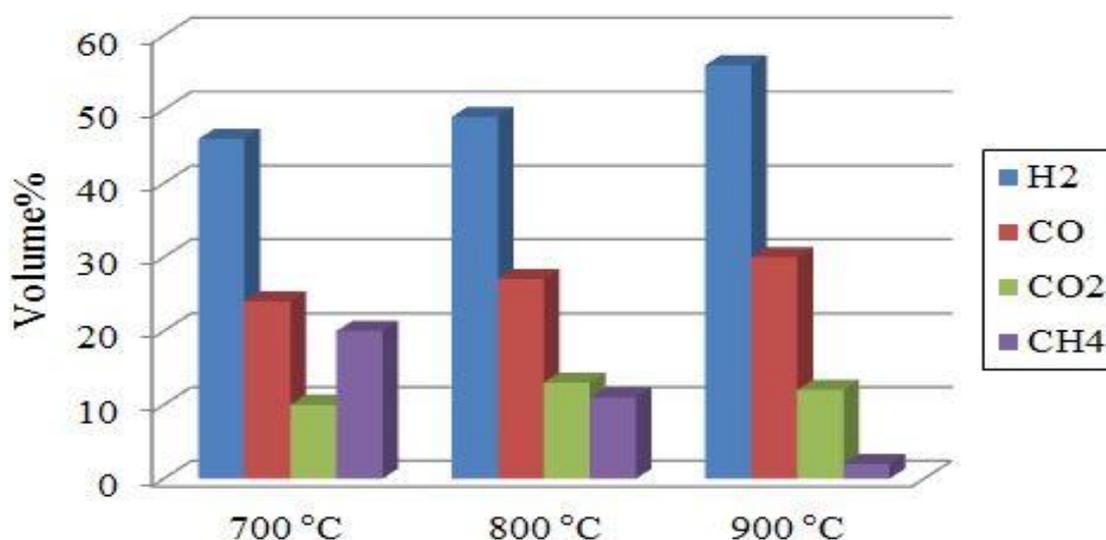


Figure 3: Effect of different operating temperature when using 0.4:0.6 of HDPE:RSS mixtures

4. Conclusions

In summary, it is found that the percentage of HDPE in the mixture and temperature significantly influenced the H₂ concentration. The highest H₂ concentration of 56 vol% can be achieved at temperature of 900 °C and using 0.4/0.6 of HDPE/RSS mixtures in the system. The CO concentration shows an increasing trend when the percentage of HDPE in the mixture decreased from 40 to 10 weight%. Conversely, the CO concentration increased from 900 to 700 °C. Furthermore, it is reported that the CO₂ concentration does not change with temperature however the CO₂ concentration reduced with the increased of HDPE content in the mixture. The CH₄ concentration is found to decrease with temperature. From the obtained results, it shows that both biomass and plastic waste are able to produce high amount of syngas specifically H₂ and CO concentration, hence this provide a potential to produce syngas at a higher throughput. Therefore, for future work, a larger scale gasifier will be used to carry out study using these feedstock.

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